Transpiration and Leaf Movement of Cotton Cultivars Grown in the Field under Arid Conditions

Chunyan Wang, Akihiro Isoda, Zhiyuan Li* and Peiwu Wang*

(Faculty of Horticulture, Chiba University, Matsudo-648, Chiba 271-8510, Japan; *Shihezi Agricultural and Environmental Institute for Arid Area in Central Asia, Shihezi, Xinjiang, China)

Abstract: Five cotton (Gossypium hirsutum L.) cultivars were grown in the field in Xinjiang, China to evaluate their adaptability to arid conditions in terms of leaf temperature, transpiration rate and leaf movement. Leaf temperature was higher in the morning and lower in the afternoon as compared with air temperature. There were large differences in the transpiration rate represented by the flow rates of stem sap per unit leaf area (FRSS) among the cotton cultivars. The transpiration rate in cotton generally depended on vapor pressure deficit (VPD). In the cultivars with a low transpiring ability, however, the influence of VPD was lower in the higher range of VPD. Cultivars with higher transpiring ability tended to have higher intercepted radiation per unit leaf area (IRL), i.e., to show active diapheliotropic leaf movement. The higher transpiring ability of cotton might be able to reduce heat stresses caused by diapheliotropic leaf movement and be profitable for yield under the arid conditions.

Key words: Diapheliotropic leaf movement, Integrated solarimeter film, Leaf temperature, Transpiration ability, Vapor pressure deficit (VPD).

Cotton orients its leaves diapheliotropically during the daytime (Lang, 1973; Miller, 1975). Similar leaf movements are well-known in leguminous crops (Kawashima, 1969; Oosterhuis et al., 1985; Berg and Heuchelin, 1990), but they move their leaves paraheliotropically during the daytime. Cotton is well-adapted to arid conditions (Peterson et al., 1992), and has higher transpiring ability than soybean under arid conditions (Isoda and Wang, 2002). Isoda et al. (1993; 1996) reported that soybean and peanut cultivars with high transpiring abilities moved their leaves less paraheliotropically, suggesting a close relationship between transpiring ability and paraheliotropic leaf movement. Paraheliotropic leaf movements in soybean might reduce water loss by transpiration and maintain dry matter production by prompting radiation penetration into the canopy, leading to improvement of water use efficiency under arid conditions (Isoda and Wang, 2001). In this experiment, we intended to analyze the relationships among transpiring ability, leaf movement and leaf temperature from the viewpoint of varietal differences, and to estimate adaptability of cotton to arid conditions.

Materials and Methods

The experiment was conducted at the experimental field at Shihezi Agricultural and Environmental Institute for Arid Area in Central Asia, Shihezi, Xinjiang, China (86°02’E, 44°18’N), in 2000. Five local bred cultivars Xinluzao 6, Xinluzao 8, Xinluzao 10, Shixuan 87 and Cultivar 9665 were used. Seeds were sown at a 12cm intra-row spacing at the density of 16.7 plants m⁻² on 24 Apr., 2000. Two alternate unequal row spacings, 30cm and 70cm were adopted. Plastic mulching was used on alternate rows. Drip tapes with emitters were set under the mulch. N and P₂O₅ were applied at the rate of 160 and 183 kg ha⁻¹, respectively. K₂O was not applied due to the high K ₂O content of the soil. Pest control was carried out according to the local standard practice. No growth regulators were applied during the experiment. The quantity of irrigation and rainfall during the growth period was 200.1 mm and 86.8 mm, respectively.

On 28 July, at the boll filling stage, the leaf temperature of three uppermost leaves in each cultivar was measured with T-type thermocouples. The thermocouples were fixed at the abaxial side of the leaves. The transpiration rate was represented by the flow rate of stem sap per unit leaf area (FRSS), which was measured with sap flow gauges (Dynagage, Dynamax Inc.) in two plants of each cultivar. The sap flow gauges were attached at the base of stem. Air temperature, humidity and photosynthetically active radiation (PAR) were also recorded at the same time by T-type thermocouples, humidity sensors (CHS-APS, TEAC) and a PAR sensor (LI-190S-1, LI-COR), respectively. The data were collected at one-minute interval by data loggers (Thermodac E, Eto Denki...
Corporation) connected with personal computers. The data used in this paper were averaged at five minute intervals. The data were collected continuously for a few days. The data of the day with the most stable weather condition (28 July) were used.

The radiation intercept was measured on 5 and 6 Aug. with simple integrated solarimeter films (Yoshimura et al., 1990). After sunset on 4 Aug., integrated solarimeter film was stuck on every leaf surface of three plants from each cultivar using double-faced tape. The integrated solarimeter films were removed at night after exposure for two days. The dye percentages were measured by a spectro-photometer (U-1000, Hitachi Corp.) before and after the exposure. After removing the integrated film, the leaf area and weight of each observed plants were recorded on 7 Aug. The experimental days were clear, and the global solar radiation for the two days was 16.3 MJ m$^{-2}$ d$^{-1}$. The mean air temperature during the daytime (0400-1900) was 26.5°C. Seed cotton was harvested by hand with three replications and 30 plants for each replication at the end of Sept. and was ginned for calculating the lint yield.

## Results

1. **Diurnal change in leaf temperature**

Fig. 1 shows PAR, air temperature and humidity on 28 July. This is a typical climatic condition of the summer season in Xinjiang. Leaf temperature of each cultivar showed the same tendencies in diurnal changes (Fig. 2). The leaf temperatures were higher from 0600 and lower from 1200 than the air temperature. The peak of the leaf temperature was observed at around 0800-1000 in all cultivars. The leaf temperature in Xinluzao 6 was higher from dawn to noon and lower in the afternoon than that in the other cultivars. In the afternoon, the highest leaf temperature was observed in Xinluzao 8. The leaf temperature of Cultivar 9665 and Xinluzao 10 was lower than that of other cultivars during the daytime.

2. **Diurnal change in transpiration rate (FRSS)**

There were large varietal differences in FRSS (Fig. 3). The FRSS in each cultivar increased rapidly after 0600. The FRSS attained the peaks at around 1000 to 1100. The peak values were 7.6, 5.5, 4.0, 3.8 and 2.3 g dm$^{-2}$ h$^{-1}$ in Xinluzao 10, Xinluzao 8, Shixuan 87, Cultivar 9665 and Xinluzao 6, respectively. FRSS was highest in Xinluzao 10 and lowest in Xinluzao 6, which was one-fourth of that in Xinluzao 10. Leaf temperature showed no significant relationship with FRSS (transpiration rate) during any period.

3. **LAI, mean single leaf area, SLA and IRL**

Table 1 shows leaf area index (LAI), mean single
leaf area (MLA), specific leaf area (SLA) measured on 11 Aug. and mean intercepted radiation per unit leaf area (IRL) measured on 5 and 6 Aug. Shixuan 87 had the largest LAI, followed by Xinluzao 6 and Xinluzao 8. LAIs of Xinluzao 10 and Cultivar 9665 were relatively low. Xinluzao 10 and Shixuan 87 showed larger leaf size in the whole canopy and in uppermost layer. Cultivar 9665 had the smallest. On the contrary, SLA of Cultivar 9665 was the largest, followed by Xinluzao 6, Xinluzao 8 and Xinluzao 10. Varietal difference in mean IRL for the whole canopy was smaller than that of the uppermost 10 cm layer. Xinluzao 10 had the largest mean IRL both in the whole canopy and the uppermost layer, suggesting that it showed the most active diapheliotropic leaf movement. Xinluzao 6 and Cultivar 9665 showed smaller values. IRL in the uppermost layer showed a significant correlation with MLA ($r=0.87^{**}$), but no significant correlation with SLA ($r=-0.02$).

### 4. Correlation of FRSS with VPD, IRL, TDW and yields

FRSS (transpiration rate) in all cultivars increased generally as vapor pressure deficit (VPD) increased (Fig. 4). Differences in the FRSS response to VPD among cultivars became larger in the range of more than 2 kPa VPD. The FRSS in Xinluzao 10 responded largely to VPD. On the other hand, the FRSSs in Xinluzao 6 and Cultivar 9665 did not respond to VPD in the range of more than 2 kPa VPD. These two cultivars had relatively low FRSS despite of increasing VPD in the afternoon.

Fig. 5 shows the relationship between transpiration rate represented by FRSS from 0400 to 1600 and the mean intercepted radiation per unit leaf area (IRL). With the increase in transpiration rate, the mean IRL in both the whole canopy and the uppermost 10 cm canopy layer increased.

Fig. 6 shows the correlation of the transpiration rate (FRSS m$^{-2}$ leaf area 12h$^{-1}$) to total dry weight (TDW) and yield. There was a tendency that both seed and lint yield, and TDW increased as transpiration rate increased, although a significant correlation was found only for lint yield.

### Discussion

It was found that the transpiration rate represented by flow rate of stem sap per unit leaf area in cotton depended generally on VPD. The result was similar to that obtained in the arid conditions by Isoda and Wang (2002), suggesting that VPD was the main transpiration promoting factor in cotton. In the high range of VPD, differences in transpiration response to VPD among the cultivars became larger as the transpiring abilities of the cultivars increased. In Xinluzao 6 and Cultivar 9665 which had low transpiring abilities, however, their
transpiration rate was less influenced by VPD after the peak of VPD as compared with that before the peak or in the other cultivars. It has been reported that when no environmental stress occurs, transpiration rate increases as VPD increases and response of stomata to VPD is not affected by transpiration rate (Bunce, 1996; Lhomme, 2001). In the afternoon, therefore, reduction in stomatal conductance might be caused by stomata closure and/or decreased hydraulic conductivity from soil to leaf in Xinluzao 6 and Cultivar 9665. Ball et al. (1994) reported that the developed root system would be responsible for high transpiration rate in cotton. In this experiment, there was no significant difference among the cultivars in root dry weight and the ratio of root to total dry weight at the periods from 24 July to 10 Aug. (data not shown). Transpiring ability in cotton may therefore be associated not with root quantity but with water absorbing ability of roots.

There was a large difference in leaf movement judging from the intercepted radiation of leaves in this experiment. The active diheliotropic leaf movement of the uppermost layer of the canopy depended on the large area of leaves not on thickness. On the contrary, a cultivar with smaller and thicker leaflets showed higher active movement in soybean (Isoda et al., 1993). Though the mechanism of leaf movement in cotton is still unknown, the transpiring ability seemed to have a close relationship with leaf movement resembling soybean, suggesting that a cultivar with active diheliotropic leaf movement has high transpiring ability. Thanisawanyangkura et al. (1997) reported that diheliotropism is profitable for photosynthesis when solar altitude is low, but it does not improve photosynthesis at noon due to photosaturation and increases in risks of water, temperature and light stresses. Ehleringer and Hammond (1987) showed that diheliotropic leaf movement in the outer canopy in cotton did not increase daily carbon gain due to photosaturation, in spite of increasing energy loads on leaves. On the other hand, the increase in stomatal conductance has been reported to be accompanied with the increase in yield without improving photosynthesis in the breeding process of Pima cotton (G. barbadense L.) (Lu et al., 1998; Ulloa et al., 2000). In this experiment, we also found a positive correlation of transpiring ability with TDW and yields, especially with lint yield. Though there was no direct evidence of the relationship between yield and transpiring ability or active diheliotropic leaf movement in this experiment, the cultivars with active diheliotropic leaf movement might not be affected by drought stresses at least by that due to a high transpiring ability. In soybean, Oosterhuis et al. (1985) reported that the increase in the angle of the terminal leaflet was clearly related to leaf water potential, stomatal resistance and plant water availability, and suggested that paraheliotropic leaf movement could be an indicator of water-stressed plants. Active diheliotropic leaf movement in cotton may not only be an indicator for drought tolerance, but also be possible criteria for selection of high yielding cultivars under arid conditions.

Acknowledgements

We are grateful to all members of Shihezi Agricultural and Environmental Institute for Arid Area in Central Asia, Shihezi, Xinjiang, China for their cooperation in collecting data.

References

Ball, R. A., Oosterhuis, D. M. and Mauromoustakos, A. 1994. Growth dynamics of the cotton plant during water-deficit stress. Agron. J. 86 : 788-795.

Berg, V. S. and Heuchelin, S. 1990. Leaf orientation of soybean seedlings. I. Effect of water potential and photosynthetic photon flux density on paraheliotropism. Crop Sci. 30 : 631-638.

Bunce, J. A. 1996. Does transpiration control stomatal responses to water vapor pressure deficit? Plant Cell Environ. 19 : 131-135.

Ehleringer, J. R. and Hammonds, S. D. 1987. Solar tracking and photosynthesis in cotton leaves. Agric. For. Meteorol. 39 : 25-35.

Isoda, A., Aboagye, I. M., Nojima, H. and Takasaki, Y. 1996. Effects of leaf movement on radiation interception in the field grown leguminous crops. IV . Relation to leaf temperature and transpiration among peanut cultivars. Jpn. J. Crop Sci. 65 : 702-708.

Isoda, A., Yoshimura, T., Ishikawa, T., Nojima, H. and Takasaki, Y. 1993. Effects of leaf movement on radiation interception in field grown leguminous crops. III . Relation to leaf temperature and transpiration among soybean cultivars. Jpn. J. Crop Sci. 63 : 657-663.

Isoda, A. and Wang, P. 2001. Effect of leaf movement on leaf...
temperature, transpiration and radiation interception in soybean under water stress conditions. Tech. Bull. Fac. Hort. Chiba Univ. 55 : 1-9.

Isoda, A. and Wang, P. 2002. Leaf Temperature and transpiration of field grown cotton and soybean under arid and humid conditions. Plant Prod. Sci. 5 : 224-228.

Kawashima, R. 1969. Studies on the leaf orientation-adjusting movement in soybean plants. 1. The leaf orientation-adjusting movement and light intensity on leaf surface. Proc. Crop Sci. Soc. Jpn. 38 : 718-729*.

Lang, A. R. G. 1973. Leaf orientation of a cotton plant. Agric. Meteorol. 11 : 37-51.

Lhomme, J. P. 2001. Stomatal control of transpiration: Examination of the Jarvis-type representation of canopy resistance in relation to humidity. Water Resour. Res. 37 : 689-699.

Lu, Z., Percy, R. G., Qualset, C. O. and Zeiger, E. 1998. Stomatal conductance predicts yields in irrigated Pima cotton and bread wheat grown at high temperature. J. Exp. Bot. 49 : 453-460.

Miller, C. S. 1975. Short interval leaf movements of cotton. Plant Physiol. 55 : 562-566.

Oosterhuis, D. M., Walker, S. and Eastham, J. 1985. Soybean leaflet movement as an indicator of crop water stress. Crop Sci. 25 : 1101-1106.

Peterson K. L., Fuchs, M., Moreshet, S., Cohen, Y. and Sinoquet, H. 1992. Computing transpiration of sunlit and shaded cotton foliage under variable water stress. Agron. J. 84 : 91-97.

Thanisawanyakura, S., Sinoquet, H., Rivet, P., Cretenet, M. and Jallas, E. 1997. Leaf orientation and sunlit leaf area distribution in cotton. Agric. For. Meteorol. 86 : 1-15.

Ulloa, M., Cantrell, R. G., Percy, R. G., Zeiger, E. and Lu, Z. 2000. QTL analysis of stomatal conductance and relationship to lint yield in an interspecific cotton. J. Cotton Sci. 4 : 10-18.

Yoshimura, T., Komiyama, K. and Ishikawa, T. 1990. Simple measurement of integrated global solar radiation. Int. J. Solar Energy 9 : 193-204.

* In Japanese with English Summary.