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Airflow characteristics, energy balance and eddy covariance measurements in a banana screenhouse☆

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Abstract

Shading banana and other orchard crops with screens is increasing in popularity due to decreased water use, increased fruit quality and other reasons. This study focused on airflow, turbulence, ventilation rate, evapotranspiration and energy balance in a large commercial flat-roof banana screenhouse in northern Israel. Measurements were made during 14 days. An eddy covariance system, consisting of a one-dimensional sonic anemometer, a fine-wire thermocouple and a Krypton hygrometer, was deployed at 5 m height, in a location allowing a minimum fetch of 100 m in all directions. Net radiation, soil heat flux and storage, soil evaporation, air temperature and humidity and turbulent airflow characteristics were measured. Comparison between wind speed inside and outside of the screenhouse suggests that the logarithmic wind profile model is approximately valid within the screenhouse. Airflow direction inside the screenhouse was usually the same as that of the external wind. Friction velocity scaled with the mean horizontal wind speed inside the screenhouse. Integral length scale calculations showed that eddies were always narrow and long and high air velocities caused eddies to become even narrower, as expected. Average turbulence intensity within the screenhouse for all data was 0.49 ± 0.12 ($\pm$ standard deviation). Spectral energy density depended on frequency to the power of about $-5/3$, typical of the inertial subrange in turbulent boundary layers. Air exchange rate increased with wind speed, as expected. Evapotranspiration averaged 5.6 ± 0.47 mm day^{-1}, in accord with the 7–8 mm day^{-1} irrigation. Analysis of energy balance closure resulted in a slope of 0.94 and an intercept of 2.4 W m^{-2}.

Keywords: Evapotranspiration; Ventilation; Turbulence intensity; Friction velocity; Net radiation; Shade

1. Introduction

Covering crops with screen materials is a common practice used to attain a number of agricultural objectives. These can be divided into several categories: shading from supra-optimal solar radiation (e.g. in citrus; Cohen et al., 1997, 2005; Raveh et al., 2003), protecting from wind, improving the thermal climate (e.g. for reducing nocturnal heat loss, Bailey, 1981), exclusion of insects (with insect proof screens), birds and fruit bats and changing the solar spectrum for induction of light mediated processes (e.g. use of coloured screens). Several of these factors are presumably responsible for the general increase in produce quality obtained. In recent years, the use of

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Nomenclature

A_f screenhouse floor area (m^2)
c_m, c_o, c_w, c_a volumetric heat capacity of minerals, organic mater, water and air in soil ($MJ\ m^{-3}\ K^{-1}$)
c_p specific heat of air at constant pressure ($J\ kg^{-1}\ K^{-1}$)
ΔC change of soil heat storage over a given period in a 0.08 m deep soil layer ($MJ\ m^{-3}$)
C_a actual heat storage in soil ($MJ\ m^{-2}$)
ΔC_a change of actual soil heat storage in a specific area ($MJ\ m^{-2}$)
$\Delta C_{a,rate}$ rate of change of actual soil heat storage ($W\ m^{-2}$)
C_{dry} heat storage in dry soil ($MJ\ m^{-3}$)
ΔC_{dry} change of soil heat storage in dry area ($MJ\ m^{-3}$)
C_{wet} heat storage in wet soil ($MJ\ m^{-3}$)
ΔC_{wet} change of soil heat storage in wet area ($MJ\ m^{-3}$)
d canopy zero plane displacement (m)
d_s screenhouse zero plane displacement (m)
D_s depth of soil heat flux sensor (m)
E spectral energy density ($m^2\ s^{-1}$)
EC eddy covariance
f measurement frequency (s^{-1})
f_m, f_o, f_w, f_a volumetric fraction of minerals, organic mater, water and air in soil
F_{dry} dry fraction of soil area
F_{wet} wet fraction of soil area
G soil surface heat flux determined as the rate of change of soil heat stored in a 0.08 m deep soil layer plus the heat flux measured at 0.08 m depth ($W\ m^{-2}$)
h canopy height (m)
H sensible heat flux ($W\ m^{-2}$)
H_s screenhouse height (m)
I $= u_h^{rms}/u_{hm}$, turbulence intensity
k von Kármán constant (=0.41)
L_{AI} leaf area index
L_i integral length scale (m)
L_{ih} resultant horizontal integral length scale (m)
L_{iv} vertical integral length scale (m)
L_{ix} x-direction horizontal integral length scale (m)
L_{iy} y-direction horizontal integral length scale (m)
L_v latent heat of vaporization ($MJ\ kg^{-1}$)
LE evapotranspiration rate ($W\ m^{-2}$)
M_a actual evaporation from the soil ($g\ m^{-2}\ s^{-1}$)
M_s soil evaporation ($g\ m^{-2}\ s^{-1}$)
M_v evapotranspiration rate ($g\ m^{-2}\ s^{-1}$)
q' deviation of specific humidity from mean ($kg\ kg^{-1}$)
r aerodynamic resistance ($s\ m^{-1}$)
r_x bulk screenhouse resistance ($s\ m^{-1}$)
R_i autocorrelation of u_i
R_n canopy net radiation ($W\ m^{-2}$)
t_{int} integral time scale (s)
T_s soil temperature (°C)
ΔT_s difference of mean soil temperature in a 0.08 m deep soil layer in a given time period (°C)
T' deviation of air temperature from mean (K)
u, v horizontal wind speed components ($m\ s^{-1}$)
u_h horizontal instantaneous resultant wind speed ($m\ s^{-1}$)
u_{hm} horizontal resultant mean wind speed based on 4-min averages ($m\ s^{-1}$)
u_{int}, u_{ext} internal (at 5 m height) and external (at 18 m height) wind speed based on 15-min averages ($m\ s^{-1}$)
u_* friction velocity ($m\ s^{-1}$)
u', v', w' deviation of wind speed components from mean ($m\ s^{-1}$)
u_h^{rms} root mean square (r.m.s.) of horizontal resultant wind speed ($m\ s^{-1}$)
U, V horizontal mean wind speed components ($m\ s^{-1}$)
V_a volume flow rate ($m^3\ s^{-1}$)
w vertical wind speed ($m\ s^{-1}$)
W vertical mean wind speed ($m\ s^{-1}$)
X_s air exchange rate (h^{-1})
z height above ground (m)
z_0 roughness length (m)

Greek letters
ρ_a air density ($kg\ m^{-3}$)
χ_i, χ_o inside and outside absolute humidity ($g\ m^{-3}$)
χ_s absolute humidity at soil surface ($g\ m^{-3}$)

light shading screens above orchards is rapidly expanding because of the possibility of saving water and the increasing demand for high quality produce.

Obviously the existence of a screenhouse modifies the exchange of radiation, momentum and mass