A GLASSHOUSE CLIMATE MODEL AS PART OF A BIO-ECONOMIC MODEL.

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Abstract

Bio-economic models can be used as base for decision support systems. In protected cultivations, the glasshouse climate is of major importance on the financial result, both by costs and by yield. In this paper, a mechanistic climate model is described in detail. This glasshouse climate model is repartioned into four submodels: radiation- and lightintensity, heat- and daily ventilation need, mean day- and 24 hours temperature and a gas consumption submodel. Variation in CO$_2$-concentration and low temperatures, especially at night had a large influence on the productivity.

1. Introduction

Growing means making decisions. These decisons can be divided in groups in different ways. One of the most common repartition is into the groups of strategic, tactical and operational decision. In the past, operational decisions were considered as most important. A 'good grower' should have 'green fingers' (skill). Because of slow developments, tactical and strategic decisions seemed to be of less influence on the results.

decision-group	most important growers characteristics
operational	'green fingers'
tactical	managers' capacities
strategic	entrepreneurship

Figure 1 - Relation between kind of decision and required growers' characteristics.

But today, to be a succesful grower it is not enough to have 'green fingers', he also has to be a good manager and entrepreneur. The operational decisions are more and more supported -and even taken over- by automated systems. Also tactical -and to a less degree strategic- decisions are today supported by computerized programs. These systems are called Decision Support Systems (DSS).

Often, the kernel of a DSS can be considered as a so

Acta Horticulturae 260, 1989
Growth & Yield Control in Vegetable Production

called Bio-Economic Model (BEM). In such a model, economic consequences of certain decisions are based on biological, physiological and technical relationships. In a BEM for heated glasshouse tomatoes, the glasshouse climate module plays an essential role (Biemond et al., 1988).

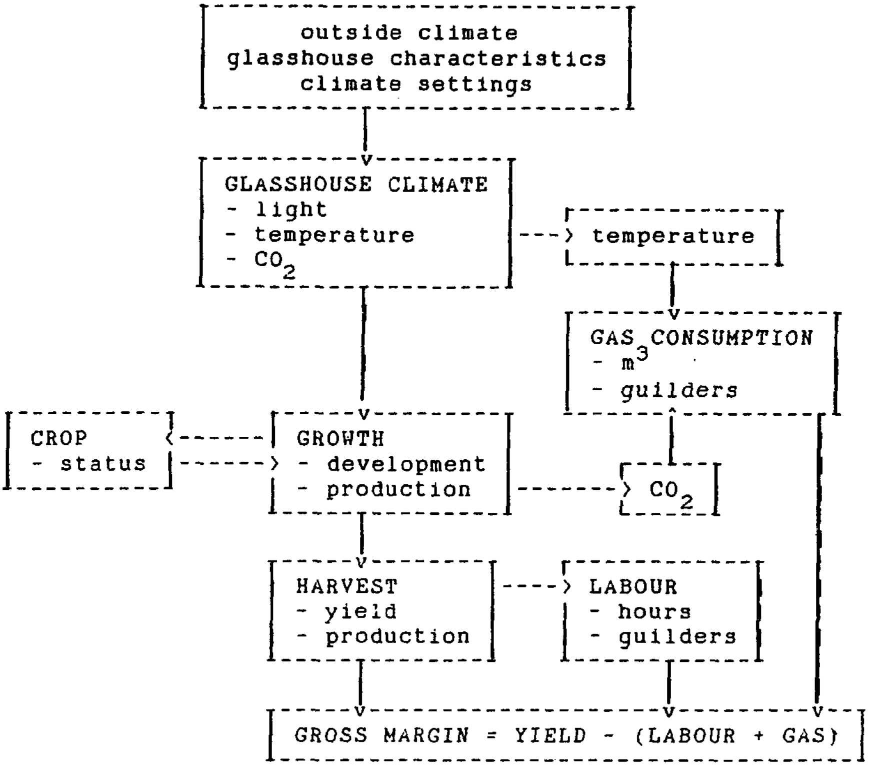

Figure 2 - Structure of the bio-economic model.

The glasshouse climate has two main effects on the profitability of growing tomatoes. First, it has a direct effect on the costs. Costs necessary for climate control can be originated by controling temperature, light, CO_2, relative humidity (RH) and the homogenity of the climate. In the discussed BEM, light is considered as an exogenous factor, CO_2 is expected to equal the setpoints and temperature is a result of outside climate, glasshouse characteristics and setpoints.

Second, glasshouse climate plays an important role on the productivity of the tomato crop. Both quantity, quality and production pattern are strongly determined by the glasshouse climate. This BEM does not consider any variablity in quality.

To illustrate clearly the importance of the glasshouse climate, table 1 gives an indication about the productivity and energy costs (mainly gas). For standard conditions in the Netherlands, a one percent change in production means a change of 1.8% in gross margin (as defined in figure 2). A one percent change in energy costs means 0.2% change in gross margin. These figures illustrate clearly the importance of the glasshouse climate.

Table 1 - Standard gross margin calculation per square meter heated glasshouse tomatoes for the Netherlands, 1988.

Production		hfl. 72.08	(100%)
Energy costs	hfl. 9.61		(13%)
Labour costs	hfl. 22.37		(31%)
	+		
Variable costs		hfl. 31.98	(44%)
		-	
Gross margin		hfl. 40.10	(56%)

Note: production, costs and gross margin are defined according to the BEM of figure 2.

The aim of this paper is to describe how the glasshouse climate can be modellized on behalf of a mechanistic BEM.

2. Material and methods

The glasshouse climate module consists of three submodules. These are strongly determining the gas-consumption. Therefor, the next four items will follow:

- radiation intensity,
- heat- and daily ventilation need,
- mean day- and 24 hours temperature and
- gas consumption.

2.1. Radiation intensity and daylength.

2.1.1. Radiation intensity.

The radiation intensity at a certain moment (t, hours) is a sinus-curve with a maximum intensity (I_{max}, W/m^2) in dependence of the daylength (DAYLE, hours).

(1a) $I(t) = I_{max} * \sin (pi/DAYLE * (t - t_o))$

For a Gauss-integration it is enough to calculate the momentaneous intensity $I(t_p)$ at only three times (p) a day (Goudriaan, 1986).

(1b) $I(t_p) = I_{max} * \sin(pi * 0.5(1.5 + P(0.15)**0.5))$

where:

(1c) $p = -1, 0, 1$

The maximum intensity is dependent of the total photosynthetic active radiation per day (PARSUM, J/m^2,day) and the daylenght.

(1d) I_{max} = pi/2 * PARSUM/(DAYLE*3600)

The PARSUM is the part (PART) of the total radiation (RSUM, J/m^2,day) with a wavelength between 400 and 700 nm, which is about 50% of the total radiation energy. Due to the effect of glasshouse and screen, this fraction has to be multiplied with a transmissionfactor (TRANS; 0.7 for single glazed roofs and 0.6 if a screen is used).

(2a) PARSUM = RSUM * PART * TRANS

(2b) <=> PARSUM = RSUM * 0.5 * TRANS

2.1.2. Daylength.

The daylength is dependent of the julian daynumber (DAYNO), the degree of latitude (DEGR, degrees) and the declination of the sun (DEC, radials), (Goudriaan et al., 1978).

(3a) DAYLE = 12 * (pi + 2*arcsin(SSIN/CCOS))/pi

where:

(3b) SSIN = sin(DEC)sin(DEGR*pi/180)

(3c) CCOS = cos(DEC)cos(DEGR*pi/180)

(3d) DEC = -23.45*pi/180 * cos(2*pi* (DAYNR + 10)/365)

2.2. Heat and daily ventilation.

2.2.1. Heat- or ventilation need at starting point.

To simplify the model this submodule distinguishes day and night, but negliges other dynamic aspects. The submodule starts with calculating the heat- or ventilation need at the beginning of the day (QFILL, J/m^2). If QFILL is negative, it means a ventilation need, otherwise it is a heat need. The QFILL is dependent of the difference between the setpoint temperature (TSET, °C) and the actual temperature (TACT, °C), multiplied with the specific heat of the glasshouse (HGLASS, J/m^3,°C) and the height of the glasshouse (HEIGHT, m). Corresponding to Schapendonk et al. (1984), HGLASS has been setted to 2580.

(4) QFILL = (TSET - TACT) * HGLASS * HEIGHT

There ventilation is only actualized if TACT is more then 2 °C above TSET, QFILL is setted to zero if TACT is between TSET and TSET plus two.

2.2.2. Heat supply.

Next, the heat supply without ventilation is calculated. Important factors are:

- radiation,
- heat conduction of the glasshouse and
- leakage ventilation.

2.2.2.1. Radiation.

In general, it is accepted that about 33% of the total radiation energy (per day or night, corrected for transmission) is transformed into heat (HSUM, J/m^2).

(5) $HSUM_{day} = RSUM_{day} * TRANS / 3$

2.2.2.2. Conduction.

With heat conduction of the glasshouse materials, heat is lost to the outside climate. The conduction is represented with K-values ($W/^{o}C,m^2$) for different screens. According to Nawrocki (1984), who calculatied with a ventilation of about 0.25 m^3 air per m^3 glasshouse per hour, the K-value is 8.41. This value is for a Venlo-glasshouse of one ha with single glazed roofs and double glazed sides and a minimum height of 3.30 m. If a screen is closed when the outside temperature is below 5 ^{o}C, then K=6.44. If a thermal screen is closed at night, the K=5.31. Multiplying the mentioned K-values with the glasshouse/ground surface ratio (GGRAT) of results in an adjusted K-value for the glasshouse considering conduction. The surface ratio for a Venlo glasshouse of 100 m long and 100 m wide and with a minimum height of 3.30 m is about 1.25.

2.2.2.3. Leakage ventilation.

The leakage ventilation can also be presented as a K-value. It is dependent of the specific heat of the air (SHAIR, J/m^3, ^{o}C), the leakage per windspeed unit (LPWU) and the average windspeed (WINAV, m/s). Multiplying these three factors result in a K-value which can be added to the K-value of conduction. The SHAIR for air with 11 g water per kg (about 75% R.H. at 20 ^{o}C) is about 1000 + 11*1.93 = 1021 J/kg,^{o}C, which equals more or less 1225 J/m^3,^{o}C.

(6a) $K' = K*GGRAT + SHAIR*LPWU*WINAV$

(6b) <=> $K' = K*GGRAT + 1225 *LPWU*WINAV$

2.2.3. Heat surplus.

A possible surplus per day or night (E, J/m^2,day or night) of heat due to a nett heat supply and/or heat surplus at the beginning of the day can now be calculated.

This surplus is, off course, dependent of the temperature difference between glasshouse (TSET+2, due to ventilation) and outside climate (TOUT) and of the length of the day or night (LEN, hours). When there is a heat surplus at the end of the night, then $(-QFILL)^{+} = -QFILL$, else $(-QFILL)^{+} = 0$.

(7) $E = HSUM - K'*(TSET+2-TOUT)*3600*LEN + (-QFILL)^{+}$

2.2.4. Ventilation.

This E needs to be removed by ventilation. The amount of air which must be exchanged with the outside climate (VENT, m^3) can now be estimated.

(8a) VENT = E/(SHAIR*(TSET+2 - TOUT)) + LPWU*WINAV*3600*LEN

Note: if TSET+2 = TOUT then VENT can not be estimated. In this case the submodule sets VENT equal to $VENT_{max}$. The same counts if E > 0 and TSET+2 < TOUT.

This VENT is limited between a minimum ventilation ($VENT_{min}$, m^3 air/m^2 glasshouse,s) when the windows are closed and a maximum ventilation ($VENT_{max}$, m^3 air/m^2 glasshouse,s) when the windows are fully opened. These limits can be derived from Bot (1983, equation 3.46).

(8b) $VENT_{min}$ = (4.8*10**-5 * GLASS) * WINAV
(8c) $VENT_{max}$ = (1.07*10**-3 * WSURF * OPMAX * e**(-OPMAX/50) + (4.8*10**-5 * GLASS) * WINAV

where GLASS is the glass surface (m^2), WSURF is the window surface (m^2) and OPMAX is the maximum angle of window opening (degrees). This means for a Venlo glasshouse with a surface ratio roof/window equal to seven and an OPMAX of 44^{o} that $VENT_{min}$ = 5.8 * 10**-5 and $VENT_{max}$ = 3.1 * 10**-3 (both in m^3 air/m^2 glasshouse,s).

2.3. Glasshouse temperature and heat consumption.

2.3.1. Glasshouse temperature.

Due to active ventilation a new K-value (heat loss factor) must be calculated. This K" depends amongst others on a ventilationfactor (VFACT, m^3 air/m^2 glasshouse,s).

(9) K" = K*GGRAT + SHAIR*VFACT

This means that also E should be adjusted to E' and that in principal the actual glasshouse temperature (TACT) can be derived. This instead of the formerly assumption that TACT equals TSET+2.

(10a) $E' = HSUM - K''*(TACT - TOUT)*3600*LEN + (-QFILL)^{+}$

and

$$(10b)\ \mathrm{TACT} = (E')^{+} / (\mathrm{HGLASS}*\mathrm{HEIGHT}) + \mathrm{TSET}$$

Combining these two equations gives equation 11a for $E' <= 0$ and equation 11b results if $E' > 0$.

$$(11a)\ E'' = \mathrm{HSUM} - K''*(\mathrm{TSET} - \mathrm{TOUT})*3600*\mathrm{LEN} + (-\mathrm{QFILL})^{+}$$

$$(11b)\ E'' = (\mathrm{HSUM} - K''*(\mathrm{TSET} - \mathrm{TOUT})*3600*\mathrm{LEN} + (-\mathrm{QFILL})^{+}) / (1 + (K''*3600*\mathrm{LEN})/(\mathrm{HGLASS}*\mathrm{HEIGHT}))$$

Now, the actual E" is known and the TACT can be calculated.

2.3.2. Heat consumption.

When both QFILL and E" are known, the heat consumption per day or night (Q, J/m^2,day or night) follows. QFILL is only important when it is positive and E" when it is negative, both at the beginning of the day or night.

$$(12)\ Q = \mathrm{QFILL}^{+} + (-E'')^{+}$$

2.4. Gas consumption.

Gas is used for two reasons. First for CO_2-supply and second for heat supply. The submodule has the possibility to deal with a buffer for heat storage. This saves gas when CO_2 has to be produced by combustion and when TACT > TSET.

2.4.1. Gas consumption for CO_2-supply.

The total amount of CO_2 needed is the sum of the amount needed at the beginning of the day (CO2FILL, g/m^2) and the amount used during daytime (CO2LOSS, g CO_2/m^2,day). By assuming that one cubic meter of gas delivers 1850 g CO_2 by combustion, the needed amount of gas can be calculated (CO2GAS, m^3/m^2).

$$(13)\ \mathrm{CO2GAS} = (\mathrm{CO2FILL} + \mathrm{CO2LOSS})^{+} / 1850$$

2.4.1.1. CO_2 supply at the beginning of the day.

To realise a sufficient concentration of CO_2 during daytime (CO2, ppm), it is necessary to increase the concentration equal to the required concentration (CO2FILL, ppm). To estimate the needed amount of CO_2 for this action, it is assumed that at the end of the night the CO_2 concentration equals the outside climate (340 ppm). The specific mass of CO_2 is 0.0018 g/cm^3.

$$(14)\ \mathrm{CO2FILL} = \mathrm{HEIGHT} * (\mathrm{CO2} - 340) * 0.0018$$

According to Schapendonk (1985) must be remarked that it is not rational to supply CO_2 below 340 ppm. Ventilating and heating is in that case maybe more efficient. But on cool, unclouded summer days, it is possible that the CO_2-concentration goes down below 340 ppm.

2.4.1.2. CO_2 supply during day.

CO_2 is removed at day by photosynthesis and ventilation. The nett photosynthesis (NPHOTO, g CO_2/m^2,day) is calculated in another submodule of the BEM (Biemond, 1989). This NPHOTO must be corrected for the efficiency of surface utilization in the glasshouse (SUREFF). $VENT_{day}$ is the ventilation at daytime (m^3/m^2).

$$(15)\ CO2LOSS = NPHOTO * SUREFF + VENT_{day} * (CO2 - 340) * 0.0018$$

2.4.2. Gas consumption for heating.

When Q is known, the needed amount of gas (HEATGAS, m^3/m^2) for heating depends upon the heater efficiency (HEFF, %). The heat of combustion of gas is assumed to equal 35.7*10**6 J/m^3.

$$(16)\ HEATGAS = Q / (35.7*10**6 * HEFF/100)$$

Due to the effect of a possible buffer, the submodule calculates the amount of gas per day ($HEATGAS_{day}$, m^3/m^2) and per night ($HEATGAS_{night}$, m^3/m^2).

2.4.3. Total gas consumption.

2.4.3.1. No heat buffer.

In case there is no heat buffer capacity, the total amount of gas needed (TOTGAS, m^3/m^2) is the sum of the amount needed at day and at night. The amount at daytime is the maximum of the amount needed for CO_2-supply and the amount needed for heating. This has no effect on the photosynthesis, because it is assumed that the CO_2-concentration equals the settings.

$$(17)\ TOTGAS = HEATGAS_{night} + \max(CO2GAS, HEATGAS_{day})$$

2.4.3.2. Heat buffer available.

When a heat buffer is available, it is possible to store the heat as by-product of CO_2. This stored heat is available for heating later on. Buffered heat ($BUFFER_{d-1}$, m^3 gas/m^2) from the last day should be multiplied with 0.92 to correct for losses. The buffer (BUFFER, m^3/m^2) is fed by the difference between CO2GAS and the amount of gas needed for heating after using the buffer ($HEATGAS_{day}'$, m^3/m^2).

When the buffer is not empty, it also can be used for heating during daytime. The total amount of gas needed at daytime ($TOTGAS_{day}$, m^3/m^2) is now the maximum of gas needed for heating and needed for CO_2-supply. The buffer can never contain a negative amount of energy (BUFFER >= 0) and is limited by a maximum ($BUFFER_{max}$, m^3/m^2).

(18a) $HEATGAS_{day}' = HEATGAS_{day} - BUFFER_{d-1}*0.92$

(18b) $TOTGAS_{day} = max(HEATGAS_{day}', CO2GAS)$

(18c) $BUFFER = BUFFER_{d-1}*0.92 + TOTGAS_{day} - HEATGAS_{day}$

The actual gas consumption at night ($HEATGAS_{night}'$, m^3/m^2) is calculated analogically and is, off course, at least zero.

(19) $HEATGAS_{night}' = HEATGAS_{night} - BUFFER*0.92$

The total amount of gas per natural day in case a buffer is available is now:

(20a) $TOTGAS = TOTGAS_{day} + HRATGAS_{night}'$

and the buffer contains a rest ($BUFFER_d$, m^3/m^2), which is at least zero.

(20b) $BUFFER_d = BUFFER - HEATGAS_{night}$

3. Results

With the above described model, the cumulative production (kg/m^2) and the average fruit weight (g/fruit) have been calculated. Both temperature and CO_2 are varying. The temperature variations were: 16, 18, 20, 22 and 30 °C. The CO_2-variations were: 400, 600 and 800 ppm.

Next there were variations between day and night temperature (16 versus 20 °C and opposite) and alternating periods of three days with temperatures of 16 or 20 °C, but these variations resulted only in a lower average fruit weight in summer at high day temperature and low night temperature and opposite. There was no effect on productivity.

The effect of temperature was significant, both on cumulative production and average fruit weight. The average fruit weight was negative correlated with temperature. The productivity was degressive positively correlated with temperature, except at 30 °C.

The effect of CO_2-concentration was degressive positive, both on average fruit weight and productivity.

Figures about the consequences for the productivity of all these mentioned variations are already given by Biemond et al. (1988). A temperature below 18 °C and variation in CO_2-concentration had the largest influences (till more then 18%).

4. Discussion and conclusions

Although the absolute results of the model are not tested until yet, the model seems quite reliable. The influences of the glasshouse climate aspects as temperature and CO_2 are comparable to the general horticultural knowledge. This gives reason to continue the research to built DSS's based on mechanistic BEM's.

It can be expected that only adjusting the already *notified weak points of the model will mean a improvement,* also on the mechanistic level. Improving the absolute forecasting power of the model must also be possible, but the modern level of accuracy seems good.

Acknowledgements

This paper is based on a masters' thesis of W.G. Trap. It was titled 'Bio-economisch model voor de (stook)tomatenteelt'. This research was co-guided by P. van Beek of the Department of Operational Research. The principal of the research was Priva b.v. at De Lier.

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