Solar Distribution in a Greenhouse at Different Crops Orientation during Production Season

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Abstract

The present study investigates numerically the effect of solar radiation distribution during the production season at three time-days in arc three span type greenhouse with continuous side vents and a different rows tomato crop orientation using a fluent CFD code. A three dimensional mesh was used to render the geometry of greenhouse's section, and the finite volume method was adopted to carry out the fully elliptic partial differential equations problem. The variation of solar incident radiation at three hours sun of atypical day was incorporated as time dependent condition using solar calculator according to a given position, date and time. Physical and Optical properties of the covering material were defined according to the wave-length of the incoming solar radiation for three spectral areas (UV, PAR and near infrared). Radiative heat transfers were modeled using the three-banded discrete (OD) model, and the culture was considered a porous medium.The results show that the radiation distribution presents symmetrical time behavior and temperature pattern inside the greenhouse is a combination of the convective flow and radiative heat transfer at a three hour sun.

Keywords: *greenhouse, microclimate, CFD, Solar radiation modelling*

1. Introduction

Agricultural production in controlled environments has been steadily increased in recent years. Greenhouse farming systems offer the opportunity to alter the indoor climate and create the optimum environment for growth and production. The most important factor affecting plant growth and development in greenhouses is solar radiation because, in addition to its indirect effect on the distribution of the inner microclimate of the greenhouse, it governs two important plant physiological mechanisms, namely, Transpiration and photosynthesis. The amount of solar radiation entering the greenhouse depends on the design of the greenhouse, the thermo-physical and optical properties of the material, and the weather conditions.

The spectrum of solar radiation outside can be significantly modified by the optical properties of the greenhouse cover. These qualitative changes in the radiation transmitted within the greenhouse induce morphogenetic effects and may lead to changes in the architecture and shape of plants with important consequences in some cases on the quality of the crop.

Takakura (1993) studied the variation of radiation as a function of time on a horizontal surface. A simple model was developed to calculate the transmission of the glass of a greenhouse as a function of the angle of incidence. Transmission and reflection for a variant of the glasses were also measured (De Zwart, 1993) as a function of the angle of incidence. The change in transmission caused by condensation on roofing materials was studied by Pollet et al. (1999).

The radiative heterogeneity at ground level of a greenhouse was simulated (Wang and Boulard, 2000) according to the geometry of the greenhouse. More recently, a computational algorithm has been presented (Vougioukas, 2004), which calculates the distribution of light in the surface of a greenhouse on the basis of a global radiation transfer model, such as those developed To numerically solve the radiative transport equation.

In recent years, the use of computational fluid dynamics makes it easier to study the parameters that describe the microclimate of greenhouses in relation to its specific structure and the equipment used (and Wang Boulard, 2002; Bartzanas, Boulard And Kittas, 2004, Fatnassi et al., 2006, OuldKhaoua et al., 2006). However, in these studies the radiation was not simulated directly by a radiative transfer equation but its effect was indirectly incorporated into their models either under boundary conditions or as an additional source term in the transport equation d 'energy.

In the present study, a CFD code Fluent v6.3.26 was used to study the distribution of solar radiation in a naturally ventilated arc type tunnel and its influence on the microclimate greenhouse, taking into account the outside incident radiation diffused in three bands of optical wavelengths. Two cases are investigated: in the first case the rows tomato crop is oriented perpendicular to vent direction (north south direction) while in the second they have oriented parallel to vent direction (west east direction). In order to carried out the influence of the incidence angle of the incoming solar radiation on the distribution of solar radiation inside the greenhouse, three hours sun (w= - 45, w= 0 and w= 45) is considered to vary during the day.

2. Materials and methods

2.1Governingéquation

The CFD methods can explicitly calculate the velocity field and the associated temperature field of a flow by numerically solving the corresponding transport equations. The three-dimensional conservation equations describing the transport phenomena for steady flows are of the general form:

$$\frac{\partial \rho \Phi}{\partial t} + \frac{\partial U \Phi}{\partial x} + \frac{\partial V \Phi}{\partial y} + \frac{\partial W \Phi}{\partial z} = \Gamma \nabla^2 \Phi + S_\Phi \quad [1]$$

Φ represents the concentration of the transport quantity in three momentum conservation equations and the scalars mass and energy conservation equations. U, V and W are the components of velocity vector;Γ is the diffusion coefficient and$\mathbf{S_\Phi}$ is the source term. CFD code Fluent 6.3.2] was used to solve equation (1), using the finite volume numerical scheme to solve the equations of conservation for the different transported quantities (mass, momentum, energy, vapour concentration).

The turbulent stresses is modeling using the k-ε model in equation (1), Φ is also represents the turbulent kinetic energy k (m2 s-2) and dissipation of the kinetic energy ε (m2 s-3). The Boussinesq model was also activated to take account the effect of gravity, which means that the buoyancy force due to the differences of the density of air is added as a source term in the momentum equation (Boulard et al., 2002).

The crops were modeled as a multi rectangular block (with dimensions 22.8 m L × 1 m W × 2m H bay block) porous media approach by the addition of a momentum source term to the standard fluid flow equations. In the case the source term was described as:

$$S_i = -\left(C_1 \mu\, u_i + \frac{1}{2} C_2 \rho |u| u_i\right) \quad [2]$$

$C_1 = 1/K$ Is the viscous resistance (m^{-2}), C_2 is the inertial resistance factor (m^{-1}).

The radiative heat transfer was also calculated by using the non-gray discrete ordinates (DO) radiation model. Considering the ray direction of $\vec{S}$; the radiative transfer equation for spectral intensity $I_\lambda(\vec{r},\vec{s})$; can be written as:

$$\vec{\nabla}.(I_\lambda(\vec{r},\vec{s})\vec{s}) + (a_\lambda + \sigma_\lambda) I_\lambda(\vec{r},\vec{s}) = a_\lambda n^2 I_{b\lambda} + \frac{\sigma_s}{4\pi} \int I_\lambda(\vec{r},\vec{s'})\, \Phi(\vec{r},\vec{s'}) d\Omega' \quad [3]$$

The incident irradiance is distributed in three wave length bands. The ultra-violet (λ=0.01 – 0.4 μm), the photosynthetically active radiation (λ=0.4 – 0.76μm) and the near infrared(λ=0.76 - 1.1μm).

The beam direction and irradiation were computed by a solar calculator according to a given position, date and time. The flow iteration was set to 10 per radiation iteration. The DOM solution required material thermal and optical parameters, as summarized in Table 1.

Properties	Cover	Side walls	Ground	Plants	Air
Density(kg m^{-3})	923	923	1300	700	1.225
Specific heat(J $kg^{-1}K^{-1}$)	2300	2300	800	2310	1006.4
Thermal conductivity($W\, m^{-1}K^{-1}$)	0.38	0.38	1.00	0.173	0.0242
Absorptivity, $\boldsymbol{\alpha}$	0.06	0.93	0.9	0.71	0.19
Scattering coefficient, $\boldsymbol{\sigma}$	0	0	-15	0	0
Refractive index, n	1.53	1.53	1.92	1.51	1
Emissivity, $\boldsymbol{\varepsilon}$	0.7	0.7	0.95	0.71	0.9

Table1: *Thermo-physical and optical material properties.*

2.2Numericaldetails

The 3D computational domain was comprised of three spam arch-roof greenhouse (Each bay was 9 m wide, 4 m high at the gutter and 6 m high at the ridge) equipped with two side roll-up vents located at a height of 2 m above the ground with a maximum opening area of 35 m^2 (35 m length × 1 m height) for each one (Fig. 1). The west opening enters air with a given velocity (2 m/s) preserving turbulent intensity 3% and temperature 300 K. The east opening is considered a constant pressure outlet boundary. The cover is considered a semi-transparent wall. A mixed boundary condition (combination of radiation and convection) is applied to the external boundary of the solid region. The side walls are considered adiabatic and opaque while the ground is considered a diffusively radiating opaque material. The plants are simulated as porous materials with viscous and inertial resistance.

The corresponding transport equations (Navier–Stokes) were solved numerically by finite volume method, using a three dimensional structured mesh consisted of 465,000 cells.

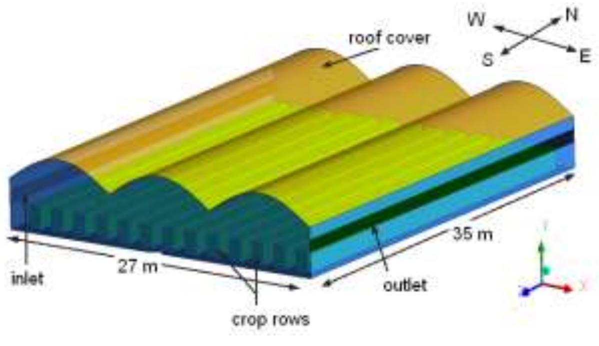


Figure 1:

The boundary condition for the incident radiation on the roof cover for study hours' time is given through solar load calculator according to Meknès city in Morocco.

3. RESULTS

Table 1 presents the mean values of the total flux Φ_S and temperature T_S in the soil for different hours Sun. The results show that the values for north-south crop orientation (cas 1) are high compared to west-east orientation (cas 2) With a maximum at midday, the same thing for the roof (Φ_T and T_T).

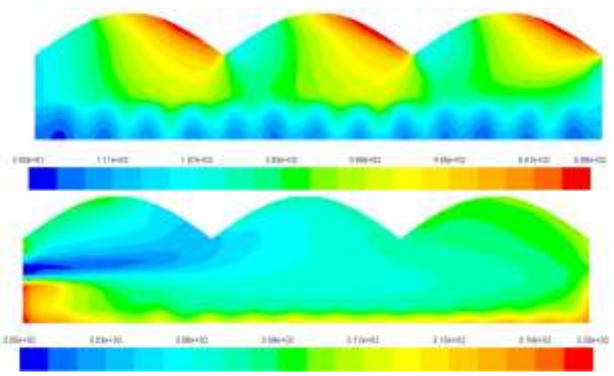
	Cas 1			Cas 2		
	W=-45	W=0	W=45	W=-45	W=0	W=45
Φ_S	-71.9	-108.11	-63.87	-66.77	-97.49	-61.35
T_S	310	314	309	309	312	308
Φ_T	210	330	188	210	329	187
T_T	306.3	309.5	305	306	309.1	306
T_V	306.8	308.9	305.5	306.5	308.45	305.27
PAR_V	122.8	184.29	110.74	124.44	186.81	112.3

Table 1: *Flux and temperature on the ground and the roof as well the radiation and temperature of the vegetation.*

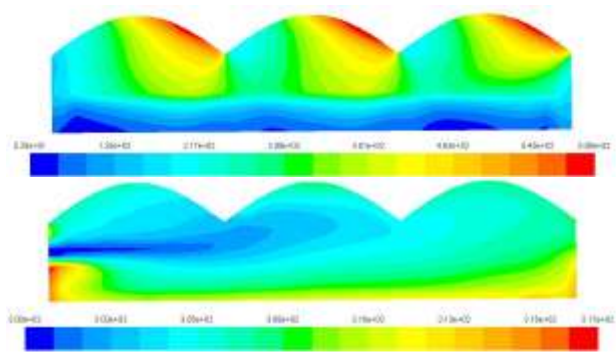
FIG. 2 a and b show the distribution of the radiation and the temperature in the longitudinal meridian plane at -45 hour sun for the two cases of the orientation of the vegetation. The results show that there is a strong heterogeneity of the distribution of photosynthetical radiation inside the vegetation in both cases. For temperature can observe a homogeneity along the greenhouse in case 2 due to the parallel crop blocks orientation to the wind direction.

FIG. 3 shows a strong attenuation of the PAR irradiation towards the bottom of the vegetation due to his absorption at the radiation and a heterogeneity along the greenhouse due to the arc shape of the roof and the position of the sun.

Irradiation along the longitudinal line (a and c) and transverse (b and d) of 1 m above the ground (cas 1: a and b; cas 2: c and d) is reported in FIG. 4. Fig. a and d represent oscillations due to the alternation of the crops blocks, the minimums corresponding to the crops and the maximum at the space between the blocks. The appearance of figure c corresponds to the minimum of figure a. And figure b correspond to the minimum of the oscillations in figure d. Of this observation it can be concluded that the crops orientation has no effect on the distribution of the radiation inside it.

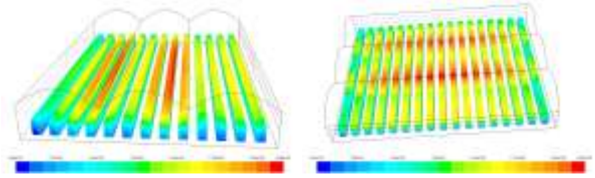


a



b

Figure 2: PAR Radiation and temperature at middle plan of greenhouse for W=-45 (a for cas 1 and b for cas 2)



a b

Figure 3 :PAR irradiation at tomato crop : a cas1 and b cas 2

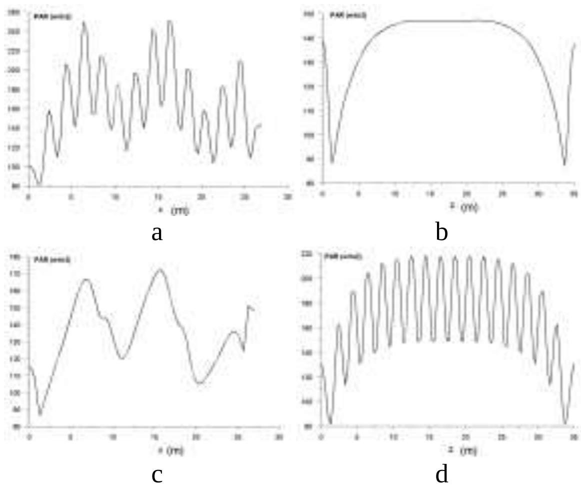


Figure 4 : PAR irradiation at the crop of 1m above the ground

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