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The application of A HEAT SUM MODEL for the budburst of sour cherry varieties grown at Újfehértó

Ladányi, M.[1], Persely, Sz.[2], Szabó, T.[3], Soltész, M.[3], Nyéki J.[3] & Szabó, Z.[3]

[1]*Corvinus University of Budapest, H-1118 Budapest, Villányi st. 29-43., Hungary*
[2]*University of Debrecen, Institute for Extension and Development, H-4032 Debrecen, Böszörményi st. 138. Hungary*
[3]*Research and Extension Centre for Fruit Growing, H-4244 Újfehértó, Hungary*

Summary: Experiences of the last decades showed univocally that the climatic changes, especially the warming up, influenced clearly the phenology, i.e. speed of growth and development of plants. To check the effects, the phenological studies became a topic of special interest. Our research has been performed at Újfehértó, the Research Institute of Fruit Growing and Extension, where the respective database accumulated observations during the period 1984–2005, where the meteorological data as well as the parallel phenological diary referring to the varieties 'Újfehértói fürtös', 'Kántorjánosi' and 'Debreceni bőtermő' during the period 1984–1991 have been utilised. The method of calculating the sum of daily mean temperatures, "degree days", is based on the observation that the plants are able to utilise cumulatively – in growth and development – the temperature above a set basic temperature. Our phenology model examined the correlation between the sum of degree days and the date of sprouting (budburst). The basic temperature has been determined by optimization, above which (threshold temperature) the accumulation of daily means was most active, or alternatively, below which the daily means are most sensitively expressed in the phenology. The model has been extended to the calculation of the end of rest period (endodormancy) – by optimization as well. Our phenology model will be suitable for two main purposes: for estimating the time of budburst for the Hungarian region during the next decades calculated on the basis of regionally downscaled climate models; on the other hand, by applying our model, the risk of damage caused by spring frosts could be estimated more exactly than earlier.

Key words: sour cherry, the phenological model, budbreak dates

Introduction

Sour cherry is one of the most favoured fruit species in Hungary (*Apostol*, 1990). At present, 18750 ha plantations exist countrywide (*KSH*, 2007); nearly 60% of them are concentrated in four counties (Bács-Kiskun, Heves, Pest as well as Szabolcs-Szatmár-Bereg counties). In county Szabolcs-Szatmár-Bereg alone there are 5500 ha of plantations, i.e. about one quarter of the whole area. In Eastern Hungary, sour cherry production around the communities is outstanding. Sour cherry is, next after apple, the second most important fruit species in the country, with yearly 40-55 thousand tons of yields. During the last decade, sour cherry cultivation varied drastically due to the negative effects of marketing and economic policies, therefore production declined to its half compared with the yields of the 1980-es (*Soltész*, 2004; *Holb & Zimmer*, 2008). The most Hungarian sour cherry plantations keep the varieties 'Újferhértói fürtös', 'Érdi bőtermő' and 'Kántorjánosi 3'. The main actual problem of the branch is the age ofplantations, being 28% of them older than 15 years, and one third of the plantations attained the fruiting age. The mean yield in the country varies between 3 and 4 tons/ha. In 2005, yields were below 3 t/ha because of the phytopathological situation.

The phenological studies are justified by the high economical value of the sour cherry culture, but the tracing of effects of climatic changes on the development of plants may offer an excellent opportunity to utilise the accumulated phenological data, and with the application of a phenology model, the estimation of the budburst date will be facilitated. The growers need help for the planning of long term and short term decisions in cultivation and phytosanitarian operations.

Material and methods

The character of growing sites

Újfehértó is located in the region of Nyírség characterised by a peculiar soil structure. The prevailing soil type is silty, humous sand without Calcium (carbonate) and with slightly acid reaction. The surface is somewhat wavy, and there are macro- and micro-depressions (Kormány, 2005). The ground water table is at about 250 cm depth as a mean. The organic fraction of the soil is mediocre.

Climatic conditions

The region belongs to the continental climatic zone with some mediterranean and oceanic effects. The main traits of the climate are shown in *Table 1*.

Table 1: Main data of the local climate

Designation	Annual	Summer half yea (April – September)
Mean temperature (°C)	9.5	16.7
Mean daily maximum (°C)	14.7	23.1
Mean daily minimum (°C)	5.6	10.6
Precipitation (mm)	583.0	363.0
Sunshine (hours)	1960.0	1433.0

Source: Szabó T., 2007.

Characterisation of years

Seasonal distribution of the precipitation in different years between 1984 and 1991 is shown in *Figure 1*. Regarding the precipitation of the winter season, the highest data are found in 1986 (221.4 mm). Spring precipitation is more than 250 mm in 3 years (1985, 1987 and 1988). The less precipitation was found in 1994. As observed, autumn precipitation did not attain 210 mm, moreover, it was only 18.3 mm in 1986.

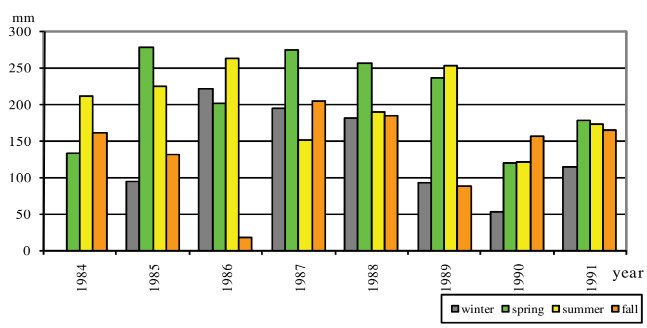

Figure 1: Precipitation during the four seasons: 1984–1991 (mm) (winter, spring, summer, autumn)

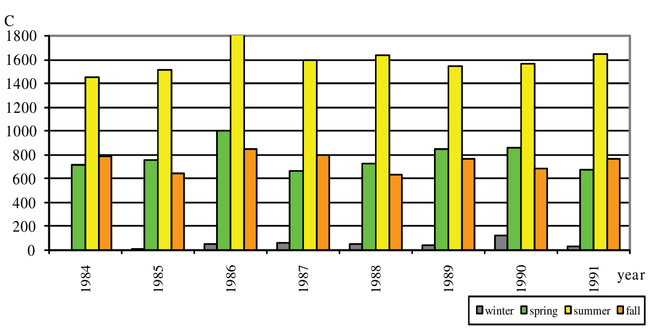

Figure 2: The sum of degree days recorded seasonally at Újfehértó between 1984 and 1991 (°C)

Figure 2 shows the sum of degree days. Daily mean temperatures are registered by subtracting the value of the lower basic temperature (2.5 °C) and only the positive differences between the two values were accumulated. The highest sum of degree days was found in the summer of 1986: 1986.9 °C, whereas the lowest in 1984: 1449 °C. The sum of temperature of the autumn season declined, whereas the sum of degree days of spring and summer increased slightly. 1986 was outstandingly hot during the spring and summer, and in 1990, the winter was extremely mild.

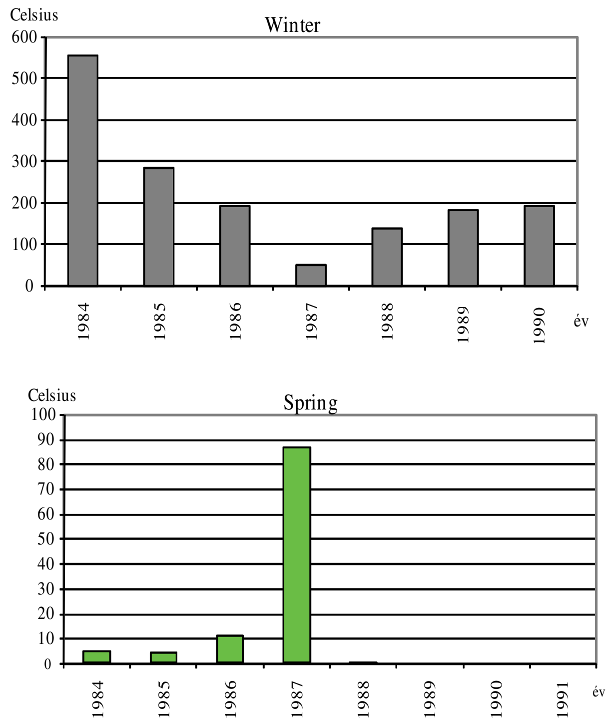

Figure 3: The sum of cold temperature at Újfehértó between 1984 and 1991 (°C) in winter (left) and in spring (right)

The sum of cold temperatures is shown in *Figure 3*. Sum of cold (temperature) is the sum of daily mean temperatures below the freezing point between early October and end of February (winter), or between early March and end of May (spring). Extraordinary cold winters are witnessed in 1984/85. The most freeze at springtime occurred in 1987, (when the sum of cold was 87 °C), subsequently, the less frosty winter ensued (1987/88). The sum of cold temperatures in the winter declined during the period of investigations.

Charaterisation of sour cherry varieties examined

'Debreceni bőtermő'

The variety has been stately registered in 1986. It was judged to be suitable for fresh consumption, canning and

Figure 3: 'Debreceni bőtermő'

other kinds of processing as well as for deep freezing. Ripening is expected at the end of June, earlier than 'Újfehértói fürtös' by 3–5 days. It has medium large or large fruits (5.5 g), its mean diameter is 20–22 mm. Mean fruit volume is 5.5 g. It starts fruiting soon, at prosperous conditions; trees yield considerable masses in the third-fourth year after planting. Yields are regular and copious. It is well adapted to excesses of Hungarian growing conditions and weather anomalities. Its susceptibility to the Monilia fungus is somewhat more pronounced than that of 'Újfehértói fürtös', but to Blumeriella leaf spot it is medium susceptible.

'Újfehértói fürtös'

Iis stately registered in 1970. It is late ripening, i.e. in early July. The process of ripening is lagging, but not prone to shedding. It is suitable for fresh consumption, for processing as well as for deep freezing. It has medium size of fruits (5.3 g), the diameter is 18–23 mm depending on the fruit charge of the tree. Fruiting starts early, yields are copious. Drought and ecological adversities are well tolerated. It is grown on humus containing sandy soils, and yields are satisfactory. It is moderately resistant to Monilia and medium susceptible to Blumeriella leaf spot.

Figure 4: Újfehértói fürtös


Figure 5: ’Kántorjánosi 3’

’Kántorjánosi 3’

Its ripening date is the end of June, early July, coincides with that of ’Újfehértói fürtös’, but depending on the growing site, some difference (2-3 days) may be observed. It is recommended for fresh consumption, processing as well as for deep freezing. The size of fruits is somewhat larger than that of ’Újfehértói fürtös’, mean volume is 5.4 g. Starts yielding soon, and yields are copious. Susceptibility to Blumeriella leaf spot is less pronounced than in ‘Újfehértói fürtös’ and ‘Debreceni bőtermő’, however, more susceptible to Monilia than other varieties mentioned.

The phenological model

The model of the sum of degree days was first spotted in the professional literature in the 1950-es (*Baggiolini*, 1952), however, a decisive argument appeared in the 1990-es, when the personal computers facilitated effectively attempts of researchers (*Bonhomme* 2000). Chuine (2000, 2003) summarised and evaluated the results up to the beginning of the 21th century, similarly, *Cortázar-Atauri* et al. (2000, 2009) published a precious comparative study. The majority of the literature is dealing with grapes (*Vitis vinifera*), whereas other fruit species (pear, apple, plum, cherry, etc.) are seldom dealt with. In Hungary, this type of research is poorly represented.

Phenology models of the date of budburst are based generally on the contention that budding starts after the chilling effect during the dormancy, subsequently, after a given amount of heat accumulating (*Carbonneau* et al., 1992; *Jones*, 2003; *Jones* et al., 2005). Correspondingly, the dormancy of the plant is divided in the deep- or endo-dormancy and the forced or ecto-dormancy. The former period is determined by the physiological status of the plant, whereas the latter is simply the result of temperature, i.e. lack of heat (*Lang*, 1987; *Cesaraccio*, 2004). In the publications, the situation is uniformly interpreted that after a given date the heat is accumulated above the given basic temperature up to a certain value computed by the summation of the daily means (*Moncur* et al., 1989).

The models of degree days, or more exactly, consisting on the sum of daily mean temperatures could be grouped according to different criteria. The function describing the process of accumulation is linear, logarithmic or saturating of other kind (*Oliveira* 1998; *Riou*, 1994). The accumulation of temperature data are registered either daily or at hourly intervals. In the latter case, we should know the terms of sunrise and of sunset or at least the length of day. The hourly accumulation of air temperatures is performed by an approaching function. The most used functions are triangular, exponential or periodical (e.g. sin), which express the kind of physiological effects of temperature on the plant (*Spano* et al., 2002). Experiences show that those models are excessively sensitive, and need the estimation of a host of parameters. At the same time, the models become utterly sensitive and in spite of that do not come up to the accuracy expected (*Riou*, 1994; *Cortázar-Atauri* et al., 2009).

For the start to accumulate data, a term of the completion of the former period of vegetation should be chosen and when the new did not start yet. As a rule, this ought to be decided at the beginning, in most cases with the first January (*Riou*, 1994; *Bindi* et al., 1997 a,b). We attempted to choose a term, which coincides with the end of endodormancy or the beginning of ectodormancy, respectively. Supposedly, that date is crucial, when temperature becomes really decisive in determining phenological processes.

We aimed to build up a relatively simple model, which will be suitable to predict the date of budburst in the 3 sour cherry varieties grown at Újfehértó applied to the period

1984–1991 with sufficient accuracy. For that purpose, a linear function was applied, where the daily accumulation of mean temperatures was attempted with an optimised starting date.

From the observed data, we calculated the sum of daily mean temperatures for the three varieties (i = 1,2,3) taken the values above the basic temperature only, from the chosen term (end of endodormancy) and cumulated them until the day of bud burst for each year (j = 1984,1985,...,1991).

$$GDD_{i,j} = \sum_{start}^{budbreak,\,i} \max\left[\left(T_{aver,\,j} - T_{base}\right);0\right]$$

Gladstones (2000) proposed that also the upper basic temperature should be considered, because the plant is unable to utilise the heat above a critical limit. For that purpose we also applied the upper basic temperature as follows:

$$GDD_{i,j\_Gladstones} = \sum_{start}^{budbreak,\,i} \max\left[\left(\min\left(T_{aver,\,j}, T_{upperbase}\right) - T_{base}\right);0\right]$$

Subsequently, we computed the mean sum of degree days over 8 years for each variety, and designated the parameter as the critical sum of degree days:

$$GDD_{i,crit} = \underset{j}{Aver}(GDD_{i,j\_Gladstones})$$

The model served for prediction of the date of budburst. In the actual year, the daily means of temperatures above the basic temperature after the date of the starting are accumulated until attaining the critical value of the respective variety ($GDD_{i,crit}$), the date of budburst should appear.

The error of the estimation has defined as the sum of squares of deviations expressed in days. The error was minimised by the calculation of the lower and upper basic temperatures as well as the starting date (day).

$$Err = \sum_i \sum_j \left(BB_{obs} - BB_{pred}\right)^2$$

For the sake of facilitating later possibilities of comparison, the error has been normalised as follows:

$$\varepsilon = \sqrt{\frac{1}{N} Err}\ ,$$

where N is a product of the number of varieties and the number of years.

Results

Figure 7 shows the accumulated daily mean temperatures between 1984 and 1991. It seems that the year 1984 was the most balanced, as after the 57th day, the means kept being above the basic temperature, and the sum of degree days increased continuously until the 78th day, then after a short stagnation increased until the 86th, when budburst ensued. In the year 1985, the temperatures above the basic value started almost at the latest date. At the beginning, after the 76th day, the accumulation progressed abruptly. In 1986, the accumulation started at the latest date (66th day), subsequently, increased continuously until the 83th day was the date of budburst. In 1987 and 1988, accumulation started rather soon (on the 42th and 43th day), whereas in 1988, only with the 74th day and progressed gradually. In 1987, the accumulation was continuous until the 53th day, but the temperature did not pass the basic temperature until the 78th day (this is shown on the Figure by a horizontal line). This cold spell lasted three weeks at least, subsequently, the accumulation was steep. The Figure informs us that in 1989, on the 51th day (20th of February), the accumulation started and on the 60th day, budburst started (with 18 °C sum of degree days). 1990 was an excessive year, because on the 50th day, accumulation started quickly, daily means were without exception above the basic temperature, all the same, budburst ensued at 42°C, although the date was rather early, i.e. on the 68th day. The year 1991 was also exceptional, because the accumulation started lately, on the 54th day, in spite of that, budburst occurred on the 74th day.

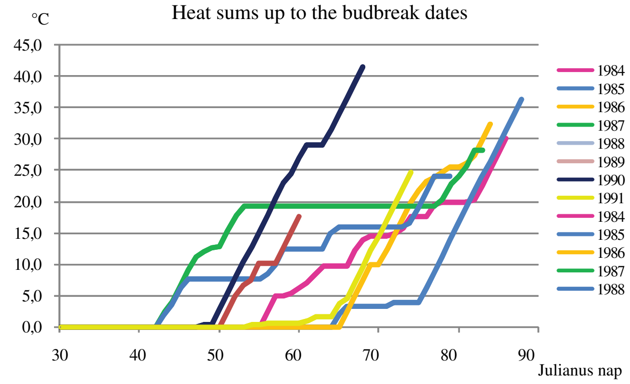

Figure 6: The sum of degree days until budburst calculated by taking the daily means between the two basic temperatures (2.5 °C and 5 °C) and starting with the optimal date (11th of February)

Table 2: The sums of daily mean temperatures and the critical averages for the varieties examined between 1984 and 1991 (°C)

CVs / Years	Újfehértói fürtös	Kántorjánosi	Debreceni bőtermő	Average
1984	30.1	30.1	32.6	30.93
1985	36.3	36.3	36.3	36.3
1986	32.3	32.3	32.3	32.3
1987	28.2	28.2	28.2	28.2
1988	23.9	23.9	23.9	23.9
1989	17.5	17.5	17.5	17.5
1990	41.4	38.9	38.9	39.73
1991	24.6	24.6	24.6	24.6

In *Table 2*, we see the sum of degree-days (in °C) of the varieties accumulated until budburst. The values presented, correspond the statements come up to the data based on the

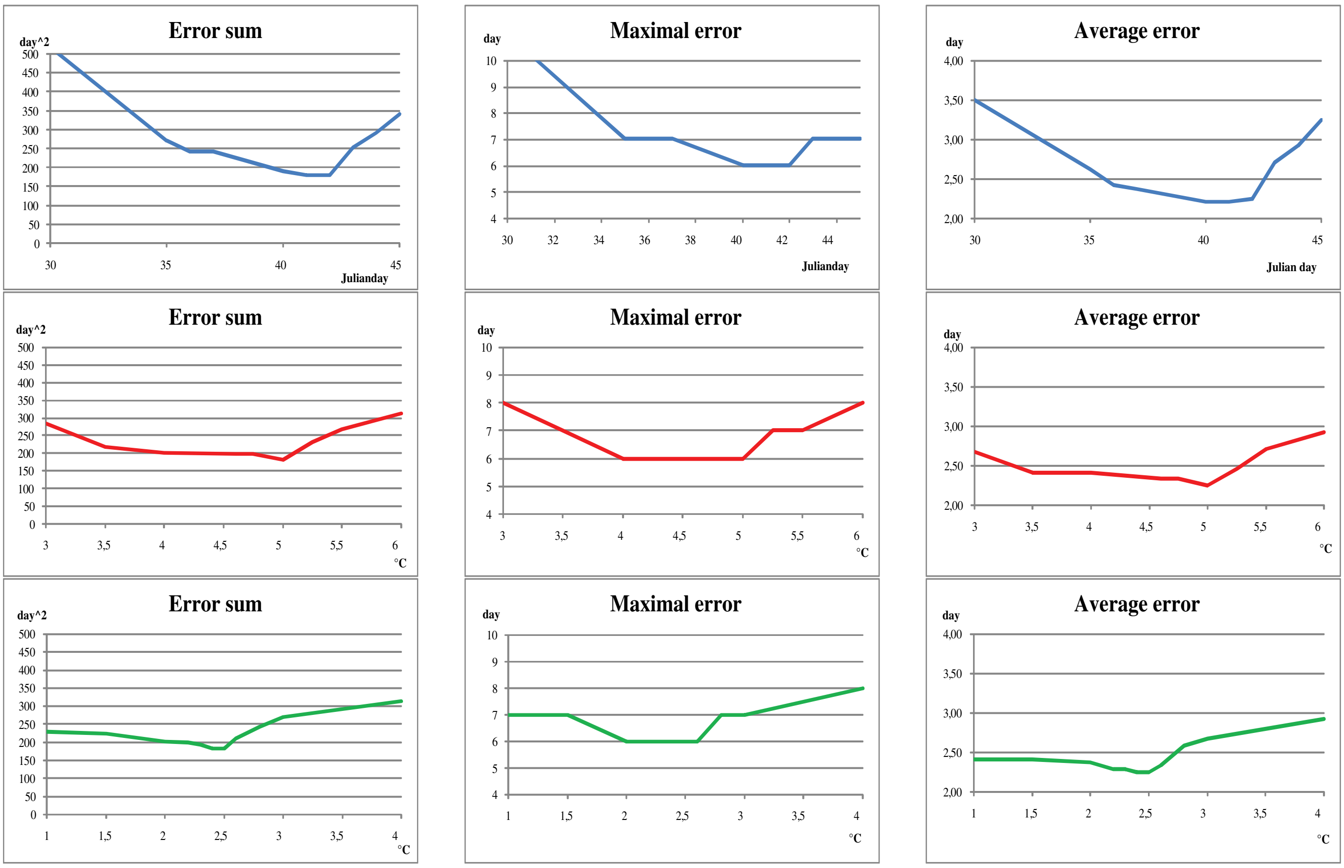

Figure 7: The optimal properties of the estimates (1. column: sum of squares of error; 2. column: maximum of the absolute error, 3. column: mean of the absolute error) with fixed lower and upper basic temperatures (2.5 °C and 5 °C) and with alternative starting days (1. row); or fixed starting day (42th Julianus day, i.e. 11th of February) and with lower basic temperature (2.5 °C) and changing the upper basic temperature (2. row); finally, fixed starting day (42th Julianus day, i.e. 11th of February) and upper basic temperature (5 °C) and changing lower basic temperatures (3. row)

physiological considerations in the literature. Among the 8 years examined, the year 1989 deserves special attention because budburst ensued at 17.5 ºC, which proves that budburst may occur even at low sum of degree-day. Substantial differences are observed between 1984 and 1990 only. Budburst of the variety 'Debreceni bőtermő' was observed at higher temperatures (32.6 ºC) in 1984, whereas in 1990, variety 'Újfehértói fürtös' performed similarly. The differences are, however, not significant, which is comparable to the phenological comparisons of Szabó (2007).

In *Figure 8*, the optimized results are presented. Three parameters (lower and upper basic temperatures and the starting date) have been fixed in order to make more accurate our model. The lower and upper basic temperatures and alternative starting days in the first row show that on the 42th day, the sum of squares of the differences in days between the registered and predicted dates of budburst were at a minimum. At the same time, the differences between absolute maximum values of differences in days and their averages were at a minimum, too. This very date is considered to be the optimum starting date.

If we take the starting date and the lower basic temperature as fixed, we see that at 5 °C, all the three errors mentioned above reached a minimum value, consequently, determination of the upper basic temperature is optimal. Finally, the fixed starting date (11th of February) and upper basic temperature (2.5 °C), where the sum of errors reached a minimum, as well as the maximum absolute error and the average absolute error, which means that the optimum temperature as lower basic temperature is well founded.

With the exception of the years, 1989 and 1990, the error of estimates did not exceed 3 days in predicting the date of

Table 3: The errors of estimates (days)

CVs Years	Újfehértói fürtös	Kántorjánosi	Debreceni bőtermő	Yearly averages of absolute values
1984	0	0	–1	0.33
1985	–2	–2	–2	2.00
1986	–1	–1	0	0.67
1987	1	1	1	1.00
1988	3	3	3	3.00
1989	5	5	6	5.33
1990	–4	–3	–3	3.33
1991	2	2	3	2.33
Averages of absolute values	2.25	2.125	2.375	2.25

budburst (*Table 3*). In the two extreme years, once occurs an error of 6 days with 'Debreceni bőtermő' (1989). In 1984, the average error was 0.33, and in 1989, it was the largest, 5.33.

The *Figure 8* shows the observed and estimated dates of budburst of the 3 varieties examined between 1984 and 1988. It is obvious that the differences between the observed and estimated values were rather small. As demonstrated in Table 2, the years 1989 and 1990 were excessive. In 1989, the differences were even 5–6 day long, i.e. budburst ensued later than signalised by the model. In 1990, the results changed in the opposite sense (–3; –4 days). Both years, 1989 and 1990, produced dates of relatively early budburst. The cause of that cannot be explained from the model. We may surmise effects of weather outside of the examined period or not registered as the temperature alone.

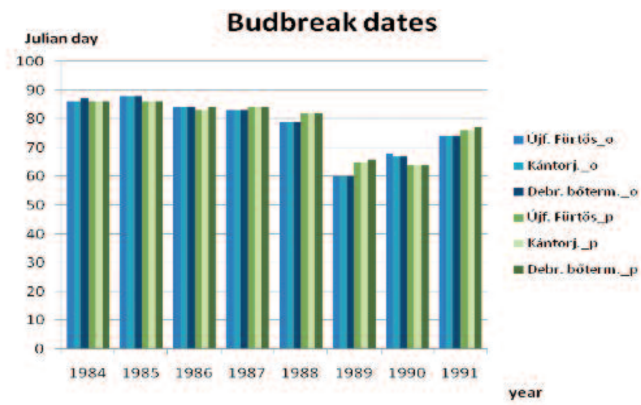

Figure 8: Observed (m) and estimated (b) dates of bud burst according to a model in 3 sour cherry varieties examined during 8 years

Application

The model developed may find general application if the same varieties will be tested and observed continuously. Further validation of the model need observations on other varieties and other periods.

Our model is a tool for facilitate decision making in planning phytotechnical and phytosanitarian operations, moreover, it offers the possibility to trace the effects of climatic changes. Regionally downscaled climatic models may help to predict changes expected in the phenology of plants. This is also the motive of our further objectives.

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