Agricultural and Forest Meteorology 201 (2015) 165–175

Contents lists available at ScienceDirect

Agricultural and Forest Meteorology

journal homepage: www.elsevier.com/locate/agrformet

Sap flow, canopy conductance and microclimate in a banana screenhouse[☆]

Liu Haijun[a,b], Shabtai Cohen[b,*], J. Hugo Lemcoff[b], Yair Israeli[c], Josef Tanny[b]

[a] College of Water Sciences, Beijing Normal University, Beijing 100875, China
[b] Institute of Soil, Water and Environmental Sciences, Agricultural Research Organization, The Volcani Centre, P.O. Box 6, Bet Dagan 50250, Israel
[c] Jordan Valley Banana Experimental Station, Zemach 15132, Israel

ARTICLE INFO

Article history:
Received 29 May 2014
Received in revised form 26 October 2014
Accepted 10 November 2014

Keywords:
Class A pan
Evapotranspiration
Decoupling
Screen
Shade
Thermal dissipation probe
Leaf boundary layer.

ABSTRACT

A field experiment was conducted to investigate the effect of a flat-roof screenhouse on banana transpiration (Tr) and microclimate during the summers and falls of 2005 and 2006 in Northern Israel. The clear polyethylene screen reduced radiation by between 8 and 25% depending on dust accumulation and aging. In the screenhouse, wind speed, global radiation and air temperature were reduced by more than 60, 20 and 1%, respectively, and relative humidity increased by 8% relative to an external meteorological station. Class A pan evaporation and reference crop evapotranspiration (ET_0) were reduced by about 44 and 33% in the screenhouse, respectively. Inside, banana transpiration (Tr), measured with thermal dissipation probes, was about 90% of that outside the screenhouse. The relatively small reduction in Tr inside was caused by increased canopy conductance in the screenhouse during much of the day, which at mid-day was double that outside. Hourly average canopy conductance increased with increasing vapor pressure deficit (VPD) during much of the day and decreased late in the afternoon. Inside the screenhouse, leaves were large and whole with a high boundary layer resistance, but outside leaves were torn by the wind, which, we estimate, reduces the characteristic leaf dimension by an order of magnitude from 1.4 to 0.14 m, decreases boundary layer resistance and reduces the decoupling coefficient. The decoupling coefficient outside was up to 0.3 in the morning and declined to less than 0.1 in the afternoon when wind speed increased. Inside, the corresponding values were 0.8 and 0.5, respectively. This indicates that inside radiative factors dominate, while outside aerodynamic factors dominate during much of the day. A sensitivity analysis showed that the reduction in ET_0 in the screenhouse is mainly due to the combined reductions of wind speed and global radiation. Inside, the screenhouse Tr was similar in two irrigation treatments (85 and 100% of class A pan evaporation) and also similar to outdoor pan evaporation.

1. Introduction

Screenhouses are popular structures in subtropical and mild winter climate agriculture (Castellano et al., 2008; Romero-Gámez et al., 2012; Tanny, 2013). They modify crop climate considerably, and a myriad of screen types and a number of structural alternatives are available (Tanny, 2013). Some of the features of screenhouses are common to all cases, and generalizations about their internal micro-climate can be made. All screens reduce solar radiation entering the screenhouse. Some screen radiative properties can be predicted from basic screen properties and geometry (Cohen and Fuchs, 1999; Möller et al., 2010; Cohen et al., 2014), but many screens cannot be treated by Cohen and Fuchs (1999) theory, nor have there been rigorous treatments of diffusion of radiation as it traverses the screens. Wind speed is also reduced by screens (Tanny and Cohen, 2003; Tanny et al., 2003, 2006a,b; Siqueira et al., 2012) but no models have been developed to predict from screen properties the magnitude of the reduction.

Crop response to reduced radiation load and wind speed has received more attention. Stanhill and Cohen (2001) reviewed the influence of moderate reductions of radiation on plants and crop yields. Productivity should be reduced at lower solar radiation; but for well irrigated crops in high radiation climates shading can reduce ephemeral water stress leading to increased mid-day leaf conductance and subsequent increased productivity, as observed in several studies in citrus and apple trees (Cohen et al., 1997, 2005; Medina et al., 2002; Raveh et al., 2003). This plant response can increase water-use under shade so that water use is similar in

---

[☆] Contribution from the Agricultural Research Organization, Institute of Soil, Water and Environmental Sciences, Bet Dagan, Israel, No. 605/14.

[*] Corresponding author. Tel.: +972 3 9683701.
E-mail address: vwshep@volcani.agri.gov.il (S. Cohen).

http://dx.doi.org/10.1016/j.agrformet.2014.11.009
0168-1923/© 2014 Elsevier B.V. All rights reserved.

and out of the shade. On the other hand, in an insect-proof pepper screenhouse Möller et al. (2004) and Tanny et al. (2003) estimated that water-use was reduced considerably and the reduction was roughly proportional to the reduction in solar radiation. Thus, for cases where leaf conductance response is minor, once the influence of the screen on climate variables like solar radiation and wind has been accounted for, standard formulas for predicting crop evapotranspiration may give accurate predictions (Möller et al., 2004; Möller and Assouline, 2007). A previous study of shading banana plants did not find evidence for a significant increase in mid-day leaf conductance, and even light shading apparently reduced photosynthesis and related processes (Israeli et al., 1995, 1996). Siqueira et al. (2012) showed that the presence of a screen results in a warmer and more humid environment inside the screenhouse, promoting reductions in both canopy photosynthesis and transpiration. However, the overall effect of the screen may be to enhance water-use efficiency, thereby resulting in water savings for the same amount of gross primary production.

Crop water-use increases nonlinearly with wind speed. At high wind speeds, the increase in evaporation with increasing wind speed is smaller than at lower wind speeds (Monteith and Unsworth, 1990). However, very high wind speeds can damage the leaf epidermis, resulting in reduced crop resistance to vapor transport (Grace, 1974). The latter introduces some uncertainty into the otherwise straightforward engineering-type calculations of the influence of wind on crop water use. High wind speeds common in some banana growing regions tear leaves (Pirkner et al., 2014), which can be detrimental to the crop (Eckstein et al., 1996). Banana leaf tearing reduces leaf dimensions and enhances the exchange of heat and mass with the atmosphere, which can reduce leaf temperatures in exposed leaves (Taylor and Sexton, 1972), but the influence of this on actual plant transpiration has not been studied.

Natural ventilation and microclimate performance of a large banana greenhouse were studied by Demrati et al. (2001). The ventilation rate through roof and side openings was measured by the energy balance approach and estimated using a linear relation with external wind speed. Ventilation rates determined by the two approaches were in good agreement. The effect of greenhouse cultivation on banana growth and production was studied by Eckstein et al. (1998) in a subtropical environment in South Africa. They found higher yield potential inside the greenhouse, which was explained by a more favorable microclimate, resulting in increased photosynthetic capacity and efficiency. Israeli et al. (1996) studied the effect of shade on bananas during their first and second production cycles. They used black screens without sidewalls (i.e. with a negligible effect on wind) with three different densities (i.e., light levels corresponding to 80, 60 and 30% of the incident light) and observed significant effects of shading on a variety of morphological and growth parameters, including yield. As expected, the effects increased with increased shading.

Banana evapotranspiration rates can range from 1200 to 3000 mm/year, depending on climate and management (Purseglove, 1985; Hedge and Srinivas, 1989; Robinson, 1996; Goenaga and Irizarry, 1998, 2000). In Israel's northern Jordan valley, banana is a major cash crop with potentially good quality and high yield, but its annual irrigation requirement is high (~2200 mm/year, Israeli & Namri, 1986). The climate is one of the hottest in Israel, with most of the tropical conditions needed for good yield. Wind speeds are sometimes high, and the local Mediterranean Sea breeze arrives at this area in mid-afternoon after it passes over the hills to the west and descends into the valley. Local agricultural researchers who began trials with screenhouses in order to protect the banana plants from high radiation load and winds soon noticed that water requirements were reduced while fruit yield and quality increased. Irrigation trials found that annual irrigation can be reduced by about 25% without any loss (and even improvement) of yield and fruit quality (Israeli et al., 2002; Tanny et al., 2007). This led to extensive application of screenhouses in recent years.

One objective of this study was to measure actual water use, potential evapotranspiration, pan evaporation and climate in a banana screenhouse. In addition, an examination of climate variables gives an indication of which variables play significant roles in the reduction of water use. Such knowledge is important for irrigation scheduling in this and other similar intensive agricultural systems. A companion study applied the eddy covariance technique for evapotranspiration measurement in a large commercial screenhouse (Tanny et al., 2006a,b). The current study was carried out in an irrigation trial in a screenhouse at a research station.

We hypothesized that inside the screenhouse, leaf conductance would be higher due to lower vapor pressure deficit (VPD) and/or less ephemeral plant water stress. This hypothesis is supported by reports that banana leaf conductance increases when VPD decreases (Thomas et al., 1998), similar to many other plants. Since evaporative demand inside is lower, that would lead to similar transpiration inside and outside the screenhouse. Alternatively, if leaf conductance was similar inside and outside, water-use inside would decrease in proportion to the decrease in solar radiation. For the latter, water-use could be predicted by using the Penman–Monteith equation after accounting for the changes in climate induced by the screen.

2. Methods

2.1. Experimental site

Measurements were conducted at the Zemach research station in a flat-roof screenhouse and an adjacent open field, which are part of a complex of banana plantations. The screenhouse was located near the southern coast of the Sea of Galilee (i.e. Lake Kinneret, 32°42′N; 35°34′E; 200 m below sea level) in Northern Israel. The local summer climate is rainless and predominantly sunny, with little variation from day to day. The transparent shading screen (Crystal type, Klayman Meteor Ltd., Petah-Tikva, Israel) with a rectangular hole size of 3.5 × 2.5 mm, was made of clear, homogeneous, high-density polyethylene round monofilament fibers, 0.3 mm in diameter. This screen reduces radiation by between 8 and 25% depending on dust accumulation and aging. The screenhouse was a rectangle, 120 × 72 m, with the long side oriented north-south. An open banana plantation was adjacent to its southern side. Tissue culture cv 'Grande Naine' (AAA, Cavendish subgroup) banana were planted in August 2004, both in and out of the screenhouse. Plant mat spacing was 2.8 m between mats along the north-south rows and 4.2 m between rows. Each experimental plot consisted of two central rows, 28 m long (i.e. 20 mats). In 2005, climatic data as well as some plant morphological characteristics were measured inside and outside the screenhouse. An average of three mother plants were cultivated at each mat during the summer of 2006, when plant physiological and hydraulic measurements were made.

2.2. Irrigation

Irrigation was provided daily around noon for 4–6 h, with an automated drip system; two laterals per row with 2.3 L h^{-1} drippers (UniTechline^{TM} AS dripper, Netafim, Tel Aviv, Israel) every 0.4 m on each lateral. When operating, this was equivalent to 2.74 mm h^{-1}. Two irrigation treatments were applied: 85 and 100% of reference pan evaporation, plus a leaching fraction, based on a time table from long-term A pan evaporation data. Treatments and codes were: 85% = T_{85} and 100% = T_{100}. The T_{100} treatment, which was the same treatment applied in the open (unshaded) banana treatment,