A MODEL FOR PREDICTION OF YIELD AND QUALITY OF CUCUMBER FRUITS

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Abstract

The mechanistic model KOSI was developed to predict the weekly fresh weight harvest of cucumber fruits and their quality. The model consists of modules for greenhouse climate, greenhouse light transmission, light interception by the crop, leaf and canopy photosynthesis, assimilate partitioning, dry matter production, fruit growth, fruit dry matter content and fruit harvest. The minimum data needed by KOSI for harvest prediction are date of planting of the crop and date scheduled for the last harvest. When only this minimum data set is used, calculations are based on long-term average data on weekly global radiation and temperature outside the greenhouse. Instead of using long-term average weather data, predicted or measured weather data can be provided as input. Model predictions can be improved by providing more input parameters, such as temperature set-point and CO_2 concentration of the greenhouse air, plant density, fruit pruning, frequency of fruit harvesting and transmissivity of the greenhouse. Model output are weekly harvest of the total fruit fresh weight, fruit number, the fresh weight and age of individual fruits and the percentage of second class fruits.
The model was validated by comparing simulation results with production data of 10 commercial growers in 1996 and 14 growers in 1997 (January - May). Even when only the date of planting of the crop and date scheduled for the last harvest were used as input to the model, the weekly harvest of total fresh weight averaged over all growers was simulated well by the model. The average error of the weekly prediction of the fresh weight yield was 14.9%, while the error of the annual yield was 2.8% in 1996. The predicted average fruit size and percentage of second class fruits corresponded reasonably well with growers' data, showing average weekly errors of 6.5% and 5.3%, respectively.

Introduction

The market demands constant prices, constant quality and continuous supply of horticultural products. For a good price setting, logistic arrangements and marketing in advance of harvest it is of utmost importance to be certain of supply at a specific time. Modern farm management implies that quantity and quality of produce can be predicted and controlled.
The economic yield of fruit vegetables, such as cucumber and tomato, is determined by the total fresh weight of the fruits and fruit quality. An important quality aspect is the fresh weight of the individual fruits with each size grading having a different market price. Besides size, important quality aspects are shape, shelf life and taste. As both young and old fruits have a short shelf life due to softening and yellowing, respectively (Kanellis et al., 1986; Lin and Ehret, 1991; Janse, 1994), the developmental stage of the fruit at harvest is a main determinant of shelf life.
For a number of crops mechanistic models for simulation of crop growth have been developed successfully (Marcelis et al., 1998). Such models might be powerful tools for prediction of production and product quality. However, most models simulate growth in terms of dry mass rather than fresh weight yield. Moreover, quality is seldom addressed

by these models. Most mechanistic crop models have to be fed by a large number of input parameters which is not feasible for large scale commercial applications.
Recently Marcelis and Gijzen (1998) developed a mechanistic model (KOSI 1.0) for prediction of the weekly fresh weight yield of cucumber fruits and the fresh weight and developmental stage of the individual fruits at harvest. The latter two being major criteria of fruit quality.
In this paper a model for prediction of yield and quality of cucumber fruits will be briefly described. Model predictions will be compared to data of commercial growers. Finally, options for model improvement and possibilities for large scale application in commercial practice will be discussed.

Description of the model KOSI

The model (KOSI 1.0) is primarily based on the model INTKAM for simulation of dry matter production (Gijzen, 1994) and the model of Marcelis (1994) for simulation of dry matter partitioning and fruit growth. The model consists of modules for greenhouse climate, greenhouse light transmission, light interception by the crop, leaf and canopy photosynthesis, assimilate partitioning, dry matter production, fruit growth, fruit dry matter content and fruit harvest.
A simple module for greenhouse climate calculates the daily temperature and daytime CO_2 concentration as a function of outside radiation, outside temperature and set-points for temperature and CO_2. Daily crop photosynthesis is derived from calculations of greenhouse light transmission, light interception and photosynthesis at 5 moments during the day. The time step of the modules for greenhouse climate, assimilate partitioning, dry matter production, fruit growth, dry matter content and fruit harvest is one day. A detailed description of the model is presented by Marcelis and Gijzen (1998).
KOSI 1.0 simulates the total weekly harvest at individual farms (kg m^{-2} $week^{-1}$ and number m^{-2} $week^{-1}$), the weight and developmental stage of the individual fruits at harvest and the percentage second class fruits. Temperature sum after anthesis (base temperature was 10°C) is used as a measure for developmental stage of a fruit, as Marcelis and Baan Hofman-Eijer (1993) have shown a close relationship between temperature sum and developmental stage of a cucumber fruit. Second class fruits are fruits with undesired shape or colour or with abnormalities. The fraction of second class fruits mainly depends on the age of the crop. At the planting of the crop KOSI can already predict the harvest for the whole growing period. It is possible to adjust these predictions every week using actual weather data of the previous week or forecast weather for the coming week.
The minimum data needed by KOSI for harvest prediction are date of planting of the crop and date scheduled for the last harvest. When only this minimum data set is used, calculations are based on long-term average Dutch weather data, i.e. weekly global radiation and temperature outside the greenhouse. When the distance to the Dutch coast is provided, weather data will be corrected for higher radiation levels close to the coast. Instead of using long-term average weather data, predicted or measured weather data can be provided as input. To keep the use of the model as simple as possible, average values are assumed for all other factors, e.g. climate control (set-points for temperature and CO_2 of the greenhouse air), light transmission of the greenhouse, harvest strategy (frequency of harvesting and whether small, medium or large sized fruits are harvested), plant density, number of fruits retained on the main stem, plant size at planting, cultivar properties and ratio between total and cropped greenhouse area. Depending on the objective or availability of data, the model calculations can be based on more or fewer input data.

Materials and methods

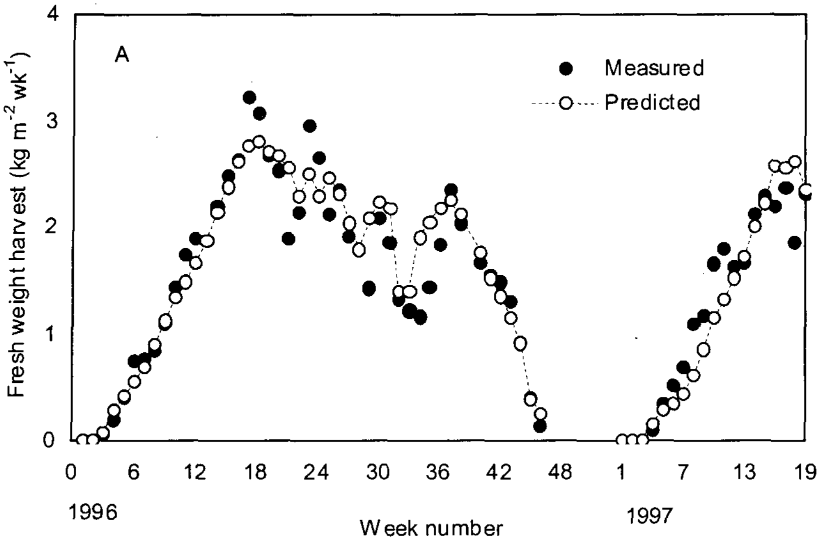
Data of commercial Dutch growers from January 1996 until May 1997 were used for validation of the model (10 growers in 1996 and 14 growers in 1997). Grower specific input parameters were week numbers of planting and removing the crop, and weekly data on outside global radiation, glasshouse air temperature and daytime CO_2 concentration. All other parameters (e.g. greenhouse light transmission, harvest strategy) were assumed to be the same for all growers. With respect to the harvest strategy it was assumed that growers harvested three times a week the fruits which exceeded a threshold weight. This threshold weight depended on the season (380 g in summer and 300 g in winter) and increased with increasing temperature sum after anthesis of the fruit. Daily climate data were calculated from the weekly data by linear interpolation between weekly records. From the daily data on global radiation hourly values were estimated by assuming a sinusoidal diurnal pattern. Each grower grew two or three successive crops a year, with planting dates differing between growers.

Results and discussion

To test whether the results of the model KOSI correspond to reality, the weekly cucumber production of commercial growers was calculated using actual climate data. The average harvest for all growers calculated by the model agreed closely with the actual harvest: the actual average production of 10 growers in 1996 was 71.8 kg m^{-2}, while the model calculated 72.0 kg m^{-2}, an error of only 0.3%. The average weekly error was 0.17 kg m^{-2}, or 12.6%. A more detailed validation of the model when actual climate data were used as input to the model is presented Marcelis and Gijzen (1998).
Subsequently, the accuracy of the model's predictions for the same group of growers was tested when only the first and last week of each crop cycle and distance from the Dutch coast were input. For outdoor temperature and radiation, long-term weather data (average of 30 years data from De Bilt, corrected for distance to the coast) were used. Average values were assumed for climate set-points and farm management. The average production of number of fruits and total fresh weight by the group of growers corresponded well with the model's predictions (Fig. 1). The average production in 1996 was 71.8 kg m^{-2}, while the model predicted 73.8 kg m^{-2}, an error of 2.8%. The average weekly error in 1996 was 0.19 kg m^{-2}, or 14.9%. The production between week number 33 and 36 was overestimated by the model, because the start of production for all growers was not predicted correctly by the model. One factor contributing to this error was that during this period of the year the initial production is quite different depending on whether the crop is planted on a Monday or a Friday, while only the week number was provided as input for the model. As discussed by Marcelis and Gijzen (1998), discrepancies between model and measurement for individual growers were larger than for the average of all growers. For a reliable prediction at individual farms more input data are necessary.

The average fresh weight of the individual fruits was predicted well by the model KOSI, except for a distinct underestimation at the end of the growing season (October - November) (Fig. 2). Probably the harvest strategy of growers changes towards the end of the year (two instead of three harvest days per week), while the model assumed the same harvest strategy throughout the year. Further analyses of harvest strategy and fruit growth in this period are needed to improve these predictions. The average weekly error of average fruit weight was 6.5%.

The amount of second class fruits, which changes markedly during a year was predicted quite well by the model (Fig. 3). The average weekly error of the percentage of second



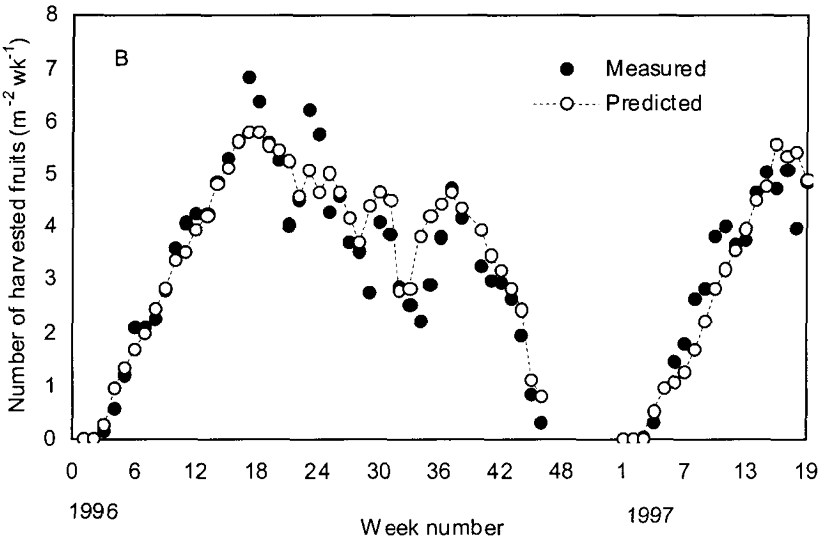


Figure 1 Predicted and measured weekly harvest in 1996 and 1997. Measured data are the means of 10 (1996) or 14 (1997) commercial growers.

class fruits was 5.3% in 1996. In the same period (the end of the growing season) when the average fresh weight was underestimated, the percentage second class fruits was underestimated.

The results show that a mechanistic photosynthesis-based dynamic growth model can be applied for accurate predictions of cucumber yield and fruit size. Such predictions can be used for optimising the price setting, logistic arrangements and marketing of the produce. As growth as well as farm specific conditions are variables of the model, such a model is also a promising tool to control the quantity and quality of the produce such that it better

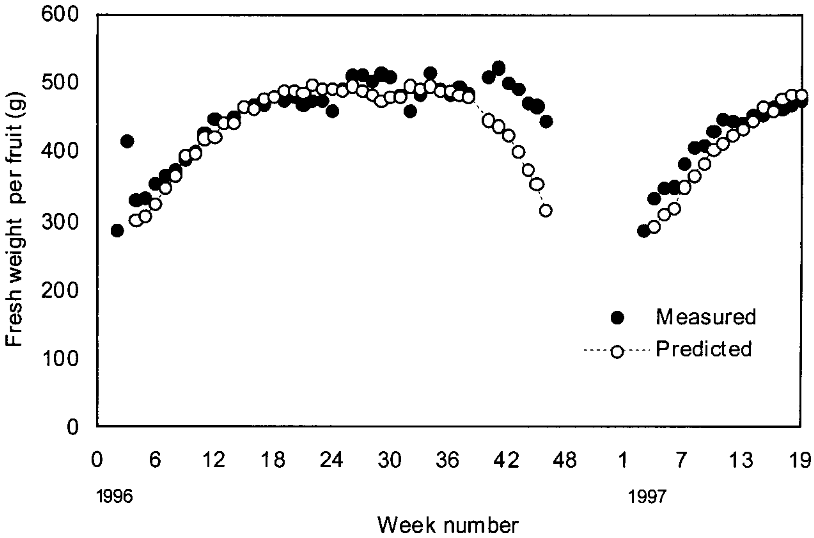


Figure 2 Predicted and measured average fresh weight of harvested fruits in 1996 and 1997. Measured data are the means of 10 (1996) or 14 (1997) commercial growers.

fits to the demand by retailers or consumers. For instance, effects of future cultivation measures and climate set-points on crop growth and harvest can be calculated, so that the most appropriate strategy can be chosen.

To keep the use of the model as simple as possible, average values were assumed for most model parameters, e.g. climate control (set-points for temperature and CO_2), light transmission of the greenhouse, harvest strategy (frequency of harvesting and whether

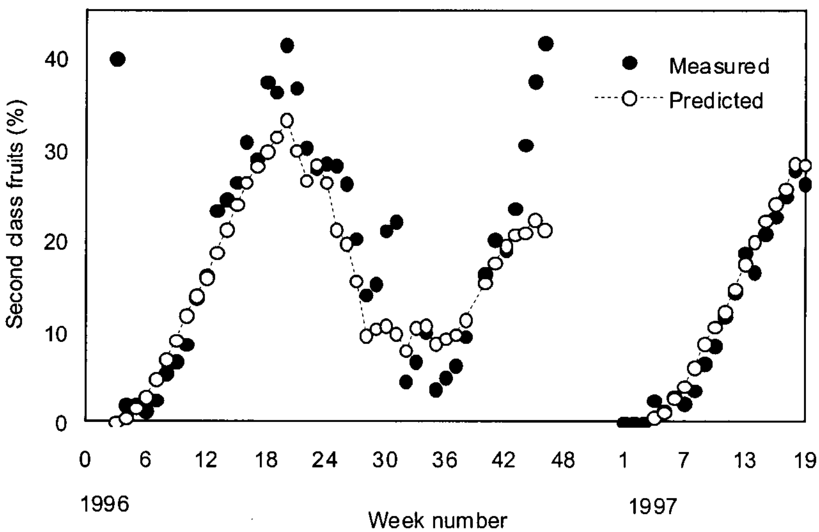


Figure 3 Predicted and measured percentage of second class fruits in 1996 and 1997. Measured data are the means of 10 (1996) or 14 (1997) commercial growers.

small, medium or large sized fruits are harvested), plant density, number of fruits retained on the main stem, plant size at planting, cultivar properties and ratio between total and cropped greenhouse area. If values of these parameters are available for individual growers, predictions could distinctly be improved. Depending on the objective or availability of data, the model calculations can be based on more or fewer input data. A cost-benefit analysis of gathering more input data that can be provided to the model is an important step towards practical application of the model. The accuracy of the model might be improved further by combining model calculations with on-line measurements of crop status (a 'speaking plant' approach).

The crop model KOSI 1.0 appears to be a promising tool for prediction of yield and quality of cucumber fruits. KOSI 1.0 will be calibrated and tested on a large scale and possibilities will be investigated for implementation of the model in IT-systems that enable large scale application.

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