HORTSCIENCE 43(6):1813–1818. 2008.

# Growth Pattern and Phenological Stages of Early-maturing Peach Trees Under a Mediterranean Climate

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*Additional index words.* BBCH General Scale, growth pattern, phenological stages, *Prunus persica*

***Abstract*. The phenological stages of early-maturing peach trees were described using the traditional nomenclature of Baggiolini and according to the BBCH General Scale. The heat requirement of each stage was calculated as growing degree hours (GDH) and growing degree days (GDD). The annual growth pattern of trunk, shoot, and fruit was also studied. After dormancy breaking involving 225 chilling units, this early peach cultivar required ≈6244 GDH to reach full bloom and 27106 GDH before the fruit could be harvested. In the case of GDD, the heat requirements were 329 and 1246 for full bloom and fruit harvest, respectively. According to plant growth measurements, shoot growth lasted ≈7 months with a significant increase in the growth rate after fruit harvest reaching a maximum value in July. Trunk growth followed a similar annual pattern as that of the shoots but with its maximum rate occurring ≈30 days latter. Fruit growth, which lasted an average of 89 days from full bloom to harvesting, took place under mild climatic conditions (10 Feb. to 10 May) coinciding with only 30% of the total annual shoot length. This pattern of reproductive and vegetative growth pointed to the interest of redirecting regulated deficit irrigation practices in early-maturing cultivars toward postharvest water-saving strategies, but only to the extent that any limitation of shoot and trunk growth does not adversely affect the productivity of the following year.**

The term "phenology" refers to the annual calendar of plant biological events such as budburst and swelling, shoot growth and increments in trunk diameter, root dynamics as well as reproductive growth like flower initiation, fruit setting, and fruit maturing. This calendar is essential for good crop management since it permits growers to schedule specific fertilization and the application of hormonal or phytosanitary products. The need to describe the growth stages of all agricultural crops has led to the introduction by Bleiholder et al. (1989) of a general scale, called BBCH, which describes the phenological stages of both herbaceous and woody plants. This method is basically a decimal system that identifies different development stages by a two-digit code. The first digit defines its major stages using values of 0 to 9, while the second digit, also scaled 0 to 9, relates to secondary stages. The BBCH General Scale has been used by various authors on different fruit trees, including pomegranate (Melgarejo et al., 1997) loquat (Martínez-Calvo et al., 1999), quince (Martínez-Valero et al., 2001), apricot (Pérez-Pastor et al., 2004), guava (Salazar et al., 2006), and olive (Cesaraccio et al., 2006).

Very early-maturing peach genotypes as well as very late varieties are of considerable interest for the peach industry in the Mediterranean area (Caruso and Sottile, 1999). These genotypes differ in the length of the fruit development period as well as the timing of fruit harvest, while their use in areas with scarce water resources such as the Mediterranean region must go hand in hand with efficient irrigation management to sustain the existing agricultural productive system. Therefore, water-saving strategies such as regulated deficit irrigation (RDI) are being considered as alternatives to traditional irrigation scheduling approaches that fully meet the water requirements of the tree (Goldhamer et al., 2006).

The RDI strategy is based on reducing water during certain periods of the plant growth cycle without affecting production and has been successfully applied in some fruit trees (Brian and Caspari, 2006; Girona et al., 2005; Goldhamer et al., 2006; Johnson et al., 1992). However, a detailed knowledge of phenological plant processes is required to profit from new varieties while improving the efficiency of irrigation water use. In this sense, the relationship between heat units' accumulation and plant growth processes can be a useful tool for predicting the crop phenological calendar.

Therefore, the objective of this study was to describe the growth pattern and the phenological stages of an early-maturing peach cultivar growing under Mediterranean conditions using the traditional nomenclature (Baggiolini, 1980) as well as the BBCH code (Lancashire et al., 1991) and to calculate the heat requirements that help predict the time to reach each phenological stage.

## Materials and Methods

*Experimental site.* The present work was conducted over a period of 3 years (2004 to 2006) in an experimental 0.8-ha plot located in Santomera-Murcia (Spain): 38°06′ N, 1°02′ W. The soil is stony and shallow, highly calcareous (56% calcium carbonate) with a clay-loam texture and low organic matter content (0.34%) with a cationic exchange capacity of 12.6 meq·100 $g^{-1}$. It is classified as Lithic xeric haploxeroll (Soil Survey Staff, 2006). The bulk density of the soil was 1.45 $g·cm^{-3}$ down to 50 cm, but more compacted (1.67 $g·cm^{-3}$) at deeper levels. The soil water content at field capacity ($\theta_{FC}$) and at wilting point ($\theta_{WP}$) as determined in undisturbed soil samples by the Richards pressure plate technique was $\theta_{FC}$ = 0.29 and $\theta_{WP}$ = 0.15 $cm^{-3}·cm^{-3}$, respectively, which implied an available soil water content of 140 $mm·m^{-1}$. Meteorological data were recorded by an automated station located within the peach orchard (Table 1).

*Plant material.* The plant material consisted of 3-year-old (in 2004) peach trees [*Prunus persica* (L.) Batsch cv. 'Flordastar', on GF-677 peach rootstock] spaced 5 × 5 m. The peach trees were planted in four blocks, each consisting of six rows of 13 trees each.

Received for publication 10 Apr. 2008. Accepted for publication 6 June 2008.
This study was supported by the Ministry of Education and Science (AGL2006-12914-C02-01), Séneca Foundation, Murcia (03130/PI/05 and 05665/PI/07), IRRIQUAL (FP6-FOOD-CT-2006-023120), and Consolider-Ingenio 2010 (CSD2006-0067) grants to the authors.
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Table 1. Monthly maximum, minimum, and mean air temperature, relative humidity (RH), wind speed (2 m), global radiation (Rg), precipitation, and mean daily crop reference evapotranspiration ($ET_o$) during the experimental period.

| | Temperature (°C) | | | | | | Precipitation | | |
|---|---|---|---|---|---|---|---|---|---|
| Month | Max. | Min. | Mean | RH (%) Mean | Wind (km·d$^{-1}$) | Rg (W·m$^{-2}$) | (mm·d$^{-1}$) | (days) | $ET_o$ (mm·d$^{-1}$) |
| 2004 | | | | | | | | | |
| January | 19.0 | 6.8 | 12.8 | 56.4 | 141.8 | 126.9 | 1.2 | 3 | 1.9 |
| February | 16.4 | 5.7 | 10.5 | 73.7 | 113.6 | 128.7 | 3.2 | 12 | 1.7 |
| March | 18.6 | 8.0 | 13.0 | 67.1 | 131.7 | 156.4 | 3.4 | 11 | 2.5 |
| April | 20.7 | 8.9 | 14.6 | 63.3 | 141.3 | 231.8 | 8.3 | 11 | 3.7 |
| May | 23.2 | 12.0 | 17.3 | 65.9 | 131.2 | 248.2 | 3.4 | 13 | 4.2 |
| June | 31.0 | 17.1 | 23.9 | 56.3 | 128.1 | 309.2 | 2.8 | 3 | 5.9 |
| July | 31.0 | 19.6 | 25.2 | 62.8 | 140.4 | 292.6 | 0.6 | 1 | 5.7 |
| August | 33.7 | 20.9 | 27.0 | 59.1 | 125.5 | 261.0 | 1.0 | 1 | 5.4 |
| September | 30.1 | 18.9 | 24.0 | 69.1 | 116.8 | 191.8 | 0.2 | 2 | 3.7 |
| October | 26.3 | 13.9 | 19.7 | 63.2 | 96.2 | 164.8 | 0.2 | 2 | 2.7 |
| November | 19.3 | 7.5 | 12.9 | 69.2 | 92.2 | 119.2 | 3.9 | 4 | 1.5 |
| December | 15.6 | 7.5 | 11.4 | 71.0 | 136.8 | 79.8 | 7.3 | 10 | 1.3 |
| 2005 | | | | | | | | | |
| January | 15.1 | 2.7 | 8.6 | 67.4 | 128.2 | 118.1 | 3.7 | 1 | 1.4 |
| February | 14.9 | 3.5 | 9.0 | 65.1 | 146.1 | 140.6 | 7.3 | 6 | 2.0 |
| March | 18.6 | 7.2 | 12.5 | 68.7 | 194.4 | 128.2 | 2.3 | 2 | 2.8 |
| April | 22.8 | 10.0 | 16.2 | 57.0 | 274.0 | 162.8 | 8.1 | 2 | 4.4 |
| May | 27.0 | 13.3 | 19.9 | 60.1 | 301.1 | 151.3 | 14.0 | 2 | 5.3 |
| June | 30.9 | 17.6 | 24.2 | 59.8 | 321.8 | 142.7 | 0.0 | 0 | 6.1 |
| July | 32.4 | 19.8 | 26.1 | 62.6 | 298.6 | 144.9 | 0.0 | 0 | 5.9 |
| August | 31.4 | 19.2 | 25.1 | 65.9 | 263.4 | 129.1 | 1.2 | 1 | 5.1 |
| September | 29.0 | 16.1 | 22.1 | 67.8 | 235.1 | 105.7 | 9.9 | 5 | 4.0 |
| October | 25.0 | 14.0 | 19.0 | 76.2 | 166.7 | 85.5 | 4.9 | 3 | 2.4 |
| November | 18.4 | 7.9 | 12.8 | 69.7 | 122.2 | 107.3 | 5.3 | 8 | 1.5 |
| December | 16.4 | 5.0 | 10.4 | 67.9 | 95.5 | 109.6 | 4.4 | 3 | 1.2 |
| 2006 | | | | | | | | | |
| January | 14.1 | 4.7 | 9.2 | 75.5 | 97.0 | 103.6 | 3.4 | 13 | 0.9 |
| February | 16.3 | 5.0 | 10.4 | 69.9 | 146.0 | 130.6 | 1.1 | 9 | 1.6 |
| March | 22.6 | 9.6 | 15.9 | 53.4 | 217.0 | 176.6 | 0.5 | 4 | 3.3 |
| April | 23.5 | 11.9 | 17.3 | 67.3 | 237.5 | 142.2 | 6.0 | 10 | 4.3 |
| May | 25.7 | 14.8 | 20.0 | 68.9 | 257.1 | 144.8 | 5.3 | 11 | 5.2 |
| June | 29.6 | 16.9 | 23.0 | 62.5 | 313.7 | 149.5 | 1.6 | 1 | 6.5 |
| July | 33.5 | 20.3 | 26.9 | 60.3 | 326.8 | 145.4 | 0.0 | 0 | 7.4 |
| August | 31.5 | 19.8 | 25.5 | 63.5 | 283.1 | 132.6 | 2.9 | 2 | 6.0 |
| September | 29.7 | 17.8 | 23.3 | 65.6 | 219.0 | 112.5 | 5.1 | 6 | 4.1 |
| October | 26.9 | 15.0 | 20.4 | 67.7 | 153.2 | 101.1 | 0.6 | 5 | 2.7 |
| November | 20.4 | 11.3 | 15.3 | 77.7 | 99.8 | 97.0 | 7.0 | 16 | 1.3 |
| December | 16.5 | 6.5 | 11.2 | 65.3 | 98.1 | 115.6 | 0.7 | 6 | 1.1 |

The central 10 trees were used for experimental measurements (control trees) and the others served as guard trees.

The trees were irrigated by a single lateral line per plant row with four (up to year 2005) and eight (year 2006) emitters per tree spaced at 0.5 m providing 2 L·h$^{-1}$. Irrigation was scheduled to cover 100% of the plant water requirements on the basis of weekly $ET_c$ estimated as reference evapotranspiration ($ET_o$) calculated with the Penman-Monteith methodology (Allen et al., 1998) and a crop factor based on the time of the year and the percentage of ground area shaded by the tree (Fereres and Goldhamer, 1990). The irrigation water used was considered to be of low salinity (electrical conductivity = 1.24 dS·m$^{-1}$). The amount of water applied during the experimental period was 221, 410, and 670 mm for 2004, 2005, and 2006, respectively. Fertilizers were applied through the drip irrigation system with $N–P_2O_5–K_2O$ (kg·ha$^{-1}$) of 120–45–85, 160–60–110, and 200–75–140 for 2004, 2005, and 2006, respectively.

*Phenology and heat requirements.* For 3 years (2004 to 2006), the main phenological stages of the peach trees were identified from bud swelling to dormancy following the BBCH General Scale (Lancashire et al., 1991), whereas reproductive phenological stages were identified according to the Baggiolini code (Baggiolini, 1980).

Accumulated heat requirement was considered as the number of growing degree hours (GDH) or growing degree days (GDD) between the date of dormancy breaking and the date when 50% of flowers were in a particular phenological stage. The dormancy breaking corresponded to the date on which the 'Flordastar' peach trees had accumulated 225 chilling units (Sherman et al., 1988) calculated by the method proposed by Richardson et al. (1974) and successfully applied in the region of Murcia by Egea et al. (2003).

Heat requirements or GDH were calculated by two cosine equations for temperatures lower or higher than optimum, respectively (Anderson et al., 1986). The equations are the following:

$$GDH(k) = \sum_{i=r}^{k} \sum_{h=1}^{24} \frac{T_u - T_b}{2} \times \left[1 + \cos\left(\pi + \pi \frac{T_h(i) - T_b}{T_u - T_b}\right)\right]$$

when $T_b \leq T_h \leq T_u$

and

$$GDH(k) = \sum_{i=r}^{k} \sum_{h=1}^{24} \frac{T_u - T_b}{2} \times \left[1 + \cos\left(\frac{\pi}{2} + \frac{\pi}{2} \frac{T_h(i) - T_u}{T_c - T_u}\right)\right]$$

when $T_u \leq T_h \leq T_c$

where $k$ is a generic day, $r$ is the day of dormancy breaking (fulfillment of chilling requirement), $T_h$ is the hourly mean temperature at hour $h$ and day $i$, $T_u$ is the optimum temperature (25 °C), $T_b$ is the base temperature (4 °C), and $T_c$ is the critical temperature (36 °C).

*Plant growth measurements.* A series of periodic measurements was conducted over the 3 years (2004 to 2006) to characterize the seasonal growth pattern of the shoot, fruit, and trunk. During dormancy, four shoots, one from each compass direction, of 1 year olds of similar diameter (12 ± 2 mm) and length (290 ± 50 mm), were tagged on four healthy trees selected randomly, one from each plot. Afterward, the increments in shoot length (including all the ramifications) were manually measured, using a tape measure, every other week from early March to late June and then every month until the beginning of leaf senescence (late September).

The fruit equatorial diameter (from cheek to cheek) was measured every 4 to 6 d from early March [≈30 d after full bloom (DAFB)] until harvesting, on 100 fruits, randomly selected from four control trees (one form each plot) using an electronic digital caliper. Fruit diameter (FD, mm) was converted into fruit dry weight (FDW, g) using an allometric relationship derived from data collected between 2004 and 2006 in the same orchard ($FDW = 4 \cdot 10^{-4} \cdot FD^{2.5376}$; n = 190; $r^2 = 0.90$).

The trunk diameter in all control trees (10 per block) was measured every 20 to 30 d at 30 cm above the grafting union using a forest caliper.

## Results

*Phenological stages.* During the experimental period, the average maximum and minimum air temperatures were 33.2 and 4.4 °C, respectively. The average annual reference evapotranspiration ($ET_o$), determined by the Penman-Monteith equation (Allen et al., 1998), was 1288 mm with a maximum of 6.4 $mm \cdot d^{-1}$ in June to July. The annual average rainfall over the 3 years was 287 mm (Table 1).

The different phenological growth stages of the 'Flordastar' peach trees, identified according to the BBCH and Baggiolini codes are shown in Figure 1, and the average date of their occurrence in the Santomera area (Murcia, southeast Spain) are presented in Table 2. The heat requirements are also presented as GDH and GDD accumulated since dormancy breaking. The evolution of the reproductive stages of 'Flordastar' peach, according to the Baggiolini code, is shown in Figure 2.

Between late December and early January, the leaf and inflorescence buds accumulated 225 chilling units to break dormancy (Stage A) and start swelling (Stage B) (Fig. 1). Afterward, as the temperature increased, successive phenological stages (C, D, and E) were developed until late January to mid-February, when more than 50% open flowers were registered (full bloom, Stage F) and after accumulating an average of 6,244 GDH or 329 GDD (Table 2). A few days later, fruit set took place and the petals started to fade and fall (Stage G) leaving a green ovary surrounded by dying sepal crown (Stage H) (Fig. 1). Fruit maturing required ≈27,106 GDH or 1,246 GDD (Table 2).

The progress of the reproductive stages from bud swelling (Stage B) to fruit set (Stage G) was very rapid (Fig. 2), although the initiation date of each stage varied considerably between years. In 2005, the full bloom was registered with a delay of ≈25 and 5 d relative to that in 2004 and 2006, respectively.

The description of the main stages (first digit) and some of the secondary stages (second digit) according to the BBCH codes, both scaled 0 to 9, is as follows:

*Stage 0: Bud development*

00: Dormancy: leaf buds and the thicker inflorescence buds closed and covered by dark brown scales; Stage A of the Baggiolini code (Fig. 1).
01: Beginning of bud swelling; light brown scales visible, scales with light-colored edges.
03: End of leaf bud swelling: scales separated, light green bud sections visible.
09: Green leaf tips visible: brown scales fallen, buds enclosed by light green scales.

*Stage 1: Leaf development*

10: First leaves separating: green scales slightly open, leaves emerging.
11: First leaves unfolded, axis of developing shoots visible (Fig. 1).
19: First leaves fully expanded (Fig. 1).

*Stage 3: Shoot development*

31: Beginning of shoot growth: axes of developing shoots visible.
32: Shoots ≈20% of final length.
33: Shoots ≈30% of final length (Fig. 1).
39: Shoots ≈90% of final length.

*Stage 5: Inflorescence emergence*

51: Inflorescence bud swelling: buds closed, light brown scales visible; Stage B of the Baggiolini code (Fig. 1).
53: Bud burst: scales separated, light green bud sections visible.
54: Inflorescence enclosed by light green scales if such scales are formed (not for all cultivars).
55: Single flower buds visible (still closed) on short stalks, green scales slightly open; Stage C of the Baggiolini code (Fig. 1).
56: Flower pedicel elongating; sepals closed; single flowers separating.
57: Sepals open: petal tips visible; single flowers with white or pink petals (still closed); Stage D of the Baggiolini code (Fig. 1).
59: Most flowers with petals forming a hollow ball; Stage E of the Baggiolini code (Fig. 1).

*Stage 6: Flowering*

60: First flowers open.
65: Full flowering: at least 50% of flowers open, first petals falling; Stage F of the Baggiolini code (Fig. 1).
67: Flowers fading: majority of petals fallen; Stage G of the Baggiolini code (Fig. 1).
69: End of flowering: all petals fallen.

*Stage 7: Development of fruit*

71: Ovary growing; Stage H of the Baggiolini code (Fig. 1).
72: Green ovary surrounded by dying sepal crown, sepals beginning to fall; Stage I of the Baggiolini code.
75: Fruit approximately half final size (Fig. 1).

*Stage 8: Maturity of fruit and seed*

81: Beginning of fruit coloring.
87: Fruit ripe for picking (Fig. 1).

*Stage 9: Senescence, beginning of dormancy*

96: More than 50% of leaves discolored or fallen (Fig. 1).
97: All leaves fallen (Fig. 1).

Table 2. Phenoclimatology for 'Flordastar' peach trees[z].

| BBCH code | Growth stage | Date | GDH (°C) initial | GDD (°C) initial |
|---|---|---|---|---|
| 00 | Dormancy breaking | 15 Dec. ± 8 | 0 | 0 |
| 11 | First leaves unfolded | 25 Jan. ± 5 | 4,946 ± 42 | 261 ± 9 |
| 19 | Fully expanded leaves | 5 Feb. ± 6 | 5,996 ± 52 | 337 ± 7 |
| 33 | 30% of final shoot length | 25 Apr. ± 6 | 22,783 ± 505 | 1,093 ± 28 |
| 51 | Flower bud swelling | 12 Jan. ± 10 | 3,476 ± 57 | 193 ± 5 |
| 55 | Calyx perceptible | 20 Jan. ± 7 | 4,498 ± 340 | 234 ± 28 |
| 57 | Flower petals perceptible | 26 Jan. ± 8 | 5,026 ± 51 | 254 ± 17 |
| 59 | Flowers forming a hollow ball | 1 Feb. ± 5 | 6,015 ± 327 | 321 ± 24 |
| 65 | Full bloom, 50% of open flowers | 10 Feb. ± 15 | 6,244 ± 198 | 329 ± 14 |
| 67 | Flower fading | 12 Feb. ± 5 | 6,838 ± 472 | 366 ± 19 |
| 72 | Green fruits with dying sepal crown | 26 Feb. ± 10 | 9,473 ± 300 | 519 ± 7 |
| 75 | 50% of final fruit size | 7 Apr. ± 7 | 16,814 ± 426 | 836 ± 24 |
| 89 | Fruit ripening | 10 May ± 7 | 27,106 ± 582 | 1,246 ± 29 |
| 95 | 50% of leaves discolored or fallen | 1 Oct. ± 15 | 77,763 ± 1,584 | 4,191 ± 81 |
| 97 | All leaves fallen | 1 Dec. ± 10 | — | — |

[z]Occurrence of BBCH codes, predominant dates, growing degree hours (GDH), and growing degree days (GDD) accumulated when 50% of the buds are in a particular stage. Values are mean of the three years ± SE.

*Growth rate pattern.* The seasonal evolution of absolute fruit, shoot growth, and trunk growth rate is shown in Figure 3. The fruit growth pattern manifested the double sigmoid curve typical of peach trees (Chalmers and van den Ende, 1975, 1977; Girona et al., 2005). The average duration of fruit development was ≈ 89 d, and the absolute fruit growth rate reached maximum values of 0.63 $g \cdot d^{-1}$ when the fruits were ready for harvest (Fig. 3).

Shoot growth lasted nearly 7 months with a maximal growth rate being reached ≈45 d after full bloom and two peaks just after

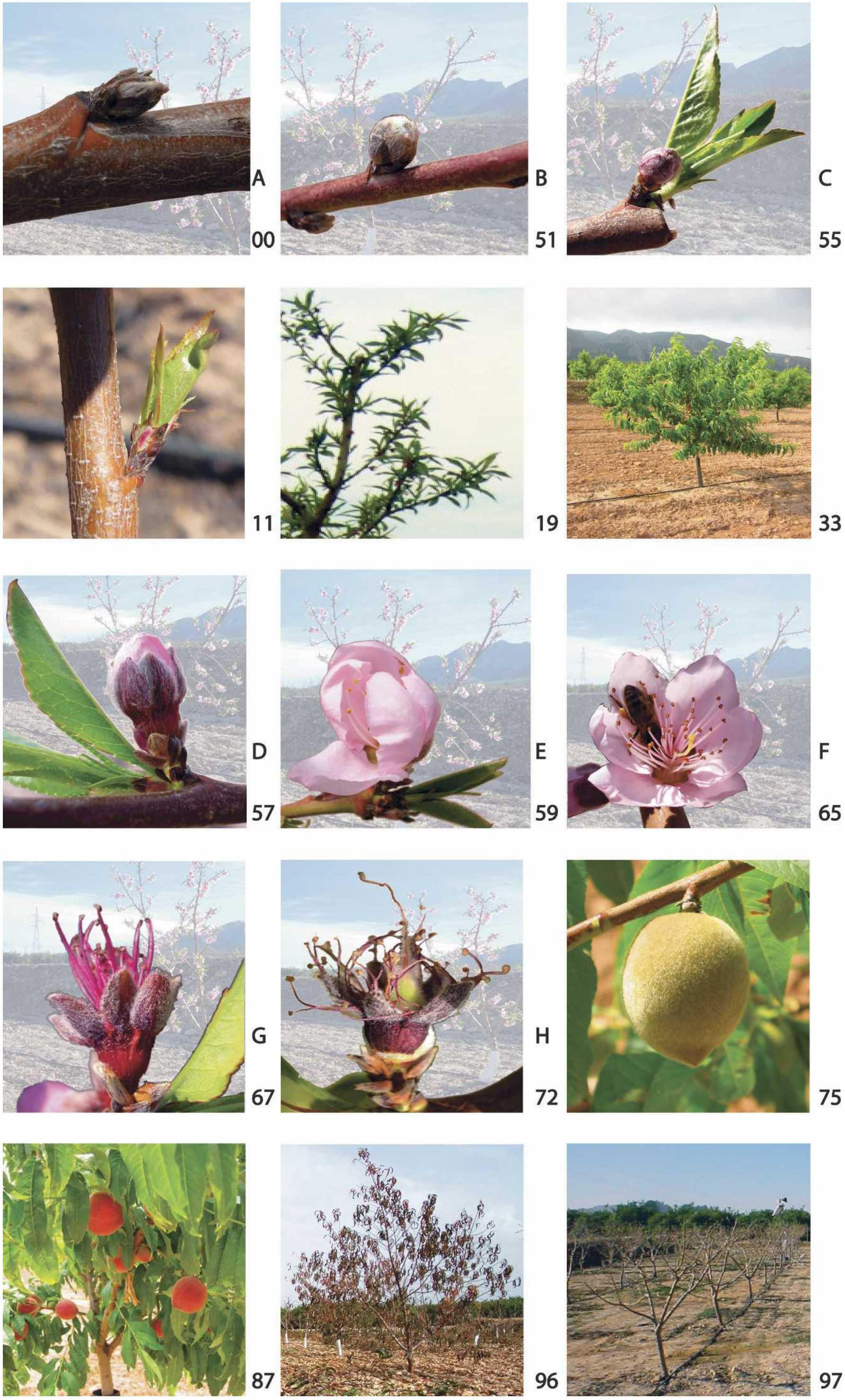


Fig. 1. Phenological growth stages of 'Flordastar' peach trees according to the BBCH (numbers) and Baggiolini (letters) codes.

fruit harvest with the absolute maximum rate occurring early in July (Fig. 3). Seventy percent of total shoot growth occurred after fruit harvest (data not shown).

The trunk grew latter than shoot and fruit growth (Fig. 3), although, even as the annual pattern of its growth rate was similar to that observed for shoot, its maximum growth rates occurred ≈30 d later (Fig. 3).

## Discussion

Our results concerning the heat requirements (GDH) for flowering were slightly lower than those found in low-heat-requirement Brazilian peach cultivars (Citadin et al., 2001) and similar to some almond cultivars (Egea et al., 2003). It is important to note that the date of full bloom showed considerable variation among years (especially between 2004 and 2005), because it could occur from late January to late February (Table 2; Fig. 2), which can be attributed to the cool temperatures registered in January to February of 2005 (Table 1). However, less variation was observed when energy units' accumulation (GDH or GDD) was measured. These results agree with those observed in pomegranate by Melgarejo et al. (1997) and on apricot by Pérez-Pastor et al. (2004), among others, and confirmed that the use of GDH or GDD, which express phenological stages on a standardized scale, rather than the number of days or a calendar date, permits comparisons to be made between different years and geographical areas (Richardson et al., 1975).

The number of maximum fruit growth rate differs between cultivars depending on their maturing time. Nicolás et al. (2006) indicated that late-maturing peach cultivars display two peaks of fruit growth rate. In the early-maturing cultivar studied, only one peak of fruit growth rate occurred, which coincided with fruit harvest (Fig. 3). However, the maximum registered values of fruit growth rate (0.63 $g \cdot d^{-1}$) (Fig. 3) were 30% less than in other early- and late-maturing peach cultivars (0.90 $g \cdot d^{-1}$) (Nicolás et al., 2006).

The presence of fruits affected the annual pattern of tree vegetative growth (Fig. 3). Berman and DeJong (2003) indicated that this is caused by the high reproductive sink demand as well as the time of maturing, which has a clear influence on the competition between vegetative and fruit growth, as is the case with early-maturing cultivars (DeJong, 1986; DeJong et al., 1987; Grossman and DeJong, 1994).

'Flordastar' peach fruits showed a first maximum in shoot growth that coincided with the lowest rate of fruit growth (Fig. 3) corresponding to Stage II of the fruit growth stage (lag phase). For late-maturing stone fruit cultivars, it has been found that shoots show two peaks of active growth rate, which both take place when the fruit was growing most slowly, indicating that the plant splits its time between vegetative growth and fruit development (Pérez-Pastor et al., 2004; Policarpo et al., 2002).

Despite the concurrence of shoot and fruit growth in our early-maturing cultivar (Fig. 3), the period of shoot growth that coincided with Stage III of fruit growth represented less than 30% of the total annual growth (Mounzer, 2005). The remaining 70% of total annual vegetative growth took place after harvesting, corresponding to the months of highest evaporative demand ($ET_o$ greater than 5 $mm \cdot d^{-1}$; Table 1).

This annual growth pattern suggests that, in early-maturing cultivars, the interest of regulated deficit irrigation practices should be directed to postharvest water-saving strategies, but only to the extent that any limitation of shoot growth and the reserve gain for the trunk during this period does not adversely affect the productivity the next year.

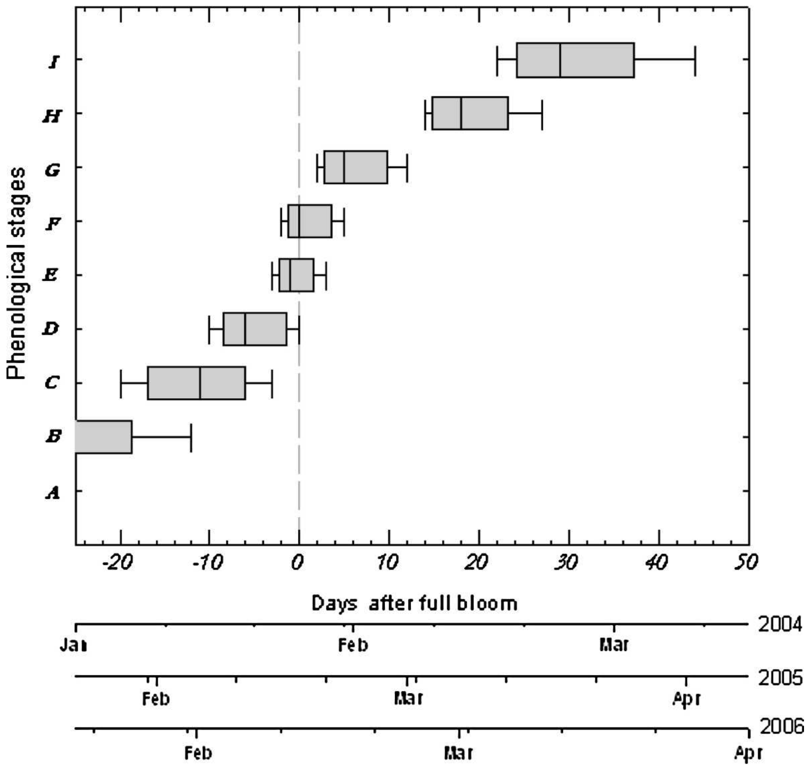


Fig. 2. Box and whisker plots showing progress of flower bud development according to the Baggiolini code for 'Flordastar' peach trees for 3 consecutive years. The plots show the time for 10%, 25%, 50%, 75%, and 90% of buds to have attained each of the stages of bud development.

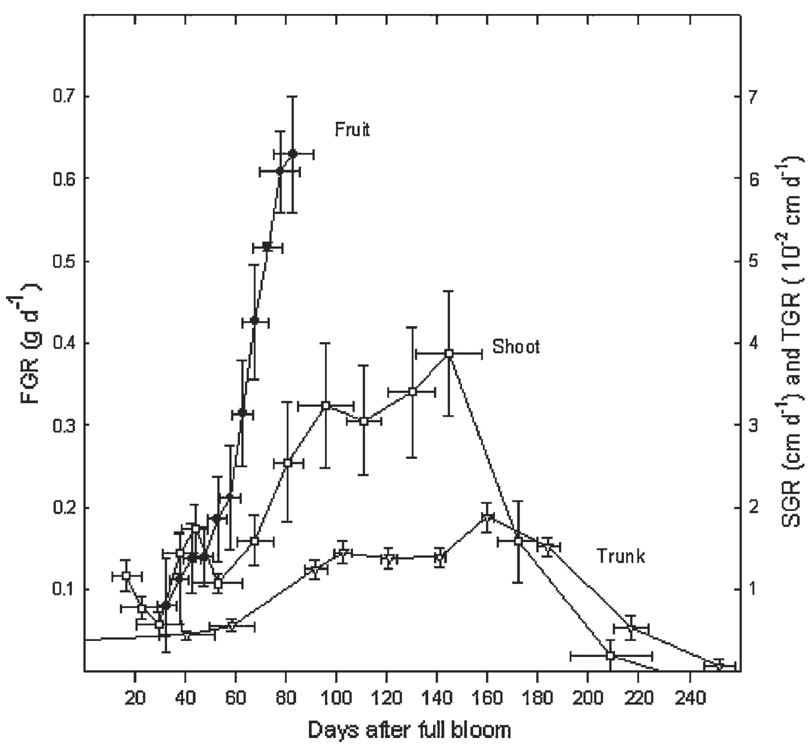


Fig. 3. Annual growth patterns expressed as shoot growth rate (SGR, $cm \cdot d^{-1}$), trunk growth rate (TGR, $cm \cdot d^{-1}$), and fruit growth rate (FGR, $g \cdot d^{-1}$) in 'Flordastar' peach trees for 3 consecutive years. Vertical bars on data point are ± SE of the mean (n = 12) and horizontal bars are ± the interannual SE (n = 3).

## Literature Cited


Allen, R.G., L.S. Pereira, D. Raes, and M. Smith. 1998. Crop evapotranspiration. Paper 56. FAO of the United Nations, Rome, Italy.

Anderson, J.L., E.A. Richardson, and C.D. Kesner. 1986. Validation of chill unit and flower bud phenology models for 'Montmorency' sour cherry. Acta Hort. 184:71–78.

Baggiolini, M. 1980. Stades repères du cerisier—Stades repères du prunier. Stades repères de l'abricotier. Stades repères du pêcher. ACTA. Guide Pratique de Défense des Cultures, Paris, France.

Berman, M.E. and T.M. DeJong. 2003. Seasonal patterns of vegetative growth and competition with reproductive sinks in peach (*Prunus persica*). J. Hort. Sci. Biotechnol. 78:303–309.

Bleiholder, H., T. van den Boom, P. Langeluddeke, and R. Stauss. 1989. Einheitliche codierung der phänologischen stadien bei kultur-und schadpflanzen. Gesunde Pflanzen 41:381–384.

Brian, G.L. and H.W. Caspari. 2006. Partial rootzone drying and deficit irrigation of 'Fuji' apples in a semi-arid climate. Irrig. Sci. 24: 85–99.

Caruso, T. and F. Sottile. 1999. La peschicoltura autunnale in Sicilia: Aspetti ambientali, varietali e colturali. Frutticoltura 2:39–46.

Cesaraccio, C., A. Canu, G. Pellizzaro, and C. Sirca. 2006. A detailed description of flowering stages in olive tree in relation to side tree crown exposure. 17th Conference on Biometeorology and Aerobiology, 1.6.

Chalmers, D.J. and B. van den Ende. 1975. A reappraisal of the growth and development of peach fruit. Aust. J. Plant Physiol. 2:623–634.

Chalmers, D.J. and B. van den Ende. 1977. The relationship between seed and fruit development in peach. Ann. Bot. (Lond.) 41:707–714.

Citadin, L., M.C.B. Raseira, F.G. Herter, and J. Baptista da Silva. 2001. Heat requirement for blooming and leafing in peach. HortScience 36:303–307.

DeJong, T.M. 1986. Effects of reproductive and vegetative sink activity on leaf conductance and water potential in *Prunus persica*. Sci. Hort. 29:131–137.

DeJong, T.M., J.F. Doyle, and K.R. Day. 1987. Seasonal patterns of reproductive and vegetative sink activity in early and late maturing peach (*Prunus persica*) cultivars. Physiol. Plant. 71:83–88.

Egea, J., E. Ortega, P. Martínez-Gómez, and F. Dicenta. 2003. Chilling and heat requirements of almond cultivars for flowering. Environ. Exp. Bot. 50:79–85.

Fereres, E. and D.A. Goldhamer. 1990. Deciduous fruit and nut tree, p. 987–1017. In: Steward, B.A. and D.R. Nielsen (eds.). Irrigation of agricultural crops. Agronomy no. 30. Published by ASA, CSSA y SSA, Madison, WI.

Girona, J., M. Gelly, M. Mata, A. Arbonés, J. Rufat, and J. Marsal. 2005. Peach tree response to single and combined deficit irrigation regimes in deep soils. Agr. Water Mgt. 72:97–108.

Goldhamer, D., M. Viveros, and M. Salinas. 2006. Regulated deficit irrigation in almonds: Effects of variations in applied water and stress timing on yield and yield components. Irrig. Sci. 24:101–114.

Grossman, Y.L. and T.M. DeJong. 1994. PEACH: A simulation model of reproductive and vegetative growth in peach trees. Tree Physiol. 14:329–345.

Johnson, R.S., D.F. Handley, and T.M. DeJong. 1992. Long-term response of early maturing peach trees to postharvest water deficits. J. Amer. Soc. Hort. Sci. 117:881–886.

Lancashire, P.D., H. Bleiholder, T. van den Boom, P. Langeluddeke, R. Stauss, E. Weber, and A. Witzenberger. 1991. A uniform decimal code for growth stages of crops and weeds. Ann. Appl. Biol. 119:561–601.

Martínez-Calvo, J., M.L. Badenes, G. Llácer, H. Bleiholder, H. Hack, and U. Meier. 1999. Phenological growth stages of loquat tree [*Eriobotrya japonica* (Thunb.) Lindl.]. Ann. Appl. Biol. 134:353–357.

Martínez-Valero, R., P. Melgarejo, D.M. Salazar, R. Martínez, J.J. Martínez, and F. Hernández. 2001. Phenological stages of the quince tree (*Cydonia oblonga*). Ann. Appl. Biol. 139:189–192.

Melgarejo, P., R. Martínez-Valero, J.M. Guilamón, M. Miró, and A. Amorós. 1997. Phenological stages of the pomegranate tree (*Punica granatum* L.). Ann. Appl. Biol. 130:135–140.

Mounzer, O. 2005. Riego localizado de precisión en frutales de hueso: *Prunus armeniaca* L. y *Prunus persica* (L.) Batsch, Polytechnic University of Cartagena, Spain. PhD Thesis.

Nicolás, E., F. Lescourret, M. Génard, C. Bussi, and J. Besset. 2006. Does dry matter partitioning to fruit in early and late maturing peach (*Prunus persica*) cultivars confirm the branch autonomy theory? J. Hort. Sci. Biotechnol. 81:444–448.

Pérez-Pastor, A., M.C. Ruiz-Sánchez, R. Domingo, and A. Torrecillas. 2004. Growth and phenological stages of Búlida apricot trees in southeast Spain. Agronomie 24:93–100.

Policarpo, M., L. Di Marci, T. Caruso, P. Gioacchini, and M. Tagliavini. 2002. Dynamics of nitrogen and partitioning in early and late fruit maturing peach (*Prunus persica* L.) tree genotypes under a Mediterranean climate. Plant Soil 239:207–214.

Richardson, E.A., S.D. Seeley, and R.D. Walker. 1974. A model for estimating the completion of rest for Red Haven and Elberta peach. HortScience 9:331–332.

Richardson, E.A., S.D. Seeley, R.D. Walker, J. Anderson, and G. Aschcroft. 1975. Phenoclimatography of spring peach bud development. HortScience 10:236–237.

Salazar, D.M., P. Melgarejo, R. Martínez, J.J. Martínez, F. Hernández, and M. Burguera. 2006. Phenological stages of the guava tree (*Psidium guajava* L.). Sci. Hort. 108:157–161.

Sherman, W.B., P.M. Lyrene, and T.E. Crocker. 1988. Flordastar, a peach for central Florida. Circular, Agricultural Experiment Station. University of Florida S-346.

Soil Survey Staff. 2006. Keys to soil taxonomy. 10th ed. USDA-Natural Resources Conservation Service, Washington, DC.