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The effect of screen type on crop micro-climate, reference evapotranspiration and yield of a screenhouse banana plantation

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ABSTRACT

Most banana screenhouses are currently equipped with transparent screens, with a nominal shading of 8–15%. Two types of screens are widely used, woven or knitted, which differ in their texture and hence in their radiative and aerodynamic properties. These differences may induce different micro-climatic conditions and hence different atmospheric water demand, plant response and yield.

We have investigated four types of screens based on different shading levels (8%, 10% or 13%) and different screen textures (woven or knitted). A large commercial banana plantation in Northern Israel was covered with patches of the four different screen types, each in 4–5 replicates, randomly located. Air velocity, temperature, humidity and net radiation were measured simultaneously below two out of the four screen types: the 10% woven and 10% knitted. The results showed that both the net radiation and air temperature were similar under these two screens. Nevertheless, under the knitted screen the horizontal mean air velocity was 18% higher and the specific humidity 8% lower than under the woven screen. Leaf lamina tearing (typical wind damage) and estimated reference evapotranspiration were higher under the knitted screen; the latter mainly during the fall–winter season. However, the horticultural measures of flowering and fruit yield characteristics were the same under all four screen types, with results typical of screenhouse banana plantations in this region. Hence, the results suggest a potential increase in water use efficiency under the woven as compared to the knitted screen.

1. Introduction

Horizontal screen covers and screenhouses protect crops from insects (Rossel and Ferguson, 1979; Möller et al., 2004), supra-optimal radiation (Cohen et al., 1997; Raveh et al., 2003), high air velocity (Tanny and Cohen, 2003) and hailstorms. Thus, the cultivation inside screenhouses, or under horizontal screens, allows significant reductions of pesticide application (if insect-proof screens are used) and increases marketable yield by reducing the radiation and wind damage to the fruit (Levi, 2012). In addition, screen covers modify the crop microclimate (Tanny et al., 2009, 2010a; Tanny, 2013), in a way which may reduce the irrigation demand, leading to water savings (Israeli et al., 2002; Rana et al., 2004).

The effects of screens on crop microclimate and water use have been investigated in several studies during the past two decades (Cohen et al., 2005; Desmarais et al., 1999; Kittas et al., 2012; Pirkner et al., 2014; Tanny and Cohen, 2003; Tanny et al., 2003, 2006, 2010a,b, 2014; Teitel and Wenger, 2010; Teitel et al., 1996). Screens not only reduce air velocity near the crop but also modify turbulence characteristics (Tanny and Cohen, 2003; Siqueira et al., 2012) and thereby reduce the wind's contribution to heat and water-vapour exchange between plants and atmosphere.

Crop water requirements depend on atmospheric water demand, which integrates the effects of radiation, wind, temperature and humidity, on crop microclimate. Hence, the modified microclimate under the screen, and especially the reduced radiation and air velocity, might reduce crop evapotranspiration (Rana et al., 2004; Moratiel and Martinez-Cob, 2012). Although crop water requirements in open-field conditions are well documented in the literature (Allen et al., 1998), their modification by screens has been less studied. Therefore, the effects of different screen materials on atmospheric water demand are of importance for improving irrigation management.

In Israel the current total area of crops grown under screens or in screenhouses, including vegetables, orchards and ornamentals is

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about 10,000 ha (Esquira, 2012). About 70% of all the banana plantations in Israel are currently grown in screenhouses (Levi, 2012). It has been demonstrated that water use efficiency of a screenhouse banana crop in the Jordan Valley region of northern Israel can be increased by about 30% compared to open field (Israeli et al., 2002). Banana screenhouses are currently equipped with transparent shading screens, with nominal shading ranging between 8–15% (Tanny et al., 2006, 2010b; Dicken et al., 2013).

The two types of screens which are widely used, woven and knitted, differ in their texture and hence in their radiative and aerodynamic properties (Fig. 1). Woven fabrics consist of two distinct threads interlaced at right angles to form a fabric or cloth. Knitted fabrics consist of consecutive rows of loops, called stitches. As each row progresses, a new loop is pulled through an existing loop. The active stitches are held on a needle until another loop can be passed through them.

The world market has a large variety of screens and farmers do not have sound criteria to choose the best ones. Therefore, better knowledge of the effect of the screen type on microclimate, crop water requirement and yield is necessary. Our goal was to investigate in a commercial plantation, growth, fruit yield and leaf tearing under four types of screens of different shading levels, and different textures. For two types of the screens, out of the four, the study also included wind-tunnel measurements of screen pressure drop, field measurements of microclimate and estimates of reference evapotranspiration.

2. Materials and methods

The study was carried out in two sites: (i) The wind tunnel of the Institute of Agricultural Engineering, Bet Dagan, Israel and (ii) a full commercial scale banana screenhouse at Kibbutz Tel-Katzir, located near the eastern shore of the Sea of Galilee (Lake Kinneret), Israel.

The wind tunnel at Bet Dagan had a cross section of 0.12×0.12 m, and air velocity was in the range 0–2.5 m s^{-1}. The tested screens were 10% woven and 10% knitted (10w and 10k in Table 1). Each screen sample was deployed perpendicular to the flow direction. Air velocity was measured by a hot wire anemometer (8450, TSI Inc., USA) positioned upstream of the screen sample to avoid flow disturbance effects due to the screen. Pressure drop across the screen was measured by a pressure transducer (FC011, Furness control, Bexhill on Sea, East Sussex, UK) at air velocities of: 0.4, 0.8, 1.2, 1.7, 2.0, 2.3 and 2.5 m s^{-1}. All wind tunnel data was recorded by a data logger (CR23X, Campbell Sci., USA).

The field measurements were carried out in a commercial banana screenhouse located in the Jordan Valley region of Northern Israel (32°42′14″N; 35°37′20″E; −160 m a.m.s.l). Banana cultivar *Grand Nain* was planted using 0.3 m tall tissue culture plantlets on April, 29, 2008, at a planting density of 833 mats ha^{-1}, three plants per mat. Row orientation was north–south. Plants were drip-irrigated and fertilized according to the best common practice for banana screenhouse cultivation in this region (Israeli et al., 2009). The dimensions of the flat-roof screenhouse were 216 m long, 120 m wide and 5.7 m in height, with the longer dimension oriented north-south. The screenhouse roof was divided into 18 plots, 36 by 40 m each (Fig. 2). Four types of transparent screens were deployed in four or five randomized replications each. The screens were of different nominal shading level, in the range 8–13%, and different texture: woven or knitted (Table 1). The study included microclimatic measurements, estimates of atmospheric water demand, plant growth analysis and yield measurements. The rate of leaf lamina tearing of the top three leaves on fully developed unshot plants was recorded in the summer of years 1–3 of the experiment. The number of leaf tears was counted in ten representative plants for each plot and averages were calculated. Horticultural data were collected from plants grown in the central 12 m × 18 m part of each plot (18 mats per plot), leaving about 12 m wide border zone on each side of a plot in order to have good separation between treatments.

Microclimatic measurements were conducted below two out of the four screen types studied: woven (10w) and knitted (10k), in two plots at the center of the screenhouse (Fig. 2). Under each of the two screens the following variables were measured (Table 2): Air velocity (at 5 m), net radiation (at 4.7 m) and dry- and wet-bulb air temperature using psychrometers at three heights (1.5, 2.5 and 4.75 m) with two replications (a total of six sensors under each screen). The aspiration fans of the psychrometers were operated for the last 5 min, and dry- and wet-bulb temperatures were measured and averaged during the last minute of every 30 min interval. Velocity data lower than 0.5 m s^{-1} was discarded due to sensor cutoff threshold. An external tower measured outside global radiation (8 m), and external air velocity (10 m). Microclimate data and latent energy (LE) calculations are reported for the following periods (Table 2): Air velocity: Nov–Dec 2010; Aug–Nov 2011; Jan–Feb 2012. Air temperature: Aug 2010–Oct 2011. Air humidity and LE model calculations: Nov–Dec 2010; Aug 2011.

To examine the potential effect of the different screens on crop water use, reference evapotranspiration was estimated using the Penman–Monteith equation adapted to a reference hypothetical grass (Allen et al., 1998). Evapotranspiration was calculated by:

$$\mathrm{LE} = \frac{\Delta(R_\mathrm{n} - G) + \frac{\rho_\mathrm{a} C_\mathrm{p}(e_\mathrm{s} - e_\mathrm{a})}{(208/u)}}{\Delta + \gamma\left(1 + \frac{70}{(208/u)}\right)} \tag{1}$$

where LE is evapotranspiration (J s^{-1} m^{-2}), Δ is the slope of the vapor pressure curve (kPa K^{-1}), R_n is net radiation (J s^{-1} m^{-2}), G is soil heat flux (J s^{-1} m^{-2}), ρ_a is air density (Kg m^{-3}), C_p is air specific heat (J Kg^{-1} K^{-1}), e_s and e_a are saturation and actual water vapor pressure (kPa), respectively, γ is the psychrometric constant (kPa K^{-1}) and u is air velocity (m s^{-1}).

For LE estimates through Eq. (1), net radiation was calculated from global outside radiation using the regressions presented below, Eqs. (2) and (3). Soil heat flux was estimated as $G = 0.1R_\mathrm{n}$ (Allen et al., 1998). Calculations of air temperature and relative humidity were made using means (of the three heights and two replicates) under the two screens. In the original Penman-Monteith model (Eq. (1)) air velocity at 2 m above the ground should be used. However, in the present estimation for banana with a plant height of 4 m, that measurement height is unrealistic since it is within the canopy. Therefore, the 2 m height in Eq. (1) was interpreted as 2 m above zero-plane displacement height, which is approximately 2.7 m for the present banana plants under neutral stability (Allen et al., 1998). Hence, the air velocity measurement height of 5 m is only slightly higher than the 4.7 m required for the model. The model was used to calculate the ratio between LE obtained for the two screen treatments under which microclimate was measured, i.e., 10%w and 10%k. These estimates were carried out during two limited periods: 19 days from November 18 to December 8, 2010 (‘fall–winter’) and 19 days from August 2 to August 20, 2011 (‘summer’).

2.1. Growth and production

Rate of growth and fruit production were recorded by common protocols for banana field experiments, including the date of shooting, plant height at shooting, pseudostem circumference at 1 m height, number of female hands per bunch, harvesting date, bunch weight at harvest and weight, length and circumference of