A TOMATO GROWTH MODEL AS PART OF A BIO-ECONOMIC MODEL.

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Abstract

A growth model for heated glasshouse tomatoes is described in detail. A mechanistic approach is used so that both development and real growth are distinguished for both crop and fruit. Some results of the growth model as part of a bio-economic model are given. Of the different phsyiological processes, the rate of photosynthesis showed the largest influence on productivity. Other regarded aspects are: rate of flowering and maturing, tomato type, intercropping and planting date.

1. Introduction

The first developed growth models did not have any relation with bio-economic models. Research goals were prevailing in developing grwoth models. But in a later phase, growth models were developed on behalf of planning and control (Liebig et al., 1985).

Challa (1985) mentioned amongst others also education and climate control. For climate control in protected cultivations, he distinguished three decision levels: actual control, set-points adn planning. The first level can mainly be based on a glasshouse climate model, the second level also needs a growth model and the third level needs weatherforecasts (outside climate model).

Still today, but especially in the first periods of growthmodels, the structure and degree of detail differed with the goals of the models. This led to all kinds of classification of models, as summarized by Trap (1988), see table 1. From this overview can be concluded that there are no strict differences between each kind of model. Most models have both 'black box' elements as well as a certain degree of a mechanistic structure. Most growth models can be seen as a kind of simulation model.

Table 1 - Possible classification of simulation models.

A: descriptive	explanatory (preliminary, comprehensive, summary)
B: static	dynamic
C: stochastic	deterministic
D: discrete	continuous
E: 'high' abstraction level	'low' abstraction level

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In this paper, a growth model is described as part of a bio-economic model (BEM) for heated glasshouse tomatoes (Biemond et al., 1988). The growth model is the kernel of this BEM. The most important aspects of input are the glasshouse climate (Biemond, 1989) and the crop status (Biemond et al., 1988). Output should at least contain information about productivity and needs of current assets and needs of labour.

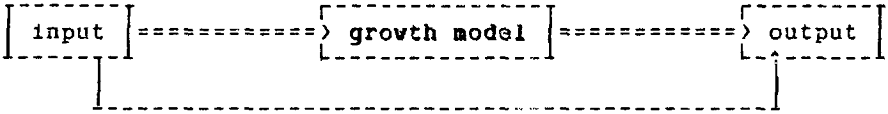

Figure 1 - Place of growth model in main structure of BEM.

The growth model in the above mentioned BEM focused five requirments. First, it should be dynamic because of daily simulation. Second, it should be mechanistic because the necessary data for regressing parameters were not available. Third, certain cultivation actions must be included. Fourth, only the production phase has to be incorporated. Fifth, a yearround is considered as standard.

The aim of this paper is to describe into detail a growth model for heated glasshouse tomatoes, which is part of a BEM.

2. Material and methods

Growth is too complicated to be easily modellized just within one structure. Therefor, fruit and crop are distinguished. Also development (more or less qualitative) and real growth (more or less quantitative) are distinguished in different submodels. A cropdata submodel functions as a buffer and medium for flow of information, also to other submodels as glasshouse climate.

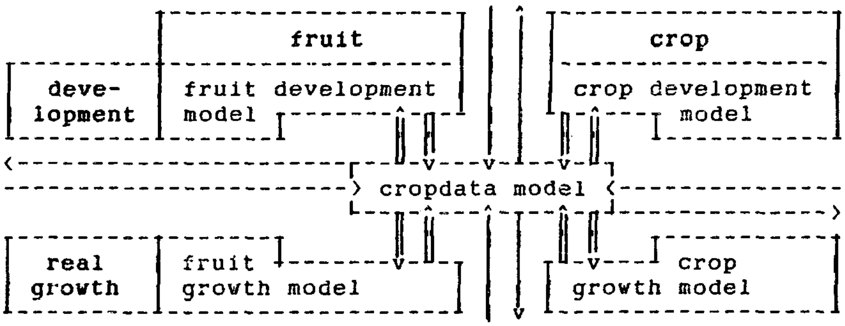

Figure 2 - Scheme of submodels in the growth model.

2.1. Cropdata model.

The cropdata model is already described by Biemond et al. (1988). For this paper, it is enough to know that all information which is used or created in other parts of the BEM, is (temporarily) stored in this cropdata model.

Stored data:

- maximum number of fruits per cluster (eight for round and four four beefsteak tomatoes)
- fruit weight (g dry matter/fruit)
- maturity stage per fruit MS(x,y) (0 = initiation, 1 = flowering and 10 = mature and harvestable)
- leaf area index (LAI)
- crop weight (CW), the sum of fruit weight (FW) and vegetative weight (PW, g dry matter/m^2)
- dry matter distribution factor (DMDF, fraction of produced dry matter distributed to the fruits)
- extinctionfactor (EXTFAC)
- transmissionfactor (TRMFAC, transmittability for light per leaflayer)
- maintenance respiration factor (MRESPF, part of the assimilated CO_2 which is used for maintenance)
- growth respiration factor (GRESPF, part of carbohydrates lossed by growth)
- CO_2-compensation point (CO2COM = 125 ppm)
- plant load (PL, number of present clusters)
- decapitation (DECAP, stopping vegetative growth)
- artificial ripening (ARTRIP, increasing maturing process artificially with ethephon),
- dry matter content of the fruits (DMCF, fresh weight %)
- tomato type (TTYPE = 1 for round tomatoes and TTYPE = 0.79/0.85 for beefsteak tomatoes)
- plant density (PD, number of plants per m^2)
- waste percentage (WPF, percentage of the non-exportable fruits).

2.2. Fruit development model.

This model is devided into three submodels:

- flowering pattern,
- flowering rate and
- maturing rate.

2.2.1. Flowering pattern.

Normally, after each three leaves a new cluster has been formed. The first flower of a certain cluster flowers at the same moment as the sixth flower of the proceeding cluster. That means that with a flowering rate of 1 cluster per week, in one week 8 flowers are flowering. Attention: this equals a flowering rate of 5/7 flower per cluster per day!

2.2.2. Flowering rate.

According to De Koning (1986) the flowering rate (FR, number of flowers per cluster per day) is influenced by the mean day temperature (MDAYT, ^{o}C). Dayan et al. () added a negative influence of the vegetative development rate. Other determing factors are variety and type (TTYPE).

The influence of the vegetative development rate is due to lack of information simplified to the plant load factor (PLF, which is based on the plant load). The PLF is modellized with a Mittschelich-function.

(1) $PLF = 1.13*(1 - e**-0.5(10-PL)^{+})$

Note: $(10-PB)^{+}$ means that (10-PB) is setted to zero when PB > 10.

The positive influence of CO_2 (Dayan) is negliged. The maximum number of clusters which are flowering at the same time is three and the the physiological zero is 13 °C (De Koning, 1986). Dayan et al. have chosen 12 °C as zero. The flowering rate is modellized in a Weibull-function.

(2) $FR = 3(1 - e**(-0.17(MDAYT-13)^{+}**0.485))*PLF*5/7*TTYPE$

2.2.3. Maturing rate.

Also the maturing rate is predominantly determined by temperature, according to general assumptions. At 13 °C there is no maturing at all, at 18 °C the maturing phase takes 65 days and at 22 °C it takes 20 days. Maturing is assumed to be an axponentional process which takes at least 30 days.

(3a) $dMS/dt = C * MS$

where C is a constant which can be derived as follows:

(3b) $C = \ln(R_{max}) / t$

Filling in function 3b for the total maturing phase gives:

(3c) $C = \ln(10)$ / duration of maturing phase

Curve-fitting to incorporate the effect of temperature gives then the following Weibull-function:

(3d) $C = \ln(10)/30 * (1 - e**(-0.068(MDAYT-13)^{+}**1.37$

Adjusting these function to reality gives:

(3e) $C = \ln(10)/30 * (1 - e**(-0.063(MDAYT-13)^{+}**1.43$

2.3. Crop growth model.

In crop growth, distinction must be made between gross photosynthesis, dry matter production and nett photosynthesis.

2.3.1. Gross photosynthesis.

The gross photosynthesis is the sum of the gross photosynthesis per leaflayer. To make this calculation, information about lichtintensity, CO_2-concentration and LAI are necessary.

2.3.1.1 Lightintensity per leaflayer.

According to Challa et al. (1986) the light intensity (I_{NLL}, W/m^2) above a specific leaflayer depends upon the following factors:

- intensity of photosynthetic active radiation (IPAR, W/m^2) above the upmost leaflayer
- extinction (EXTFAC = 0.6, comparable to absorption)
- transmission (TRMFAC = 0.15)
- number of leaflayer (NLL = 1 for the upmost leaflayer).

(4a) $$I_{NLL} = IPAR*EXTFAC / (1-TRMFAC)*e**(-EXTFAC*NLL)$$

(4b) <=> $$I_{NLL} = 0.6 * IPAR / 0.85*e**(-0.6*NLL)$$

2.3.1.2. Gross photosynthesis per leaflayer.

Seginer et al. (1986) modellized the gross photosynthesis per leaflayer ($GPHOTO_{NLL}$, g CO_2/m^2 leaflayer,hour) without the effect of temperature. It is, amongst others, dependent of the actual CO_2-concentration (CO2, ppm). CO2COM has been set to 125 ppm, allthough it is known that this should be variety dependent (Nilwick et al., 1982).

(5a) $$GPHOTO_{NLL} = 5.0 * (CO2 - CO2COM)^{+} / \{250 + 126*(CO2/I_{NLL})\}$$

(5b) <=> $$GPHOTO_{NLL} = 5.0 * (CO2 - 125)^{+} / \{250 + 126*(CO2/I_{NLL})\}$$

2.3.1.3. Total gross photosynthesis per day.

To simplify the calculation of the total gross photosynthesis per day, a Gauss-integration is used (Goudriaan, 1986). With this method, a reasonable estimation can be made by taking into account only three leaflayers (NLL_p) and three times (t_p) per day, depending on the daylenght (DAYLE, hours). To determine NNL_p, a exponentional light distribution in the crop has been assumed. In both formulas, p has to be set to -1, 0 or 1.

(6a) $$t_p = 12 + 0.5(0.5 + p(0.15)**0.5)*DAYLE$$

(6b) $$NLL_p = (0.5 + p(0.15)**0.5) * LAI$$

For p = 0 a weighing factor of 1.6 counts, for the other values of p the weighing factor equals one. To use these factors, both the gross photosynthesis per time ($GPHOTO(t_p)$, g CO_2/m^2,hour) and next, per day (GPHOTO, g CO_2/m^2,day) can be estimated.

$$\text{GPHOTO}(t_p) = \{(\text{GPHOTO}(\text{NLL}_{-1}) + 1.6*\text{GPHOTO}(\text{NLL}_0) + \text{GPHOTO}(\text{NLL}_1)) \ / \ 3.6\} * \text{LAI} \tag{7a}$$

$$\text{GPHOTO} = \{(\text{GPHOTO}(t_{-1}) + 1.6*\text{GPHOTO}(t_0) + \text{GPHOTO}(t_1)) \ / \ 3.6\} * \text{DAYLE} \tag{7b}$$

2.3.2. Dry matter production.

The dry matter production (DMP, g dm/m^2,day) is the result of the process which transforms the the gross photosynthesis minus the respiration. First, this respiration consists of a maintenance respiration factor (MTRESPF, %), which is about 1.5% of the modern dry matter (dm) crop weight (CW, g dm/m^2) with $Q_{10}=2$ around 20 °C (Spitters, 1982). Second, a growth respiration (GRESPF) has to be considered. It is generally assumed that the growthrespiration is about 30% of the formed carbohydrates. To transform CO_2 into carbohydrates (CH_2O), a multiplication with 30/44 is necessary. The model is started with DMP = 35.

$$\text{DMP} = \text{GPHOTO} * ((1 - \text{MRESPF})*2**((\text{MDAYT}-20)/10)*\text{CW}) * 30/44 * (1-\text{GRESPF}) \tag{8a}$$

$$\text{DMP} = \text{GPHOTO} * (0.985*2**((\text{MDAYT}-20)/10)*\text{CW}) * 30/44 * (1-0.30) \tag{8b}$$

2.3.3. Nett photosynthesis.

To calculate the nett CO_2-uptake (NPHOTO, g CO_2/m^2,day), the gross photosynthesis at is decreased with the respiration at daytime. The maintenance respiration at daytime is assumed to equal these at night. The growthrespiration at daytime (GRESPF_{day}, %) is assumed to equal sixteen percent of the gross photosynthesis minus the maintenance respiration (Schapendonk et al., 1984). The effect of actual glaashouse temperature at daytime (TACT_{day}, °C) is incorporated by $Q_{10} = 2$.

$$\text{NPHOTO} = 0.84(\text{GPHOTO} * 0.985*2**((\text{TACT}_{day} - 20)/10) * \text{CW} * \text{DAYLE}/24) \tag{9}$$

2.4. Fruit growth model.

In this submodel, the available assimilates for fruit growth are distributed amongst the fruits according to their estimated competion power (COMPOW), which equals the potential growthrate (Augustin, 1984). This competition power depends upon the relative maturity RMS.

$$\text{RMS} = 100*\ln\text{MS}/\ln 10 \tag{10a}$$

$$\text{COMPOW} = 0.22 * e**(-0.05(\text{RMS}-17.16)) * (1 + e**(-0.05(\text{RMS}-17.16)))**(-5.35) \tag{10b}$$

An ethephon-treatment (artificial ripening) is incorporated in the model as stopping the growing process. The maturing process continues, so that all last fruits are harvestable within a short period.

2.5. Crop development model.

This model is devided into three submodels:
- leaf area index (LAI),
- dry matter distribution factor (DMDF) and
- plant load.

2.5.1. Leaf area indes (LAI).

As mentioned earlier in this paper, after each trhee leaves a new cluster will be formed. Other knowledge about LAI is scarce, and therfor the LAI is based on the number of the last flowering cluster (LFC) until fifteen clusters have flowered. Then the LAI reached the maximum value of four.

$$(11)\ LAI = -0.26*(15 - LFC)^{+} + 4$$

2.5.2. Dry matter distribution factor (DMDF).

The DMDF indicates the part of the produced dry matter which is dedicated to the fruits. This factor is related to the number of clusters (plant load, PL) present, which is limited by a maximum of ten.

$$(12)\ DMDF = 0.1*PL$$

2.5.3. Plant load (PL).

The plant load is simplified to the difference between the highest and the lowest number of present clusters.

3. Results

The growth model as described above, was combined with the other submodels of the BEM (Biemond et al., 1988). A sensibility analysis was carried out for the rates of flowering, maturing and photosynthesis. Only the rate of photosynthesis had a significant positive effect on both productivity and average fruit weight. The maturing rate had only a small negative effect on the average fruit weight. The flowering rate had a small positive effect on productivity.

Other calculations showed that intercropping did not affect the total productivity, but it increased the productivity in summer and decreased the average fruit weight in the second half of the production season. Beefsteak tomatoes showed a slightly lower productivity but a significant higher average fruit weight. The date of first flowering had a significant progressive positive effect, both on productivity and average fruit weight.

4. Discussion and conclusions

Most of the results showed expected patterns in productivity and average fruit weight. Only the effect of intercropping is remarkebly. There is no significant positive effect, neither on productivity, nor on average fruit weight. Opposite, there is a significant negative effect on average fruit weight. According to the model results, intercropping is a non-rational action, because it has its own costs and does not improve the results. This model result is in contradiction with pratice; intercropping is still a common cultivation method. Therefor, the model has to be adjusted with regard to this point.

But in general terms, the model shows an interesting level of detail, combined with a sufficient accuracy.

5. Acknowledgements

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