Predicting Harvest Labour Allocation in Bell Pepper Production

L.M.M. Tijskens and R.E. Schouten
Group Horticultural Production Chains
Agrotechnology & Food Innovations
Wageningen University, Wageningen
The Netherlands

W.C. Lin
Agriculture and Agri-Food Canada
Agassiz, BC
Canada

Abstract

In the production of tomatoes in greenhouses, a more or less constant number of tomatoes are ready for picking at each harvest time. In the production of bell peppers, however, large fluctuations exist in number of fruits ready to pick. This major problem in bell pepper production is called 'flushing': weeks with high yields are alternated by weeks with low yield. This irregular harvest pattern makes it difficult for growers to meet regular weekly demands. As this cyclic production pattern is more or less the same for all growers, it results in weeks with a high market supply and low prices alternating with weeks with a low market supply and high prices. Flushing also results in strong fluctuations in labour demand in the greenhouses. Hence, avoiding an irregular pattern of sweet pepper production is of great economic importance. Flushing makes it very difficult for the growers to allocate sufficient labour force at a certain time in production. Both allocating too many and too few pickers will have financial consequences for the grower. The aim of this study is to predict the optimal harvest date based on repeated colour measurements of the growing bell peppers. The fruit ripening of bell peppers has been followed by colour imaging in the greenhouse. A commercial digital camera was used to record the development of colour for two cultivars of bell peppers over time. The images were analysed by image processing to obtain the R, G and B values. At the same time the time to harvest was recorded for the same fruits. Using these data a model was developed, on the basis of an exponential function towards a fixed asymptotic end value, to describe the colour development during fruit growth in terms of R/G ratio and to predict the optimal harvest date of the fruits.

INTRODUCTION

Unlike tomatoes, bell peppers (*Capsicum annuum*) show a highly irregular yield pattern in number of ripe fruits (Heuvelink and Körner, 2001). The presence of developing fruits inhibits subsequent set and growth of new fruits both by competition for limited assimilates as well as by dominance (ill-balanced control) due to the production of plant growth regulators (Marcelis and Baan Hofman-Eijer, 1997). This results in the (weekly) fluctuation of the number of harvestable fruits. Since these fluctuations can be quite large (see Fig. 1) it will become difficult to estimate the number of harvesters necessary at a certain point in time.

By monitoring the ripening fruit, growing in a greenhouse, taking pictures with a digital camera and assessing the colour of the bell peppers on the picture, the development of ripening was followed. Based on these repeated colour measurements a model for the (colour) ripening is proposed. The model aims to predict the number of harvestable fruits for each week during a growing season.

Of course there are still quite a number of difficulties, and the method is certainly not ready for commercial use right now, but the prospects of using commercial digital cameras for online monitoring of growth is promising.

MATERIALS AND METHODS

Preliminary experiments were conducted in 2001 on two cultivars: one red (exp. Type 444) and one yellow (Bosanova) colouring cultivars, with 4 samplings in spring and autumn season. More extended experiments were conducted in 2002 on the same two cultivars (red and yellow) for a complete season from early June until late November.

Proc. 5th Int. Postharvest Symp.
Eds. F. Mencarelli and P. Tonutti
Acta Hort. 682, ISHS 2005

A commercial digital camera was used to picture the growing fruit. Later, the pictures were evaluated by computer imaging into the RGB values. By using a commercial digital camera under non-standardised conditions in the greenhouse, a large variation will be introduced in the data. Using a ratio of colour aspects greatly reduced this large variation. The ratio of R/G was therefore used to model the ripening fruits. The fruits were harvested when approximately red or yellow for 90% of the surface. The harvest date and date of incipient coloration were recorded. Additional information was gathered during the experiments, like e.g. average temperature and light, number of ripening fruits on the same plant, either above or below the actual fruit etc. However, all these data and information have not yet been analysed properly.

RESULTS AND DISCUSSION

Model Development and Data Analysis

The ratio of Red to Blue (R/G) turned out to increase exponentially with growing time starting from an asymptotic value, which represent the most green colour that cultivar can obtain (data not shown). However, since the starting point for measurement in time is located somewhere during the season, the number of days to harvest is a much more elegant and appropriate way to express time. By this conversion, the time is simple reversed.

The general equation for exponential behaviour can be described as:

$$\mathrm{Col} = (\mathrm{Col}_0 - \mathrm{Col}_{\mathrm{fix}}) \cdot e^{-k \cdot t} + \mathrm{Col}_{\mathrm{fix}} \qquad \text{Eq. 1}$$

with the time t represented as days to harvest, the rate constant k is positive, expressed against Julian dates, the rate constant is of course negative. Col is the colour ratio (R/G), indices 0 for initial and fix for the asymptotic value.

Equation 1 describes the colouring process for each bell pepper. However, it is not very useful for describing the harvest date for flushes of bell peppers. For instance, not all bell peppers are harvested when they reach the same colour. Actually, the grower uses a target colour ($\mathrm{Col}_{\mathrm{tar}}$). The colour of each bell pepper is assessed and harvested when exceeding $\mathrm{Col}_{\mathrm{tar}}$. Furthermore, as bell peppers tend to be harvested in distinct batches ('flushes'), it seems convenient to use a batch approach. This approach allows to describe and to include the biological variance in ripeness during growth. This approach has been used frequently (Tijskens, 1997, 2000; Schouten et al., 2003, 2004). Applying $\mathrm{Col}_{\mathrm{tar}}$ and the batch approach transforms Eq. 1 into Eq. 2:

$$\mathrm{Col} = (\mathrm{Col}_{\mathrm{tar}} - \mathrm{Col}_{\mathrm{fix}}) \cdot e^{-k \cdot (t + \Delta t)} + \mathrm{Col}_{\mathrm{fix}} \qquad \text{Eq. 2}$$

Index tar stands for target. $\mathrm{Col}_{\mathrm{tar}}$ was arbitrarily set to .75, the value that the majority of individual fruit had reached at the moment of harvest.

The time shift factor Δt is a stochastic variable, with a value for each individual in the complete batch. It represents the biological variance in reaching ripeness during growth (Tijskens et al., 2003).

After intensive testing in preliminary data analysis, searching for additional effects of temperature, light, row and plant number, and the season (early, late), it was concluded that these factors do not really contribute to the variation in Δt (data not shown). So the stochastic variable Δt was only estimated for the fruit number, irrespective of previously mentioned factors. The analyses were conducted with the non-linear mixed effects procedure (nls) in the statistical package S-Plus (Mathsoft Inc, USA). The rate constant k and the asymptotic value $\mathrm{Col}_{\mathrm{fix}}$ were estimated in common for all individuals and all circumstances.

In Table 1 the results of the analysis is shown for the parameters in common ($\mathrm{Col}_{\mathrm{fix}}$ and the rate constant k) and for the mean value of the stochastic variable Δt. The stochastic properties of Δt are shown in Table 2.

The red cultivar clearly fits better to the model than the yellow cultivar Bosanova, as can be taken from the values of AIC, BIC and LogLik. The standard errors are rather low, also indicating a good fit to the model, especially when considering the large number of data point (about 2800 per cultivar) and the range in the season (from June until November). The same conclusions can be drawn from the scatter plots (Fig. 2) for both cultivars. Again the red cultivar is considerably better than the yellow one. The range in colour changes is much smaller (1.6) for the yellow cultivar than for the red one (10). The R/G colour here merely expresses the decrease in green colour of the yellow cultivar, while for the red cultivar the formation of red colouration is included in the total range. Also, it is most likely to be the reason why the data of the yellow cultivar do fit much less to the model. It has to be tested whether another colour ratio would generate a better approach for the yellow colouring cultivar. On a first glance at the data, however, this does not seem to be the case.

The stochastic behaviour of the time shift factor Δt is shown in Fig. 3. Here the estimated time shift for each individual fruit over the whole season is graphically shown with the normal distribution with the same standard deviation as estimated. A positive value of Δt indicates ripening fruits; a negative value indicates an already ripe fruit (that is harvested too late). The red cultivar (top) is clearly almost normal distributed with the major aberration to the positive side (too late harvested); the yellow cultivar again exhibits the major aberration at the positive side, but seems to exhibit an additional peak (i.e. a double peak distribution). This possibility was not further investigated at the moment.

Differences between the Successive Experiments

Huge differences exist between the results of the successive experiments. In 2001, only a few fruits were individually monitored in the commercial greenhouses. The general behaviour of the red cultivar (again experimental cultivar 444) was exactly the same (Fig. 4), but the parameter values showed major differences (Table 3). The estimated value of the rate constants is not that different (about .5 in 2001 and about .4 in 2002). The most amazing and puzzling differences are the range, the colour can change (up to 15 units), the value of the colour ratio at the moment of harvest (more then 3, compared to .75 in 2002), and the value for the asymptotic end value (.73 compared to .33). What causes these differences is not clear. Most probably the lack of standardisation in the measuring circumstances has a major effect on this: the data of 2001 were obtained in a local commercial greenhouse and those of 2002 were collected from an experimental greenhouse. More experiments are needed to validate the usefulness of this technique for successive seasons and different growing conditions.

Effect of Light and Temperature

The average temperature showed a decrease from about 30ºC in July to less than 20ºC at the end of October (Fig. 5 top). The average light intensity decreased from about 3000 J/cm^2 to almost zero in the same period (Fig. 5 bottom). Although it was felt that these huge differences during the production season should have a major impact on the growing rate and colour range of the ripening fruits, but no effect could be found in statistical analysis. The actual daily temperature and light intensity could not be included in the mixed effects analysis. Although this system is very advanced in that respect, it is not capable of conducting analyses based on numerical integration.

Literature Cited

Heuvelink, H. and Körner, O. 2001. Parthenocarpic fruit growth reduces yield fluctuation and blossom-end rot in sweet pepper. Annals of Botany 88: 69-74.

Marcelis, L.F.M. and Baan Hofman-Eijer, L.R. 1997. Effects of seed number on competition and dominance among fruits in *Capsicum annuum* L. Annals of Botany 79: 687-693.

Schouten, R.E., Jongbloed, G., Tijskens, L.M.M. and van Kooten, O. 2003. Relation between Cultivar and Keeping Quality for Batches of Cucumbers. Acta Hort. 599:

451-459.

Schouten, R.E., Jongbloed, G., Tijskens, L.M.M. and van Kooten, O. 2004 Cultivar specific keeping quality of cucumber and strawberry. Postharvest Biol. Technol. 32: 299-310.

Tijskens, L.M.M. 1997. Acceptability. Proc. International Conference ‘ An Integrated View of Fruit and Vegetable Quality’. Potsdam, Germany May.

Tijskens, L.M.M. 2000. Acceptability. p.125-143. In: R.L. Shewfelt and B. Brückner (eds.), Fruit and vegetable quality: an integrated view. Technomic Press, USA.

Tijskens, L.M.M., Konopacki, P. and Simčič, M. 2003. Biological Variance, Burden or Benefit? Postharvest Biol. Technol. 27: 15-25.

Tables

Table 1. Results of the statistical non-linear mixed effects analysis (season 2002).

	Red		**Yellow**	
	Value	**Std.Error**	**Value**	**Std.Error**
Col_{fix}	0.330402	0.003847	0.310206	0.002155
Col_{tar}	0.75	Fixed	0.75	Fixed
Δt (mean)	-5.39969	0.191665	-1.85395	0.238804
k	0.365577	0.005365	0.228358	0.005854
AIC	-1068.96		-4964.96	
BIC	-1039.34		-4935.17	
LogLik	539.4822		2487.482	
N_{obs}	2764		2861	
N_{fruits}	132		134	

Table 2. Statistical result for the stochastic variable Δt (season 2002).

	Red		**Yellow**	
	Value	**Residual**	**Value**	**Residual**
mean	-5.39969		-1.85395	
StdDev	2.082247	0.181508	2.569593	0.09569

Table 3. Results of statistical analysis (without biological variation) in season 2001.

	Estimate	**s.e.**
Col_0	3.3551	0.0839
k	0.4919	0.0652
Col_{fix}	0.7248	0.0479
R^2_{adj}	95	
Nobs	42	

Figures

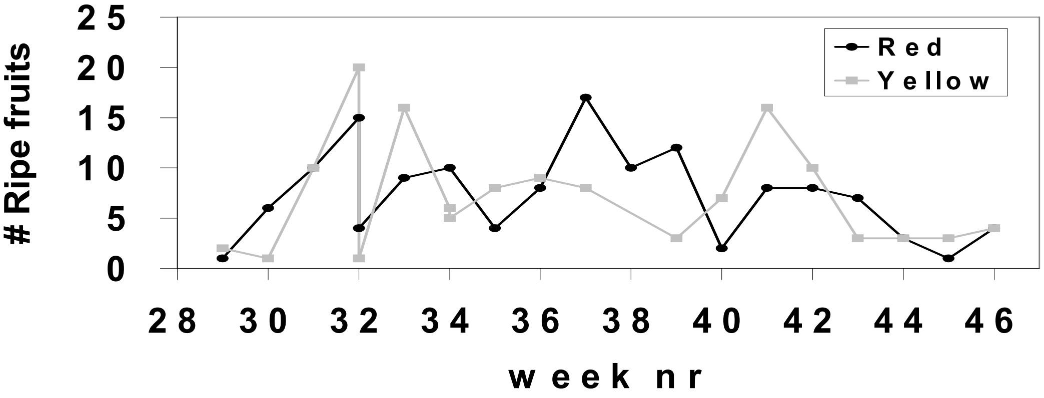


Fig. 1. Number of fruits ready to be picked as a function of week number in the year (season 2002).

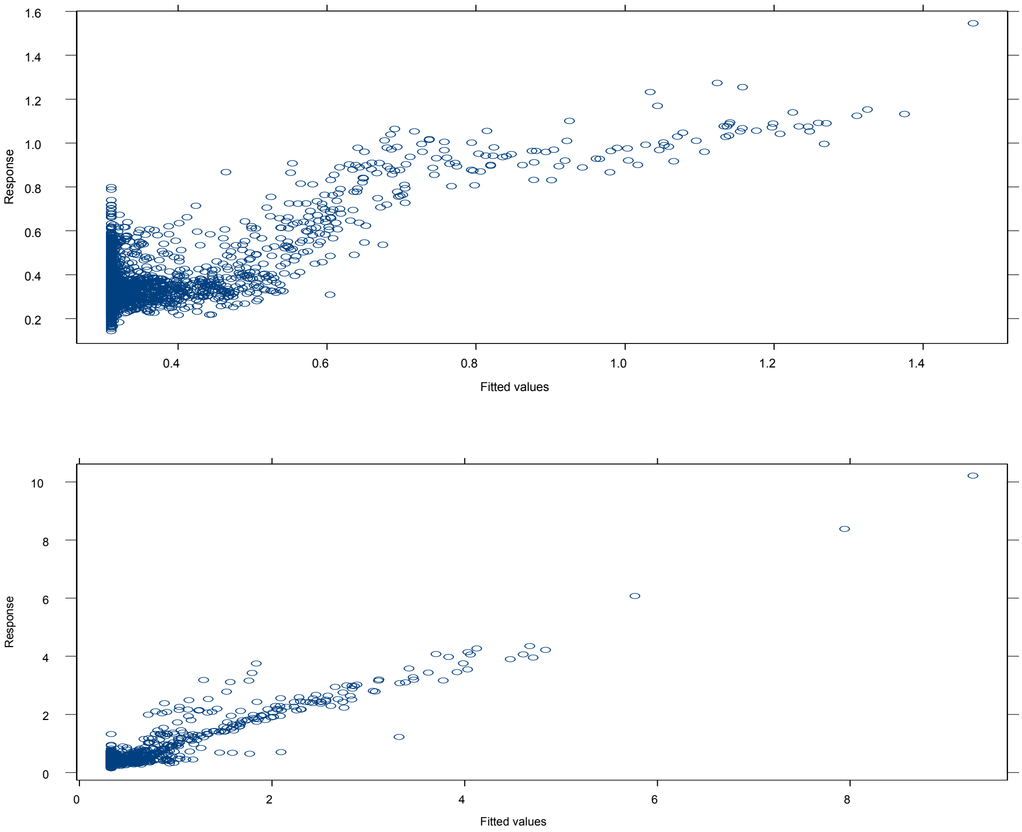


Fig. 2. Scatterplot (measured values of R/G against fitted values) for the Yellow (top) and Red (bottom) cultivar, based on non-linear mixed effects analysis according to Eq. 2.

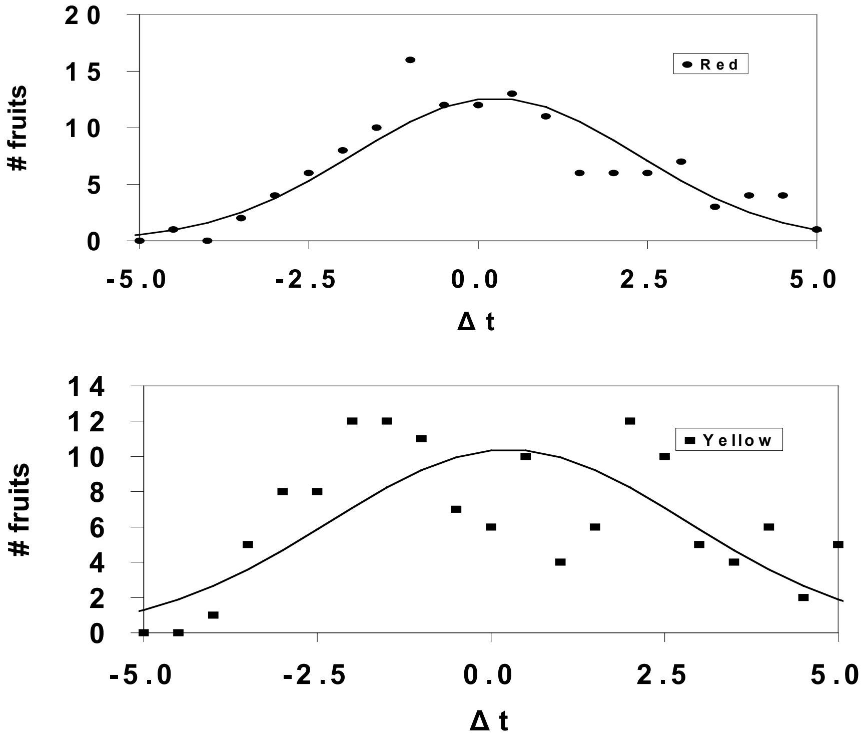


Fig. 3. Distribution of the time shift factor.

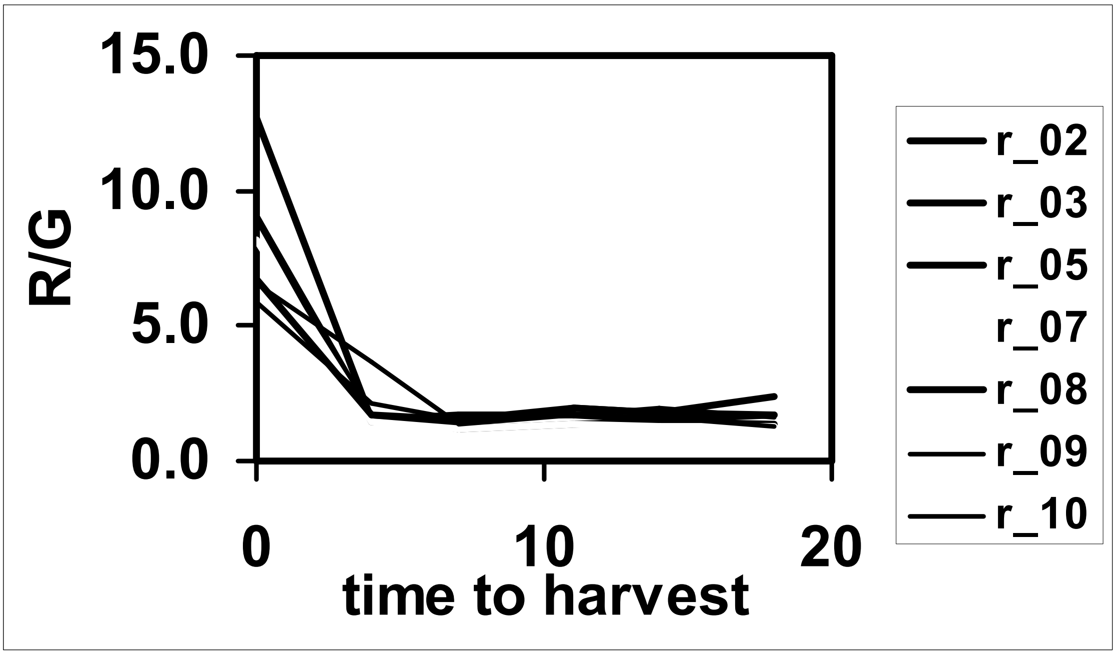
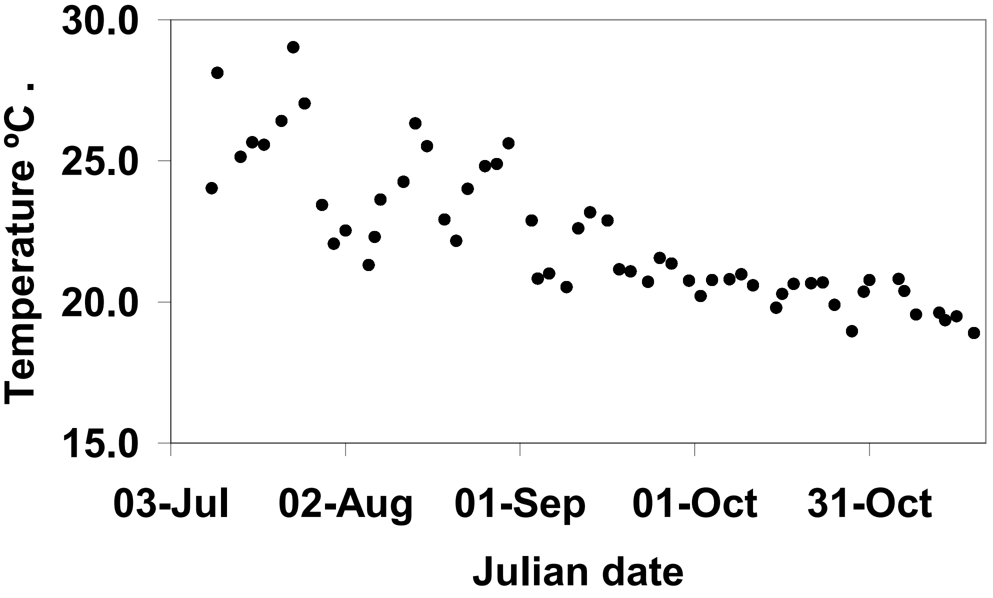


Fig. 4. R/G as a function of time to harvest based on data (Oct 2001).



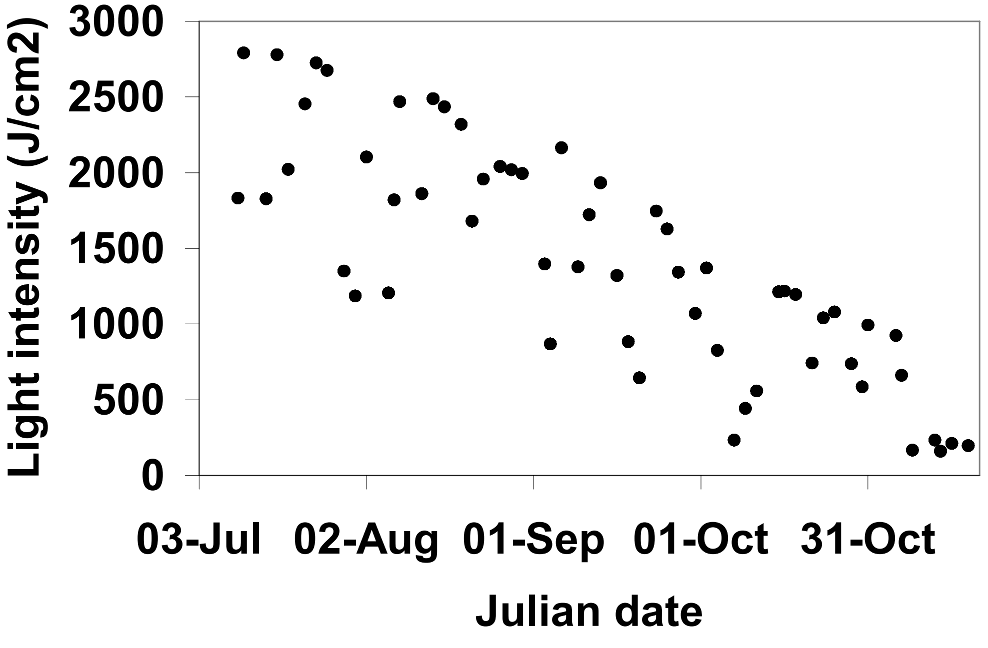


Fig. 5. Average temperature (top) and light (bottom) measured in the greenhouse during the season 2002.