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

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Abstract. The phenological stages of early-maturing peach trees were described using the traditional nomenclature of Baggolini 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 (Baggolini, 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 (θ_{FC}) and at wilting point (θ_{WP}) as determined in undisturbed soil samples by the Richards pressure plate technique was $\theta_{FC} = 0.29$ and $\theta_{WP} = 0.15$ cm³·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.

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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.

Month	Temperature (°C)			RH (%) Mean	Wind (km·d ⁻¹)	Rg (W·m ⁻²)	Precipitation		ET _o (mm·d ⁻¹)
	Max.	Min.	Mean				(mm·d ⁻¹)	(days)	
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 (Feres 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-P₂O₅-K₂O (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

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

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_0), determined by the Penman-Monteith equation (Allen et al., 1998), was 1288 mm with a maximum of 6.4 mm·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 Baggolini 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 Baggolini 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 $\approx 27,106$ 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 Baggolini 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 $\approx 20\%$ of final length.

33: Shoots $\approx 30\%$ of final length (Fig. 1).

39: Shoots $\approx 90\%$ of final length.

Stage 5: Inflorescence emergence

- 51: Inflorescence bud swelling: buds closed, light brown scales visible; Stage B of the Baggolini 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 Baggolini 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 Baggolini code (Fig. 1).
- 59: Most flowers with petals forming a hollow ball; Stage E of the Baggolini 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 Baggolini code (Fig. 1).
- 67: Flowers fading: majority of petals fallen; Stage G of the Baggolini code (Fig. 1).
- 69: End of flowering: all petals fallen.

Stage 7: Development of fruit

- 71: Ovary growing; Stage H of the Baggolini code (Fig. 1).
- 72: Green ovary surrounded by dying sepal crown, sepals beginning to fall; Stage I of the Baggolini 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).

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·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

Table 2. Phenoclimatology for ‘Flordastar’ peach trees².

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 $\pm 1,584$	4,191 ± 81
97	All leaves fallen	1 Dec. ± 10	—	—

²Occurrence 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 $\pm$ SE.

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 ($0.63 \text{ g} \cdot \text{d}^{-1}$) (Fig. 3) were 30% less than in other early- and late-maturing peach cultivars ($0.90 \text{ g} \cdot \text{d}^{-1}$) (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; Policarpa 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_0 greater than $5 \text{ mm} \cdot \text{d}^{-1}$; 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, $\text{cm}\cdot\text{d}^{-1}$), trunk growth rate (TGR, $\text{cm}\cdot\text{d}^{-1}$), and fruit growth rate (FGR, $\text{g}\cdot\text{d}^{-1}$) in 'Flordastar' peach trees for 3 consecutive years. Vertical bars on data point are $\pm$ SE of the mean ($n = 12$) and horizontal bars are $\pm$ the interannual SE ($n = 3$).

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