# DYNAMIC SIMULATION OF DRY MATTER DISTRIBUTION IN GREENHOUSE CROPS

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## Abstract

Dry matter distribution is an important factor determining the crop yield. A preliminary model for dry matter distribution in crops with indeterminate growth like cucumber and tomato is described and some results are shown. The simulated dry matter distribution is primarily regulated by the sink strengths of the individual (clusters of) fruits. The sink strengths of individual (clusters of) fruits can be quantified by their potential growth rates, i.e. the growth rates under conditions of non-limiting assimilate supply.

The simulated dry matter distribution among individual clusters of tomato fruits corresponded reasonably well to measured data.

## 1. Introduction

Under normal growing conditions the total demand for assimilates of all sink organs exceeds the rate of photosynthesis of glasshouse cucumber and tomato (Pharr et al., 1985; Venkateswarlu & Visperas, 1987). Therefore the rate of photosynthesis is an important factor determining the total dry matter production. Many simulation models for crop growth are mainly based on calculations of photosynthesis and respiration (Spitters et al., 1988). However, the economic yield depends not only on the total dry matter production, but also to a great extent on the dry matter distribution among the plant organs.

In simulation models the dry matter is often distributed among plant organs according to fixed ratios which are dependent on developmental stage or time (Barnes, 1979; Spitters et al., 1988). This procedure gives reasonable predictions for field crops which show determinate growth like maize and wheat (Spitters et al., 1988). However, the dry matter distribution in crops which grow indeterminately, like cucumber and tomato, changes dynamically (Liebig, 1978; De Koning, 1988). Liebig (1978) showed for cucumber that even under constant climate conditions periods of high fruit growth rates and low vegetative growth rates continuously alternated with periods of low fruit growth rates and high vegetative growth rates. Moreover large fluctuations in dry matter

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distribution were correlated with a low total yield (when grown under the same climate conditions). These fluctuations in dry matter distribution increased with temperature (Liebig, 1978).

A simulation model can help to get a better understanding of the mechanism of dry matter distribution, which may lead to improved climate control, pruning techniques and growing methods. The simulation of dry matter distribution can result in predictions of number and size of harvestable fruits and can help a grower to predict labour requirements.

In this paper a preliminary model is described to simulate the distribution of dry matter among individual cucumber fruits or tomato clusters of fruits (figure 1) and some results are shown. The approach proposed in this paper might be generalized to simulate dry matter distribution among all plant organs.

## 2. Materials and methods

### 2.1. Experimental set-up

### *2.1.1. Growth of cucumber fruits*

Cucumber plants (*Cucumis sativus* L., cv. Corona) were grown on an aerated modified Hoagland solution (Steiner, 1984) in a climate room illuminated with high pressure mercury lamps (Philips HPLN 400W) during 14 h per day. Temperature during day and night was kept at 25 °C and relative humidity at about 80%. At the start of the experiment the light intensity was approximately 65 W $m^{-2}$ (400-700nm) at the top of the plants. Because the light intensity increased with height in the climate room, the plants received about 75 W $m^{-2}$ when they had reached their maximal length.

When the 12th leaf was unfolded (29 days after sowing) the plants were pruned to 12 leaves per plant. All lateral branches were removed continually. To achieve potential fruit growth (non-limiting assimilate supply) only one fruit per plant was left in the 6th leaf axil. For measurement of fruit growth under normal conditions of limiting assimilate supply 7 fruits per plant were left in the 6th to 12th leaf axil.

Dry weight growth of the fruit in the 6th leaf axil was estimated by daily measurements of length and circumference in analogy with Schapendonk & Brouwer (1984). Growth of 3 replicate fruits was recorded from flowering until 26 days after flowering, which is beyond the commercial harvest stage. The mean cumulative dry weight of the 3 replicates was fitted versus time with a Richards growth function (Richards, 1959). The first derivative of this function is the growth rate.

### *2.1.2. Experiments for validation*

Two experiments with tomato (*Lycopersicon lycopersicum* cv. Counter) were conducted in glasshouse compartments. A spring crop was sown on 17 November 1987, planted on 25 January 1988 and the experiment was ended on 9 June 1988. For a summer crop this was respectively 25 March, 27 April and 6 August 1987.

Climate was computer controlled and set-points for day and night temperature were 18 °C. Plants were grown in soil and treated as a commercial crop (Anonymous, 1986). However, the number of fruits per cluster was limited to 7.

Each week on 6 plants dry weights of the individual clusters were measured. From these measurements the available assimilates for fruit growth were calculated as the cumulated growth rate of all clusters on the plant (weekly values). These values, together with the average daily temperatures, were used as input in the model for simulation of the dry matter distribution among the individual clusters.

## 2.2. Theory - description of the model

In the model the dry matter distribution is primarily regulated by the sinks, as suggested by Evans (1975), Gifford & Evans (1981) and Verkleij & Challa (1988). Wareing & Patrick (1975) proposed that the competitive ability of an organ depends on its sink strength. They defined sink strength as the potential capacity of a sink to accumulate assimilates. The sink strength of an organ can be quantified by its potential growth rate, i.e. the growth rate under conditions of non-limiting assimilate supply. In the model the available assimilates are distributed among individual cucumber fruits or tomato clusters of fruits according to the sink strengths of the individual fruits or clusters, which is comparable to the approach of Schapendonk & Brouwer (1984).

The simulated formation rate of fruits depends on temperature and radiation; for cucumber the effects of light and temperature on fruit formation rate have been quantified by Challa & Van De Vooren (1980). For tomato the simulated formation rate of clusters depends upon the temperature only. In the model every day the sink strength of each fruit or cluster is calculated. The sink strength, which is defined as the potential growth rate, changes with the developmental stage of the fruit or cluster. Up to now, potential growth rate of tomato clusters is not well quantified so this growth rate has to be estimated. Every day, starting from cluster formation, the mean temperature which a cluster has received is calculated. Using this mean temperature, the total growing period (time from flowering to ripening: GROPER) is predicted. Potential growth rate is calculated according to a Normal distribution function (Dixon & Massey, 1983) with $\mu = 0.5*\mathrm{GROPER}$ and $\sigma = 0.25*\mathrm{GROPER}$ (figure 2). Maximum cluster dry weight (7 fruits per cluster) is set to 45 g dry weight (data not shown).

The sink strengths of all fruits or clusters on a plant are cumulated and compared to the available assimilates. The available assimilates can be calculated by a simulation model or by measurements of the cumulated growth rate of all fruits or clusters. When the available assimilates equal or exceed total fruit or cluster sink strength, the growth rates of the individual fruits or clustes occur at the potential rates. When the available assimilates are less than the total sink strength, the assimilates are distributed among the individual fruits or clusters according to their sink strengths relative to the total fruit or cluster sink strength.

When the cucumber fruits have reached the commercial harvest weight they are removed from the plant. Fruits which have not reached a threshold weight within a few days after formation are assumed to abort and are removed from the plant. Tomato clusters are removed from the plant as soon as the time from cluster formation (flowering) exceeds the predicted total growing period (GROPER).

## 3. Results and discussion

Figure 3 shows that the growth curve of cucumber fruits is sigmoidal, which is in accordance with results of Davies & Kempton (1976) and Tazuke & Sakiyama (1984). The growth curves are not symmetric and the growth rate is maximal before half of the final weight has been reached. This curve approaches the Gompertz form (Richards, 1959), as also observed by Tazuke & Sakiyama (1984). It was assumed that the fruit growth on the plant with only 1 fruit was not limited by the assimilate supply. Therefore the growth rate of this fruit was assumed to be the potential rate. Under normal conditions of many fruits competing for available assimilates, the growth rate appears to be much less than potential (figure 3).

Table I shows the results for the tomato experiments and simulations. For the spring crop, simulation of final cluster dry weights of the 1st and 2nd cluster is too high, while the 4th cluster dry weight is simulated too low. For the summer crop, measurements and simulation results agree fairly well, except for the 3rd cluster. The measured and simulated growth curves of the 1st and 5th cluster of the summer experiment are presented in figure 4.

At this moment it is only possible to speculate why some simulation results do not correspond with the measured data. An important reason could be the fact that we used the symmetric Normal distribution function as potential growth rate. The potential growth curve of cucumber fruits (figure 3) is asymmetric, while also data of De Koning (1988) indicate an asymmetric growth curve for tomato clusters. A wrong relation between potential growth rate and time might have caused discrepancies between measurements and simulation. Furthermore the cluster sink strength is probably influenced by the number of fruits on the cluster, which was not always 7 in the experiments, due to bad fruit setting (sometimes only 4 fruits per cluster). If indeed a rather small variation in number of fruits per cluster influences cluster sink strength, simulation of the individual fruit growth is necessary, as with cucumber. Also the simulation of cluster formation rate (temperature dependent only) and total growing period need validation.

We conclude from these experiments that dynamic simulation of dry matter distribution by using potential growth rate as sink strength is possible. This can help to get a better understanding of the mechanism of dry matter distribution, which may lead to improved climate control, pruning techniques and growing methods.

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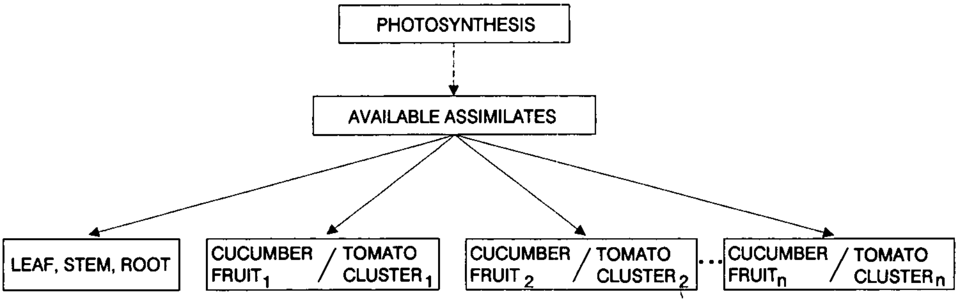

Figure 1 - Schematic representation of the model.

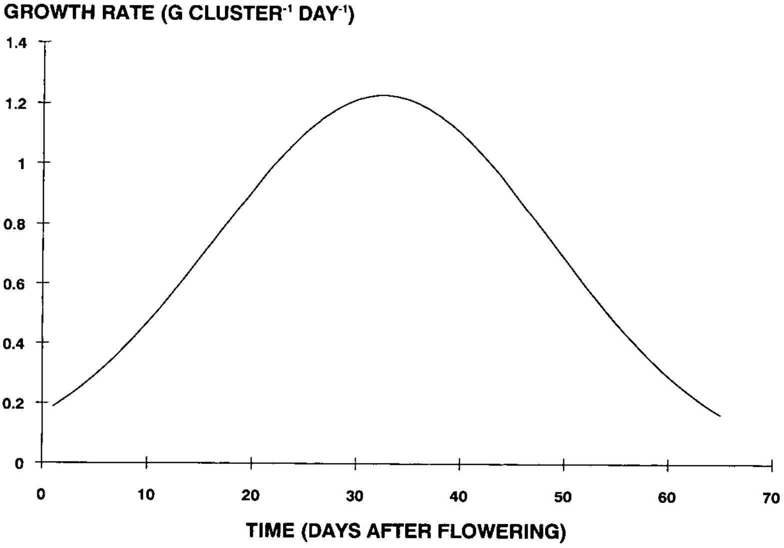

Figure 2 - Normal distribution function ($\mu$ = 32.5 days, $\sigma$ = 16.25 days, area below curve is 45 g) used as potential growth rate for tomato clusters with a total growing period (GROPER) of 65 days.

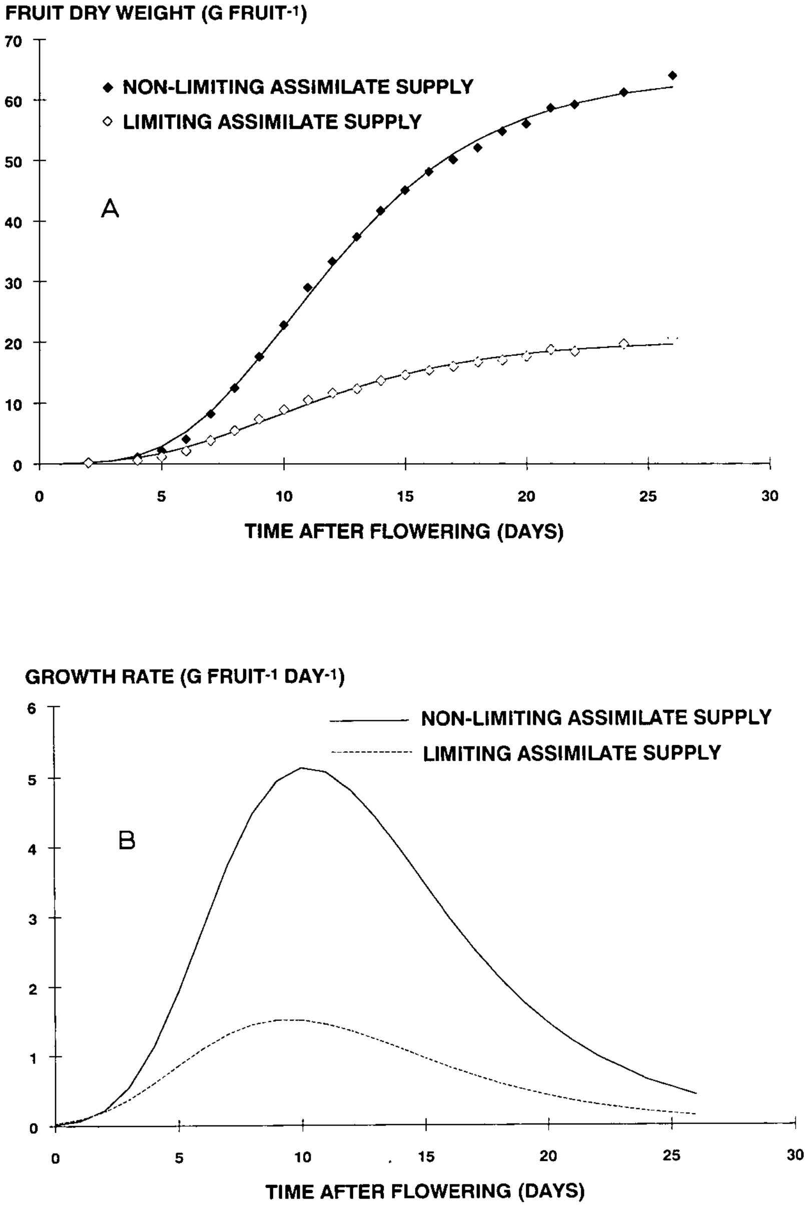

Figure 3 - Cumulative growth (A) and growth rate (B) of a cucumber fruit on a plant with 1 (non-limiting assimilate supply) and 7 fruits (limiting assimilate supply) per plant (n=3).

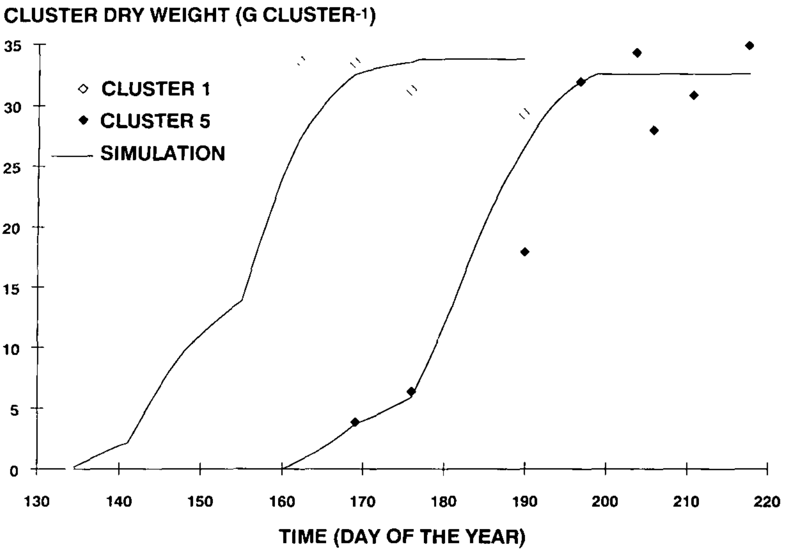

Figure 4 - Measured (n=6) and simulated growth curves of $1^{st}$ and $5^{th}$ cluster on a tomato plant in a summer crop.

Table I - Measured (n=6) and simulated final fruit cluster dry weight for a spring and summer tomato crop. The difference between simulated and measured cluster dry weights as percentage of measured cluster dry weight is given.

| | Spring crop | | | Summer crop | | |
|---|---|---|---|---|---|---|
| cluster number | measured (g) | simulated (g) | difference (%) | measured (g) | simulated (g) | difference (%) |
| 1 | 23.2±1.8 | 32.3 | +39 | 33.0±2.6 | 33.8 | + 2 |
| 2 | 25.3±2.7 | 29.1 | +15 | 34.4±2.3 | 33.4 | - 3 |
| 3 | 28.8±1.4 | 27.4 | - 5 | 38.7±6.0 | 27.0 | -30 |
| 4 | 32.3±5.7 | 28.3 | -12 | 29.8±2.7 | 28.5 | - 4 |
| 5 | 29.6±5.1 | 29.2 | - 1 | 32.0±3.2 | 32.5 | + 2 |
| 6-15 | 195.9±17.9 | 188.1 | - 4 | 152.2±14.6 | 165.0 | + 8 |