WFL Publisher
Science and Technology
Meri-Rastilantie 3 B, FI-00980
Helsinki, Finland
e-mail: info@world-food.net

Journal of Food, Agriculture & Environment Vol.15 (2): 74-79. 2017

www.world-food.net

Improvement of greenhouse design and climate control in Mediterranean conditions

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Received 4 January 2017, accepted 26 March 2017.

Abstract

The Mediterranean Region is one of the most important areas of the world in terms of protected cultivation. Turkey, with its increasing greenhouse area, is one of the representative countries of the region. Thanks to the mild winter climatic conditions, cultivation of vegetables under simple structures is possible. However, due to the changing concerns and demands on product quality and increasing competition in the market, there is a need to increase productivity. The aim of this study was to evaluate and suggest practical and economic improvements of both greenhouse structure and management, for both low tech and high tech greenhouses, in two different climatic zones of Turkey. Locally collected data were used to validate an existing greenhouse design tool, to predict greenhouse climate and tomato yield at given local climate conditions. Thereafter, alternative greenhouse designs and climate control strategies were simulated and evaluated. The results show that ventilation area should be at least 17% in all cases if insect net is not used. Among active climate management means: heating is worthwhile and temperature should not be less than 15°C for high tech greenhouses and CO_2 enrichment (albeit with a limited capacity) should be considered. It can be concluded that such a combined climate-yield model, by quantifying the effect on yield of greenhouse improvements, can be used as an analysis tool for estimating the profitability of an investment.

Key words: Simulation models, greenhouse management, tomato, ventilation, heating, CO_2 enrichment.

Introduction

Protected cultivation is the general term for different types of structures sheltering crops from adverse (non-productive) climate conditions. This makes possible extending the cultivation season (in low plastic tunnels) or providing off season crop production (in greenhouses) [23]. In this paper the word greenhouse refers to permanent, metal structures, with a gutter height of at least 2 m, covered with either plastic or glass. Among the various types of protected cultivation, greenhouse cultivation results in higher potential production, thanks to an extended growing cycle, higher yield and better quality. However, such structures are also more expensive to build and run, and the potential profit is strongly related to the greenhouse design and technology used, and the climate control strategies and crop management used.

Greenhouse cultivation shows significant differences between the countries located in different climate zones. Lower investment, simpler design, less climate control can be found in mild winter climates, while more sophisticated structures and advanced technology are used with extended environmental control in the higher latitudes.

Turkey is one of the mild-winter countries in the Mediterranean Region. Serious commercial greenhouse cultivation started in 1970s, using very simple structures to lengthen the growing season. Since then, the protected cultivation area has gradually increased reaching 66,362 ha in 2015. Greenhouses occupy 76% of this area, an increase of 42% over the last decade. Approximately 80% of the protected cultivation area is located on the southern part of the country, where the climatic conditions allow for protected cultivation without any additional heating. Antalya is the major province for greenhouse cultivation with 83% of the glasshouses, 52% of the plastic greenhouses and 12% of high tunnels of the total [22]. Lately, however, most growth in greenhouse cultivation area is in the western part (Aegean Region) thanks to the availability of geothermal water which can be used as a cheap heating resource.

The greenhouses can be sorted in two main groups in terms of greenhouse design and level of technology used, namely low-tech and high-tech greenhouses [24]. The average size of the low-tech is small (less than 1 ha), there is no heating system except some simple precautions (roof sprinkler irrigation) for frost protection. The ventilation area is small: the ratio of ventilation window openings to greenhouse floor area is less than 5%. In these greenhouses, the length of the growing cycle (and production) is mainly dependent on the outside climatic conditions. The area of high-tech greenhouses has increased sharply during the last decade due to the traders' and the consumers' demands for quality and safe produce, mainly on the export market. Production is done in large-scale greenhouses (at least 2 ha) with automated climate control systems, very often substrate crops and with due consideration of environmental issues. The newest ones are located predominantly in regions where geothermal energy is available. Significant differences in terms of investment and input use within the two types of greenhouses result in differences in yield, product quality and profitability.

For the horticultural sector there is a need to develop locally adapted strategies for different types of greenhouse design and climate control management in order to be able to improve on the present performance. Greenhouse climate-crop simulation models can be used in order to evaluate designs and control strategies. The relations and the interactions between outside climate, inside greenhouse climate and crop processes (such as photosynthesis and transpiration) were described based on a given greenhouse construction, properties of covering materials, and set points for controllers [10, 14, 15]. There are also models which provide a powerful tool for investigation of different scenarios in order to improve economical productivity [6]. However, different models have been developed and tested in different climatic conditions such as subtropical [12, 15, 25] or tropical conditions [8, 9] or different regions [3, 25, 27] for design and/or climate control optimization. In this study the integrated design methodology described by Vanthoor *et al.*[25, 26] was used for simulations of different scenarios in Turkey, Mediterranean climate.

The scientific aim of this work was to study the effect of various climate control technologies on different growing systems (low- and high-tech) and strategies in both systems. A practical aim was to analyse and suggest improvements for both low-tech and high-tech greenhouses in Turkey. Our approach was to validate a suitable analysis tool by using local data of greenhouse climate and production, and use scenario calculations to evaluate alternative greenhouse designs with different levels of technology and different climate control strategies.

Materials and Methods

Description of the model: For this study the combined greenhouse climate and crop yield model developed by Vanthoor *et al.*[25, 26] was used. This dynamic model predicts greenhouse climate, based on the outdoor climatic conditions (temperature, humidity, sun radiation, wind speed), greenhouse construction (dimensions, area and position of openings), properties of covering material and different climate control technologies (i.e. heating, cooling, CO_2 enrichment, ventilation, screens). Different climate management setpoints can be used as input. The model calculates potential dry matter production as a function of the main factors affecting photosynthesis (canopy temperature, photosynthetically active radiation (PAR) level and greenhouse CO_2 concentration). Final tomato yield is determined by functions accounting for the effect of sub- and supra-optimal greenhouse temperature on the other growth processes. Especially this latter part of the growth model differs from other, simpler simulation models.

The model structure, with a common carbohydrate buffer and carbohydrate distribution to plant organs (as function of the availability of carbohydrates in the buffer and of the growth rate coefficient of the organs) is similar to existing crop yield models. This model describes the effect of sub- and supra-optimal temperatures on yield, by accounting for other processes in addition to photosynthesis, which is only weakly affected by temperature. Indeed, tomato is sensitive to temperature in different physiological process [17]: particularly flowering, pollination [18] and fruit growth [1] can be adversely affected if the temperatures are extreme. Fruit set is optimum at 18-20°C [1] while fruit set is poor if temperatures are less than 10°C; parthenocarpic or misshapen fruits may appear at less than 13-14°C [1, 20]. In Vanthoor's model the outflow of carbohydrates from the buffer is affected also by temperature. The overall temperature effect is described by two growth-inhibition filters, one depending on the instantaneous temperature and the other on the 24 h mean temperature. Based on literature results, the temperature boundaries for unrestricted growth were 14 and 28°C (instantaneous) and 18 and 22°C (24 h mean). The development stage of the crop was determined by the temperature integral (degree days). For instance, this defines the timing of first fruit set and the time at which the carbohydrate distribution to the fruits reaches its potential.

The validation of the crop response to non-optimal temperatures (unheated greenhouse conditions) was performed by using a number of data-sets for Mediterranean conditions.

Validation: We validated Vanthoor's model, respectively, with data from a commercial, heated greenhouse, near Aydin and a low-tech bi-tunnel of the experimental farm of Ege University, Western Turkey, both greenhouses are covered with polyethylene. In both cases we had concurrent, hourly climate data (in- and out-side) and yield. An overview of the two greenhouses is given in Table 1. The sun radiation transmission coefficient was estimated from data of similar houses. The management of ventilation in the low-tech greenhouse was manual and a small heater (with diesel fuel) was used to prevent freezing in exceptionally cold nights. As the model cannot handle a manual control, we deduced "ventilation setpoints" from behavior of the grower (in general opening in the morning and closing in the evening) and the corresponding in- and out-side temperatures.

In both cases we had hourly records of temperature and humidity within and outside the greenhouse and sun radiation and wind speed outside, for the whole growing period we considered. Radiative temperature of the sky (a necessary input to the model) was assumed to be 9°C lower than outside temperature [14]. With respect to crop yield, for the high tech greenhouse we used the commercial records of the farm (which give marketable yield) whereas for the low-tech greenhouse we had the weight of each harvest.

Calibration: The first step for using Vanthoor's model was calibration of the different parameters. No parameter adaptation was done in the greenhouse climate sub-model, as described by Vanthoor *et al.* [25]. On the other hand, some calibration proved to be necessary for the tomato yield sub-model [26].

Obviously quite a number of the parameters in such a model are variety (and crop management) dependent. We changed some according to the related literature [2, 4, 7], accounting for the varieties and crop management typical of the Mediterranean region (Table 2). Calibrated LAI was higher due higher plant density.

Scenario calculations: Due to the high importance of Antalya and Izmir in terms of both present and potential greenhouse cultivation area, and in order to evaluate the effect of the difference in climate, we carried out scenarios for both provinces. In order to account for the different climate in the two places, we used the local airport meteorological station records (www.wunderground.com) available on an hourly base, and used

Table 1. Location, production characteristics, greenhouse dimensions and climate set points at the two greenhouses.

	High-tech	Low-tech
Location		
Latitude	37°52'N	38°27'N
Longitude	28°09'E	27°13'E
Elevation	57 m ASL	27 m ASL
Production characteristics		
Crop cycle	Long cycle 08.09.2009 until10.07.2010	Spring crop 17.03.2010 until 30.06.2010
Tomato cultivar	Bandita	Duru
Greenhouse dimensions		
Length (m)	155	50
Width of each span (m)	9.6	8.28
Number of spans (-)	18	2
Area of one compartment (m^2)	27000	828
Ventilation opening area (m^2)	8044.5 (roof)	228 (side and roof)
Transmission (%)	55	55
Set points climate control		
Ventilation on/off (°C)	24/20	24/10 (estimated)
Heating temperature night (°C)	14	5
Heating temperature day (°C)	20	5
Screen temperature night (°C)	8	No screen

Table 2. Parameters of the crop yield sub-model changed with respect to Vanthoor *et al.* [26] for calibration.

	Original parameters	Parameters after calibration
Specific leaf area (SLA) (m^2 leaf per mg CH_2O)	$2.66\cdot10^{-5}$	$3.20\cdot10^{-5}$
Initial leaf area index LAI (-)	0.3	2
Maximum leaf area index LAI (-)	2.5	5
Temperature sensitivity of respiration Q10 (°C)	2	1.6
Upper boundary of the instantaneous temperature (°C)	28	32
Degree days for anthesis of 1st truss (°C)	850	650

the climatic data of the period in 2009 and 2010, for which we had also yield records. Sun radiation is not a standard measurement for these airport stations, so solar radiation, I_{sun} was estimated from cloudiness data, as follows:

$$I_{sun} = I_{clear}\frac{10 - 1.1Cl}{11}$$

where I_{clear} is the clear sky radiation calculated from the geographical position and time of the year and *Cl* is the reported cloudiness on a scale 0 (clear sky) to 8 (fully overcast). This empirical formula proved to give reasonable estimates for the few instances where we had reliable radiation data.

Also for the scenario calculations the radiative temperature of the sky was assumed to be 9°C lower than outside temperature. Minimum temperatures were -0.5 and -6°C for Antalya and Izmir, for a total of 1 and 63 freezing hours, respectively. Also maxima were higher in Antalya, with a total of 32 and 18 hours exceeding 35°C, respectively. Total monthly radiation, average minimum and maximum temperatures of both sites are presented in Table 3. The potential for improving climate management was evaluated for both types of greenhouse (low- and high-tech) in both regions. For low-tech we considered the effect of heating (and of different heating setpoints) and of various ventilation areas. For high tech greenhouses, besides various heating setpoints we considered CO_2 enrichment. The different scenarios are listed in Table 4.

Results and Discussion

Model validation: The model was validated using the measured climate variables (in- and out-side) for the growing period of each greenhouse (see Table 3). A high determination coefficient R^2 of 0.87 between measured and simulated hourly air temperature inside for the whole period was found for high-tech greenhouse, whereas the relative mean square error RSME was 1.9°C. In the low-tech greenhouse the determination coefficient R^2 was 0.93, the relative mean square error RSME was 1.5°C.

Total harvested fresh yield of tomato was measured and simulated for a high tech and low tech greenhouse (Fig. 1). In both cases the prediction was good: $R^2 = 0.99$ and SE = 1.12 kg m^{-2} and $R^2 = 0.98$ and SE = 0.3 for the low tech greenhouse. The issues where measured and simulated yield differ (particularly for the high tech greenhouse) may be caused by a relatively high incidence of unmarketable yield (which was not recorded) and/or pathologies.

Ventilation area: In the Mediterranean climatic conditions, high temperatures during the beginning (planting in early autumn) and last period (late spring) of a long growing cycle have an impact on

Table 3. Average monthly radiation (MJ m^{-2}), min. and max. temperatures (°C) of both sites.

		İzmir			Antalya		
		Min. temp.	Max. temp	Solar rad.	Min. temp.	Max. temp	Solar rad.
2009	September	17.64	30.53	190.47	20.55	25.14	232.59
	October	14.48	28.27	122.92	17.72	22.33	166.81
	November	8.91	24.69	81.28	12.69	16.16	93.46
	December	8.09	20.99	42.21	7.47	11.52	92.46
2010	January	6.26	20.46	49.61	7.4	15.79	79.72
	February	7.27	24.35	58.76	8.41	16.56	118.18
	March	7.96	26.16	131.53	9.58	20.26	198.58
	April	11.88	29.74	178.26	12.23	23.64	264.35
	May	13.52	30.12	240.15	16.39	26.56	301.76
	June	17.70	32.25	233.79	20.28	29.63	326.29

Table 4. Scenarios simulated with the greenhouse design model of Vanthoor *et al.* [25, 26] for different construction type of greenhouses.

Type of greenhouse	Climate control technology	Climate control set points
High tech	Heating temp. set points	5, 8, 10, 13 and 15°C
	Capacity of the CO_2 supply	0, 50, 100, 150 and 200 kg ha^{-1} h^{-1}
Low tech	Heating temp. set points	No heating, 8 and 13°C
	Ventilation area/greenhouse floor area	3.6; 5.4; 10.7 and 21.5%

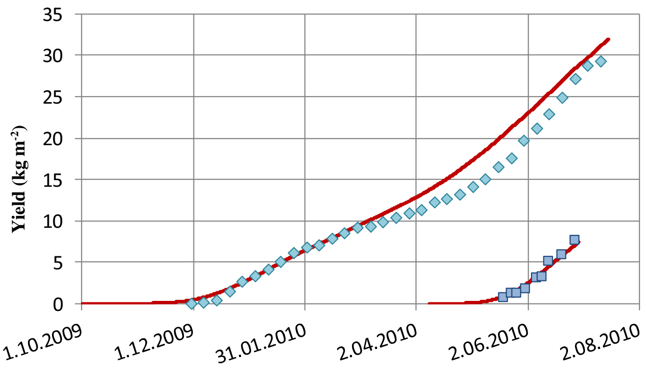

Figure 1. Cumulative measured (symbols) and simulated (line) tomato fresh yield in the high tech greenhouse long crop cycle (diamonds) and in the low tech greenhouse in spring cycle (squares).

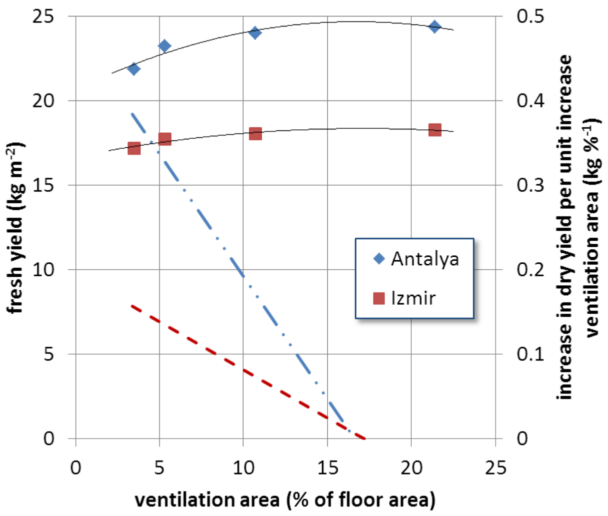

Figure 2. Effects of ventilation area on total tomato yield for the two climatic zones. The straight lines (right y-axis) are the derivative of the best-fit curves shown (Antalya: dash-dot; Izmir: dash). They give the effect of an unitary increase of the ventilation area above the one on the x-axis.

crop production. In particular, this is more important for low tech greenhouses since they often do not have sufficient ventilation opening area. The results of model calculations increasing the rate of ventilation area to floor area are shown in Fig. 2, calculated with a heating set-point of 10°C. As the lines show, the effect of increasing the ventilation openings is largest at small areas and in Antalya, where the need for ventilation to dispose of sun energy is highest. For instance, increasing the ventilation area of 1%, from the admittedly low level of 3.5%, increases yield by almost 0.4 kg m^{-2} in Antalya but "only" by 0.17 kg m^{-2} in Izmir. It is worth noticing that in both cases there is nothing more to be gained by increasing the ventilation area beyond about 17% of the floor area. As in the simulations we did not account for the presence of insect nets (something which is increasingly done to reduce application of crop protection chemicals), the ventilation area should be increased accordingly. For instance, an anti-aphids screen (24x12 threads cm^{-1}; thread diameter 0.19 mm; porosity 0.42), causes an airflow reduction of 33% [16], that is: the opening should be increased by double in order to ensure the same airflow as before fitting the net.

Heating: In Turkey, high tech greenhouses do have heating. However, heating costs are considerable and tend to increase as a result of the growing scarcity of fuel. Therefore, in order to determine a cost-benefit response to heating, we evaluated the effect of different temperature set points, on long-season (August

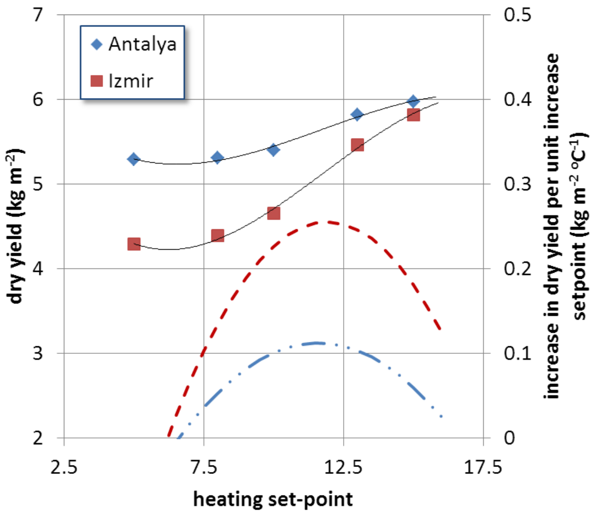

Figure 3. Effects of temperature increase on total dry yield for the two climatic zones. The dashed lines (right y-axis) are the derivative of the best-fit curves shown (Antalya: dash-dot; Izmir: dash). They give the effect of a setpoint increase of 1°C above the temperature on the x-axis.

to August) production in a fictive 1 ha, high tech, greenhouse, either in Antalya or Izmir (Fig. 3). The calculated yield is shown in Table 5. To see any effect of heating in Antalya the heating setpoint has to be above 10°C. On the other hand, the lower temperature in Izmir, ensures that a heating temperature setpoint of 10°C would increase yield by 10% (with respect to no heating). In the case of 13 and 15°C, the yield increased, respectively, 12.2 and 17.7% for Antalya and 34 and 50% for Izmir (Table 5). Results should not be extrapolated outside the range of the calculations.

Table 5. Predicted total tomato fresh yield (kg m^{-2}) and increase at different minimum heating temperature setpoints compared to 5°C.

	5°C	8°C	10°C	13°C	15°C
Antalya					
Fresh yield	28.75	28.86	29.46	32.26	33.79
Increase	100	100.4	102.5	112.2	117.5
Izmir					
Fresh yield	20.02	20.63	22.05	26.94	29.94
Increase	100	103	110	134	150

CO_2 enrichment: CO_2 is one of the major factors influencing photosynthesis rate in the plant. Increase in the atmospheric CO_2 concentration increases intercellular CO_2 concentration resulting in increase in net photosynthesis rate despite the increasing stomatal resistance [21]. In a greenhouse without CO_2 injection, indoor CO_2 concentration will drop whenever the CO_2 consumption rate by photosynthesis exceeds the supply rate through the greenhouse ventilation [19]. In a naturally ventilated greenhouse during a sunny day with high wind speed (3-5 m s^{-1}) a CO_2 depletion of 10-15% can occur [21], whereas depletions exceeding 20% were measured in poorly ventilated greenhouses[13]. Even in unheated greenhouses in the Mediterranean Region, CO_2 enrichment during autumn-winter can increase cucumber fruit production (both fresh and dry matter) by 19% [5].

We evaluated the effect of CO_2 supply, with a set-point of 800 vpm, which was maintained in so far as the supplying capacity was able to deliver. As the ability of maintaining a given concentration is limited by the ventilation requirement and the supply capacity of the system, we simulated scenarios for both regions and a supply capacity of: 0 (no supply), 50, 100, 150 and 200 kg ha^{-1} h^{-1}. As there is little covariance to be expected between heating and CO_2 supply (they are usually applied at different times) we calculated the scenarios for a heating setpoint of 10°C. The results are shown in Fig. 4. There are two aspects of the figure worth noticing: one is that the effect of CO_2 supply is less in Izmir than in Antalya, and the other that there is, in both cases, a capacity beyond which no effect is to be expected. The first is the consequence of the different light intensity: there is little advantage in supplying CO_2 when photosynthesis is limited anyway by low light levels, which must happen more in Izmir than in Antalya. To understand the second, one has to think what happens increasing the ventilation rate in a greenhouse with CO_2 supply: the CO_2 losses to the atmosphere will increase and the concentration within the greenhouse will approach asymptotically outside concentration, whatever the capacity of the supply system. The ventilation requirement is higher in Antalya than in Izmir, but the value of maintaining an higher concentration in the house is higher in Antalya (as explained above), the two effects balance neatly, and the net result shown by the dashed lines in the figure is that the capacity of the supply system should not exceed in both cases 100 kg h^{-1}·ha $^{-1}$.

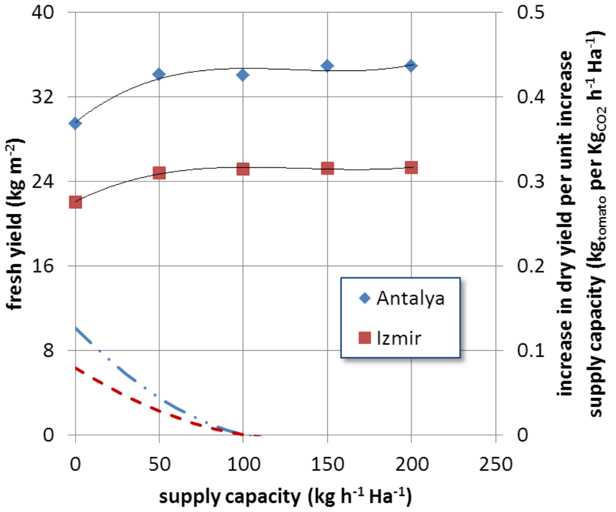

Figure 4. Effect of CO_2 supply on total tomato yield for the two climatic zones. The dashed lines (right y-axis) are the derivative of the best-fit curves shown (Antalya: dash-dot; Izmir: dash). They give the effect of an unitary increase of the supply capacity above the one on the x-axis.

The effect of CO_2 supply is predominantly seen between November and March, particularly in Antalya, which is understandable, since the ventilation requirement in late spring makes CO_2 supply redundant. It is worth noticing that this is also the period when tomato prices are the highest, thanks to the dearth of production in Central Europe.

Conclusions

We have shown that simulation models can be used for greenhouse design and prediction of crop yield in the Mediterranean area. Integrated models of greenhouse climate and crop yield allow for a reasonable estimate of return on investment in building or improving a greenhouse. Such models can also be a good tool for estimating the cost-benefit balance of different climate setpoints once the technology is there. From our study it can be concluded that the easiest gain is to have adequate ventilation capacity and management. We have found that for both high and low tech and for both climatic zones (South and West Turkey) the ratio of the ventilation area to soil area should be at least 17%, 25% when fitted with anti-aphid nets. Among the "active" means for climate control, heating should be considered first (certainly for the relatively cold region of Izmir), and the minimum heating temperature setpoint should not be less than 15°C. Furthermore, CO_2 enrichment with a dosage capacity of at least 50 kg ha^{-1} h^{-1} is worthwhile considering for both regions.

Models can assist also low-tech growers to see the impact of climatic conditions and show the possible improvements in the management of ventilation and of the heater. Our results show, in particular, that ventilation of low tech greenhouses in Turkey is usually insufficient. This work also shows the importance of the right climate setpoints. The need to maintain a good control of temperature requires mechanisation (if not automation) of the control of the ventilation openings, even in low tech greenhouses. The obvious weak point is the need to know the response of the cultivar to non-optimal temperatures, which seldom is known in detail. Calibration may be needed to local cultivars, as we did here. On the other hand, such a model is able to quantify the value of improved cultivars and could be used as input by breeders.

Acknowledgements

Much of the work presented here has been carried out within the project EUPHOROS, co-funded by the European Commission, Directorate General for Research, within the 7th Framework Programme of RTD, Theme 2 – Biotechnology, Agric. & Food, contract 211457. The views and opinions expressed in this article are purely those of the writers and may not in any circumstances be regarded as stating an official position of the European Commission.

References

[1]Adams, S.R., Cockshull, K.E. and Cave, C.R.J. 2001. Effect of temperature on the growth and development of tomato fruits. Annals of Botany **88**:869-877.

[2]De Koning, A.N.M. 1994. Development and Dry Matter Distribution in Glasshouse Tomato: A Quantitative Approach. PhD thesis, Wageningen University, 240 p.

[3]De Zwart, H.F. 1996. Analyzing Energy-Saving Options in Greenhouse Cultivation Using a Simulation Model. PhD thesis, Wageningen University, 236 p.

[4]Fanwoua, J., de Visser, P., Heuvelink, E., Angenent, G., Yin, X., Marcelis, L. and Struik, P. 2012. Response of cell division and cell expansion to local fruit heating in tomato fruit. Journal of the American Society for Horticultural Science **137**:294-301.

[5]Sanchez-Guerrero, M.C., Lorenzo, P., Castilla, N., Soriano, T. and Baille, A. 2005. Effect of variable CO_2 enrichment on greenhouse production in mild winter climates. Agricultural and Forest Meteorology **132**(3–4):244–252.

[6]Hammer, G. L. 1998. Crop modelling: Current status and opportunities to advance. Acta Hort. **456**:27-36.

[7]Heuvelink, E. 1995. Growth, development and yield of a tomato crop: Periodic destructive measurements in a greenhouse. Scientia Horticulturae **61**(1-2):77-99.

[8]Impron, I., Hemming, S. and Bot, G. P. A. 2007. Simple greenhouse climate model as a design tool for greenhouses in tropical lowland. Biosystems Engineering **98**(1):79-89.

[9]Impron, I. 2011. A Greenhouse Crop Production System for Tropical Lowland. PhD thesis, Wageningen University, The Netherlands.

[10]Katsoulas, N., Sapounas, A., De Zwart, F., Dieleman, J.A. and Stanghellini, C. 2015. Reducing ventilation requirements in semi-closed greenhouses increases water use efficiency. Agricultural Water Management **156**:90-99.

[11]Kumar, K.S., Tiwari, K.N. and Jha, M.K. 2009. Design and technology for greenhouse cooling in tropical and subtropical regions: A review. Energy and Buildings **41**(12):1269-1275.

[12]Kumar, K.S., Jha, M.K., Tiwari, K.N. and Singh, A. 2010. Modeling and evaluation of greenhouse for floriculture in subtropics. Energy and Buildings **42**(7):1075-1083.

[13]Lorenzo, P., Maroto, C. and Castilla, N. 1990. CO_2 in plastic greenhouse in Almeria (Spain). Acta Hort. **268**:165-169.

[14]Luo, W., de Zwart, H.F., Dail, J., Wang, X., Stanghellini, C. and Bu, C. 2005a. Simulation of greenhouse management in the subtropics. Part I: Model validation and scenario study for the winter season. Biosystems Engineering **90**(3):307-318.

[15]Luo, W., Stanghellini, C., Dai, J., Wang, X., de Zwart, H.F. and Bu, C. 2005b. Simulation of greenhouse management in the subtropics. Part II: Scenario study for the summer season. Biosystems Engineering **90**(4):433-441.

[16]Montero, J. I., Muñoz, P. and Antón, A. 1997. Discharge coefficients of greenhouse windows with insect-proof screens. Acta Hort. **443**: 71-77.

[17]Picken, A. 1984. A review of pollination and fruit set in the tomato (*Lycopersicon esculentum* Mill.). J. Hort. Sci. **59**(1):1-13.

[18]Rylski, I., Aloni, B., Karni, L. and Zaidman, Z. 1994. Flowering, fruit set, fruit development and fruit quality under different environmental conditions in tomato and pepper crops. Acta Hort. **366**:45-56.

[19]Schapendonk, A.H.C.M. and Gaastra, P. 1984. A simulation study on CO_2 concentration in protected cultivation. Scientia Hort. **23**(3): 217-229.

[20]Shaked, R., Rosenfeld, K. and Pressman, E. 2004. The effect of low night temperatures on carbohydrates metabolism in developing pollen grains of pepper in relation to their number and functioning. Scientia Hort. **102**(1):29-36.

[21]Thongbai, P., Kozai, T. and Ohyama, K. 2010. CO_2 and air circulation effects on photosynthesis and transpiration of tomato seedlings. Scientia Hort. **126**(3):338-344.

[22]TUIK 2015. Turkish Istatistical Institution. www.tuik.gov.tr (access date 04.07.2015)

[23]Tuzel, Y. and Leonardi, C. 2010. Protected cultivation in Mediterranean Region: Trends and needs. Journal of Ege Univ. Fac. of Agriculture **46** (3):215-223.

[24]Tuzel, Y. and Oztekin, G.B.O. 2015. Protected cultivation in Turkey. Cronica **55**(2):21-26.

[25]Vanthoor, B.H.E., Stanghellini, C., Van Henten, E.J. and De Visser, P.H.B. 2011a. A methodology for model-based greenhouse design: Part 1. A greenhouse climate model for a broad range of designs and climates. Biosystems Engineering **110**(4):363-377.

[26]Vanthoor, B.H.E., De Visser, P.H.B., Stanghellini, C. and Van Henten, E.J. 2011b. A methodology for model-based greenhouse design: Part 2. Description and validation of a tomato yield model. Biosystems Engineering **110**(4):378-395.

[27]Fitz-Rodríguez, E., Kubota, C., Giacomelli, G.A., Tignor, M.E., Wilson, S.B. and McMahon, M. 2010. Dynamic modeling and simulation of greenhouse environments under several scenarios: A web-based application. Computers and Electronics in Agriculture **70**(1):105–116.