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Phenology, growth, and yield of almond cultivars under organic and conventional management in southwestern Spain

Francisco T. Arroyo, Juan F. Herencia and Nieves Capote

Andalusian Institute of Agricultural and Fisheries Research and Training (IFAPA), Center "Las Torres". Ctra. Sevilla-Cazalla km 12.2. Alcalá del Río, 41200 Sevilla, Spain

Abstract

Aim of study: To advance implementation of sustainable agriculture from organic production system on almond crop by means of the assessment of physiological and agronomical responses of commercial almond cultivars.

Area of study: Irrigated almond in the Guadalquivir River Valley.

Material and methods: Physiological and agronomic aspects of almond such as defoliation, phenology, tree growth, N and P leaf reserves, susceptibility to aphids and fruit yield were assessed on five almond cultivars under organic and conventional production management during four consecutive seasons from 2017 to 2021.

Main results: A lower flower density, tree growth, and almond production, an earlier and more intense defoliation degree, and a higher susceptibility to aphids were observed in the organic plot compared to the conventional orchard. 'Lauranne' was the cultivar that showed the best productivity under organic and conventional management. 'Marcona' showed the higher flower density and medium vigor, although was the most susceptible cultivar to aphids and the less productive cultivar under both managements.

Research highlights: Cultivation of irrigated almond still presents numerous difficulties, especially the control of pests and diseases due to the use of environmentally friendly pesticides which are less effective than chemicals. These pathogenic factors and others such as nutrition especially affect the yield of the crop, although the differences with the conventional system are reduced over time. Despite these difficulties, the high added value of organic almonds together with the increasing demands by consumers of healthy environmental practices and food safety are a stimulus to continue and develop research on sustainable agriculture.

Additional key words: aphids; defoliation; ecological system; flowering; leaf reserves; *Prunus dulcis* production; TCSA.

Abbreviations used: C (conventional); O (organic); PE (production efficiency); TCSA (Trunk cross section area); YE (yield efficiency).

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Correspondence should be addressed to Nieves Capote: marian.capote@juntadeandalucia.es

Introduction

Almond, *Prunus dulcis* (Mill.) D.A. Webb, is one of the most important nut crops in Spain in terms of extension, being currently the country in the world with the largest area dedicated to almond cultivation with around 700 thousand ha, which experienced a rise of 34% between 2011 and 2020 (http://www.fao.org/faostat/en/#data). Despite this, it is the world's second largest producer of almonds, with 400 thousand tons, behind the USA, and its yield is ten times lower. Andalusia, Southern Spain, contains about 30% of the almond cultivation of Spain, 200 thousand ha in 2019, of which more than 87% are in rainfed conditions and a production of around 110 thousand tons (MAPA, 2020). However, in the last five years the surface of irrigated crop has expanded from 8 to 26 thousand ha, which represents an increase of 8% in that period (MAPA, 2020). The change into an irrigated regime have provided higher yields, more than six times compared to rainfed lands (2,500 *vs*. 350 kg ha^{-1}) aimed at satisfying the growing demand for almond production and consumption, which has increased the commercial value of the almond (Murua *et al*., 2020; Iglesias *et al*., 2021).

On the other hand, the agricultural area of organic farming in Spain is around 2.25 million hectares, approximately 50% of which is located in Andalusia (MAPA, 2020). The area of almond crop certified in organic management in Andalusia is close to 50 thousand hectares, most of them in a rainfed regime and in marginal areas where inputs are very scarce, while organic cultivation in irrigated lands represents a small fraction (Iglesias *et al*., 2021). Organic fertilization and especially the control of pests and diseases through authorized organic products constitute a challenge for farmers (van Bruggen *et al.*, 2016; El-Shafie, 2020). However, the high added value of organic almonds together with the increasing demands by consumers of healthy environmental practices and food safety are a stimulus for this production system (Casanova, 2003; Iglesias *et al*., 2021). In this way, the implantation of the irrigated almond cultivation in organic management requires a greater knowledge of the response of the crop under these conditions.

The phenology of fruit trees is influenced by local climatic conditions, length of the season, accumulated chill units during the winter, etc. that fluctuate from year to year (Rodrigo & Herrero, 2002; Montagnon, 2007). In the same way, the tree growth is influenced by different factors including soil type, rootstock and cultivar genotype (Vahdati *et al*., 2021; Hosseini *et al*., 2022), climatic conditions (solar radiation, temperature, humidity, rain) (Legave *et al*., 2006), fertilization, irrigation and other cultural practices (removal of adventitious, pruning, etc.) (Hester & Cacho, 2003; Rufat *et al*., 2011; Kükükyumuk *et al*., 2012). Also, pests and diseases affect different physiological processes in plants and represent factors for reducing growth and production (Kropff *et al*., 1995; Donatelli *et al*., 2017). Therefore, numerous studies are necessary on the physiological and agronomic behavior of almond cultivars, especially under organic management.

In this work, the phenological development, flower density, seasonal defoliation, vigor and growth, nitrogen (N) and phosphorus (P) leaf reserves, susceptibility to aphids, as well as production efficiency (PE), yield efficiency (YE) and kernel yield, were compared in five irrigated almond cultivars grown under organic and conventional management in the Guadalquivir River basin (SW Spain). These results will be useful to gain insights on the adaptability and agronomical behavior of commercial almond varieties grown under agroecological practices, looking for an efficient and sustainable agriculture.

Table 1. Physicochemical analysis of the soil in the conventional (C) and organic (O) orchards at the time of planting the almond trees (2016) at two depths (5–25 and 25–50 cm).

	C	O	C	O
	0-25		25-50	
pH	8.06	7.96	8.21	8.17
EC (dS m^{-1})	0.45	0.29	0.37	0.35
$CaCO_3$ (g kg^{-1})	175	181	245	249
OM (%)	1.20	1.48	0.60	0.65
N total (g kg^{-1})	0.78	1.13	0.55	0.61
P_{Olsen} (mg kg^{-1})	33.65	25.90	17.78	9.82
K (mg kg^{-1})	345.57	358.70	233.90	203.12
B (mg kg^{-1})	0.98	1.09	0.65	0.72
Fe (mg kg^{-1})	2.36	2.06	3.79	2.05
Zn (mg kg^{-1})	0.65	0.86	0.48	0.65

[1] EC: electric conductivity. [2] OM: organic matter. [3] K: extractable $ACNH_4$. [4] B: extractable Mehlich-3. [5] Fe, Zn: extractable DTPA (diethylenetriaminepentaacetic acid).

Table 2. Physicochemical characteristics of manure compost.

Characteristics [1]	Mean ± SD [2]
Moisture (g/kg)	245 ± 24
pH (1: 2.5)	8.1 ± 0.4
EC (1: 2.5) (dS/m)	4.2 ± 0.5
TOC (g/kg)	224.4 ± 24.5
TN (g/kg)	16.1 ± 2.2
Carbon/Nitrogen	13.9
Phosphorus (g/kg)	4.2 ± 0.8
Potassium (g/kg)	8.2 ± 1.2

[1] EC: electrical conductivity; TOC: total organic carbon; TN: total nitrogen. [2] Data are the mean ± standard deviation of five samples analysed before application to soil. Data are based on oven-dry weight of compost.

Material and methods

Experimental plots

The study was conducted in two experimental orchards located at Andalusian Institute of Agricultural and Fisheries Research and Training (IFAPA) Centro Las Torres, Alcalá del Río (Seville) in the Guadalquivir River Valley (SW Spain, 37º 30' 48'' N; 5º 57' 46'' W). Almond plantation was established in January 2016 and was made up of two plots of about 6000 m^2 each, 500 m apart from each other, managed under organic and conventional production systems respectively, containing almond trees 7 × 6 m spaced. The experimental design was in randomized blocks with four almond cultivars. 'Guara', 'Marcona', 'Lauranne', and 'Marta' grafted onto Garnem® rootstock, with eight replications, and four trees per replication. Cultivar 'Carreró' was used as a pollinator and was arranged among cv. 'Marcona' allowing to have eight trees in each plot. The soil of the experimental plot was a loam soil (43% sand, 26% silt, 31% clay) classified as Entisol group Xerofluvent subgroup Typic. The main physicochemical characteristics of both plot soils are presented in Table 1.

Plots management

Both plots were drip-irrigated form March to October by using two pipelines with emitters of 2.3 L h^{-1} following requirements estimated by García-Tejero *et al.* (2014, 2020). Meteorological data were collected from a weather station installed at IFAPA Centro Las Torres (Davis Advance Pro2, Davis Instruments, Valencia, Spain): daily mean, maximum and minimum temperature, relative humidity, and accumulated rainfall. The chilling hours model (Chandler, 1942) was used, and accumulated chilling hours throughout the dormant season were summed up (Luedeling, 2012). Fertilization in the organic plot consisted of the annual application of composed beef cattle manure (2 kg m^{-2} year^{-1}) (Table 2) and the use of green cover crops of a mixture legume:cereal (75% *Vicia sativa* L: 25% *Avena sativa* L) in 2017, 2019 and 2021, alternate with bean cover (*Vicia faba* L.) in 2018 and 2020. Cover crops were sowed each year in autumn after the first rains and were mechanically cut and incorporated into the soil in the following March or April with a farm tractor. In the conventional plot, the same fertilization program was followed each year, based on the application of a N-P-K complex fertilizer (15-15-15, 150 kg ha^{-1}) at flowering. No cover crops were used in the conventional orchard.

Pests and diseases in the organic and conventional plots were treated according to the Regulation (EU) 2018/848 of the European Parliament on organic production and labelling of organic products (OJEU, 2018) and with the regulations for integrated production in Andalusia (BOJA, 2012). The severity of aphid attack was measured in a scale 0-5 according to Arroyo *et al.* (2013). Maximum severity index of aphid attack was used for comparison among cultivars in both management systems. To avoid weeds, herbicides were applied in the conventional orchard and manual tillage joined to a straw cover around the trees were used in the organic orchard. Almond pruning was similar in both orchards. Almond trees were pruned during the dormant period, following a training vessel.

Phenological analyses

The flowering period, including the beginning and end dates of flowering, was determined by analyzing two trees per cultivar, repetition, and cultivation management. For this, the BBCH scale was used: beginning of flowering (first open flowers), full flowering (> 50% open flowers), and end of flowering (all petals fallen) (Hack *et al.*, 1992; Sakar *et al.*, 2019). Likewise, the flower density was evaluated for each cultivar, repetition, and treatment, counting the number of flowers of three branches per tree, in the N, ESE, and WSW positions, in a section of one meter from its branching (Loren, 2013). In addition, the kinetics of defoliation was evaluated each 2 weeks from October to December each year, using a scale of 0-5, where 0 is no fallen leaves; 1, up to 20% of fallen leaves; 2, up to 40% of fallen leaves; 3, up to 60% of fallen leaves; 4, up to 80% of fallen leaves and 5, complete defoliation.

Tree growth, foliar analyses and production

Growth and vigor of two trees of each cultivar and repetition in the organic and conventional plots was de-

Table 3. Agroclimatic conditions registered in the study area. Temperature, relative humidity, and rainfall are the average for January-March period (current year). Chilling hours are the period from November 1st until February 15.

Year	Temperature (ºC)	Relative humidity (%)	Rainfall (mm)	Chilling (h)
2018	10.36	84	288	818
2019	11.67	78	38	676
2020	12.82	81	167	408
2021	13.34	87	225	355

termined in November of each year, at the end of the growing season, measuring the perimeter of the trunk at 20 cm above the graft. Trunk cross section area (TCSA) was calculated as an estimate of tree growth (Arquero *et al.*, 2005; Arroyo *et al.*, 2013). Content of N and P in the leaves was measured in June of each analyzed year. Fully leaves from five to eight well-exposed non-fruiting spurs were taken for the analysis. Leaves were carefully detached, washed under tap water to remove any attached soil particles, rinsed twice with distilled water, and then dried at 60 °C. Afterwards, dried samples were passed through 40-mesh screens and stored in plastic containers. Leaf analysis was determined by microwave acid digestion and posterior determination by an autoanalyzer (BRAN+LUEBBE, method G-188-97). For P analysis, a sample of grinded leaf was exposed to microwave digestion by using the mixing of nitric and perchloric acid. The element concentration was determined by inductively coupled plasma (ICP). Production efficiency (PE) was estimated as almond in shell production (kg of almond in shell per tree) normalized with the size of the trees (TCSA in cm^2). Yield efficiency (YE) was calculated as kernel production (kg kernel per tree) normalized with the size of the trees (TCSA in cm^2). Kernel yield was the percentage of seed with respect to the weight of the entire nut fruit (Casanova-Gascón *et al.*, 2019). PE, YE and kernel yield were determined on the total of almond nuts collected in each repetition per cultivar and crop management (4 trees per repetition, and 8 repetitions per cultivar in the two managements).

Data analysis

Statistical analyses were performed using Statistix software (v. 9.0, NH Analytical Software, USA). Data corresponding to flower density, TCSA, N and P leaf content, and production were subjected to analysis of variance (ANOVA) and multiple comparisons of means were analyzed by LSD (least significant difference) at $p<0.05$. Defoliation in each date analyzed, and maximum severity index of aphid attack were analyzed with the Kruskal-Wallis non-parametric test at $p<0.05$ level of significance. To quantify the relationship between temperature and defoliation degree, the non-parametric Spearman's correlation coefficient was used.

Results

Climatic conditions, phenological development and flower density

Table 3 shows the accumulation of chill units during the cold season and the average temperatures, relative humidities and rainfall during the flowering period registered in the almond orchards. Analyzing the average mean temperature in the period from January 15 to March 15 in the location, an increase of 2.98 ºC was observed from 2018 to 2021 (Fig. 1). The relative humidity did not suffer variations, and the rainfall was very variable throughout the four seasons studied. The chilling hours progressively decreased from 2018 to 2021.

Figure 2 shows the average flowering period of all cultivars studied from the beginning to the end of flowering, in the organic and conventional plots from 2018 to 2021. Results reveal a general early bloomer, as well as a lengthier flowering interval in conventionally managed trees compared to trees under organic management: in 2018 and 2019, the onset of flowering was 2 to 4 days earlier in the conventional plot. However, it was very similar in both plots in 2020 and 2021. The data also show a gradual advance of the onset of flowering from 2018 to 2021, of 12 days in the conventional plot and 13 days in the organic orchard. Regarding flowering interval, trees under conventional management had an average of 19 days of flowering compared to an average of 15 days displayed by trees organically managed. The analysis of flowering by cultivars indicated

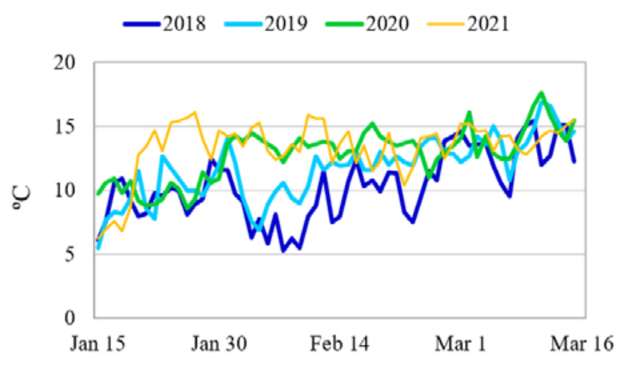

Figure 1. Daily mean temperature of the period from 15th January to 15th March for 2018, 2019, 2020 and 2021 in the study area.

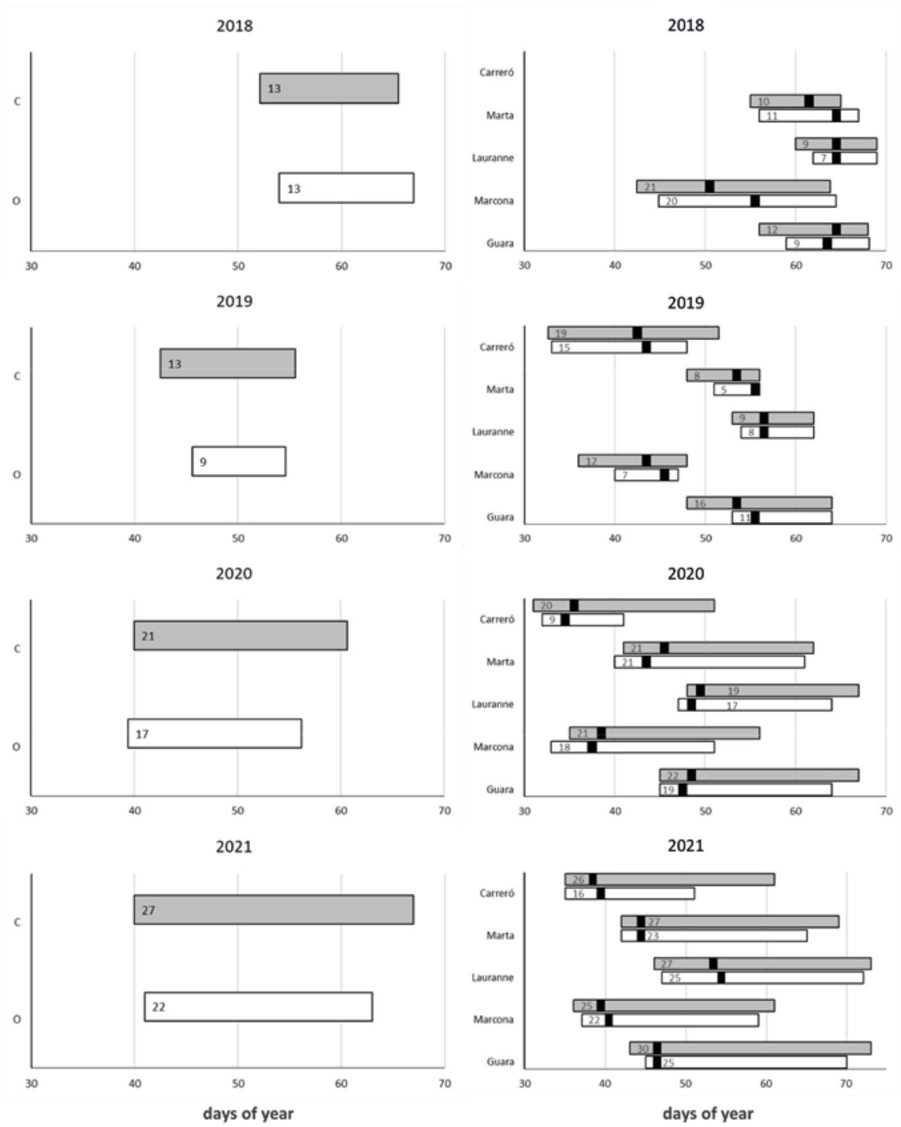

Figure 2. Left: Flowering period of almond trees under conventional (grey bar) and organic (white bar) management systems under drip irrigation in the Valley of Guadalquivir River from 2018 to 2021. Right, flowering period in different almond cultivars 'Carreró', 'Marta', 'Lauranne', 'Marcona' and 'Guara'. The left and right ends of the bars represent the beginning (first open flowers) and the end (all petals fallen) of flowering, respectively. Black squares indicate full bloom date. Numbers inside bars indicate the duration of flowering period in days.

that 'Carreró' and 'Marcona' were the earliest in flowering in both, the organic and the conventional plots, although no flowering was produced in cv. 'Carreró' in 2018 (Fig. 2). Flowering in 'Carreró' started earlier than in 'Marcona', fulfilling its function as a pollinator of the latter variety, which is considered not self-fertile and needs cross pollination. In general, flowering came earlier, a few days for each cultivar, in the conventional plot with respect to the organic one, this pattern was repeated in 2018, 2019 and 2021. In 2020, the trend was reversed, and flowering began earlier in the organic plot for all cultivars, except for 'Carreró'. 'Lauranne' was the latest cultivar to start flowering in all the years studied, and in both production systems (Fig. 2). Likewise, the flowering interval increased for all cultivars from 2018 to 2021, probably due to the growth and vigor increase of the trees in this period. There were no significant differences in the flowering interval between both production systems for cvs. 'Marta' and 'Lauranne' in 2020, and for 'Lauranne' in 2021.

The flower density of the different almond cultivars under organic and conventional management from 2018 to 2021 is shown in Table 4. 'Marcona' was the cultivar that produced the highest number of flowers in all the years studied, under organic and conventional management. All cultivars increased its flower production in both plots over the four years, significantly differing between conventional and organically managed trees, except for 'Lauranne' which showed a similar flower density in both plots in 2021. Cultivars 'Marta' and 'Carreró' showed the lowest flower produc-

Table 4. Flower density measured as number of flowers per one meter of branch in five almond cultivars managed under organic (O) and conventional (C) production systems, respectively, both under drip irrigation.

Cultivar	2018		2019		2020		2021	
	O	C	O	C	O	C	O	C
Guara	0.36c	1.14c*	9.70b	12.26b*	13.24a	21.55b*	13.18c	23.48c*
Marcona	7.78a	8.60a	11.5a	25.00a*	12.69a	30.27a*	33.13a	51.94a*
Lauranne	1.42b	2.06b*	8.65b	11.94b*	8.92b	13.58c*	20.38b	20.67c
Marta	1.23b	1.73b*	3.54c	7.82c*	4.27c	9.33d*	4.46d	8.50d*
Carreró	0	0	0.33d	1.96d	1.05c	20.63b*	14.63c	32.33b*
Mean	2.35	3.06*	5.09	12.91*	8.80	18.82*	17.27	26.93*

Data are average of 3 branches from 2 trees and 8 repetitions per cultivar. For each year, the asterisk indicates significant differences between the two management systems. Per columns, different letters indicate significant differences among cultivars at $p \leq 0.05$.

tion in 2018, 2019 and 2020 in both plots, although 'Carreró' had a large flower production in the conventionally managed plot in 2020 and 2021. In general, the mean number of flowers was significantly higher in the conventional plot than in the organic one in all years studied (Table 4).

Defoliation and severity of aphid attack

Seasonal leaf fall was evaluated from October to December for all cultivars. Considering the whole orchards, defoliation began earlier, up to two weeks in some cultivars, and was more intense in the organic orchard than in the conventionally managed plot throughout all the seasons analyzed (Fig. 3). All almond trees from the organically managed orchard showed a significant higher leaf drop and were completely defoliated before those in the conventional orchard. 'Guara' and 'Marcona' were the cultivars that presented significantly the most premature and intense defoliation, especially in the organic orchard. On the contrary, 'Marta' was the most backward cultivar and the one in which an overlap of old non-fallen leaves with new leaves was observed under both managements. 'Guara' and 'Lauranne' showed the lowest defoliation differences between organic and conventional management. Significant differences in the degree of defoliation between the two managements were only observed in the intermediate evaluation dates (from October 11 to November 23) for all varieties (Fig. 3). The defoliation dynamics of almond trees fluctuated for all years studied. The daily mean temperature in the period from 1st October to 18 December is showed in Fig. S1 [suppl]).

A high negative Spearman correlation was observed between the mean defoliation degree of almond cultivars in each plot and the average temperature of the analyzed period for all varieties in all years studied (Table 5). This correlation was specially observed in warmer periods that occurred in 2019 (October 29 to November 5) and 2020 (November 12 to 19) that corresponded to a slow down of the defoliation in these periods.

The severity of aphid attack was more intense in the organic orchard for all cultivars in all years analyzed.

Table 5. Spearman's rank correlation coefficients between mean defoliation degree of almond cultivars and mean temperature from 1st October to 18 December period. Comparisons were performed per almond cultivar under organic (O) and conventional (C) managements and as a mean per type of management.

Almond cultivar	Plot management	Defoliation *vs.* Temperature		
		2018	2019	2020
Guara	O	-0.964	-0.836	-0.700
	C	-0.955	-0.836	-0.700
Marcona	O	-0.964	-0.756	-0.700
	C	-0.955	-0.709	-0.700
Lauranne	O	-0.955	-0.755	-0.700
	C	-0.927	-0.721	-0.700
Marta	O	-0.955	-0.721	-0.700
	C	-0.867	-0.710	-0.700
Carreró	O	-0.955	-0.860	-0.700
	C	-0.867	-0.721	-0.700
Mean per management	O	-0.964	-0.709	-0.714
	C	-0.964	-0.709	-0.714

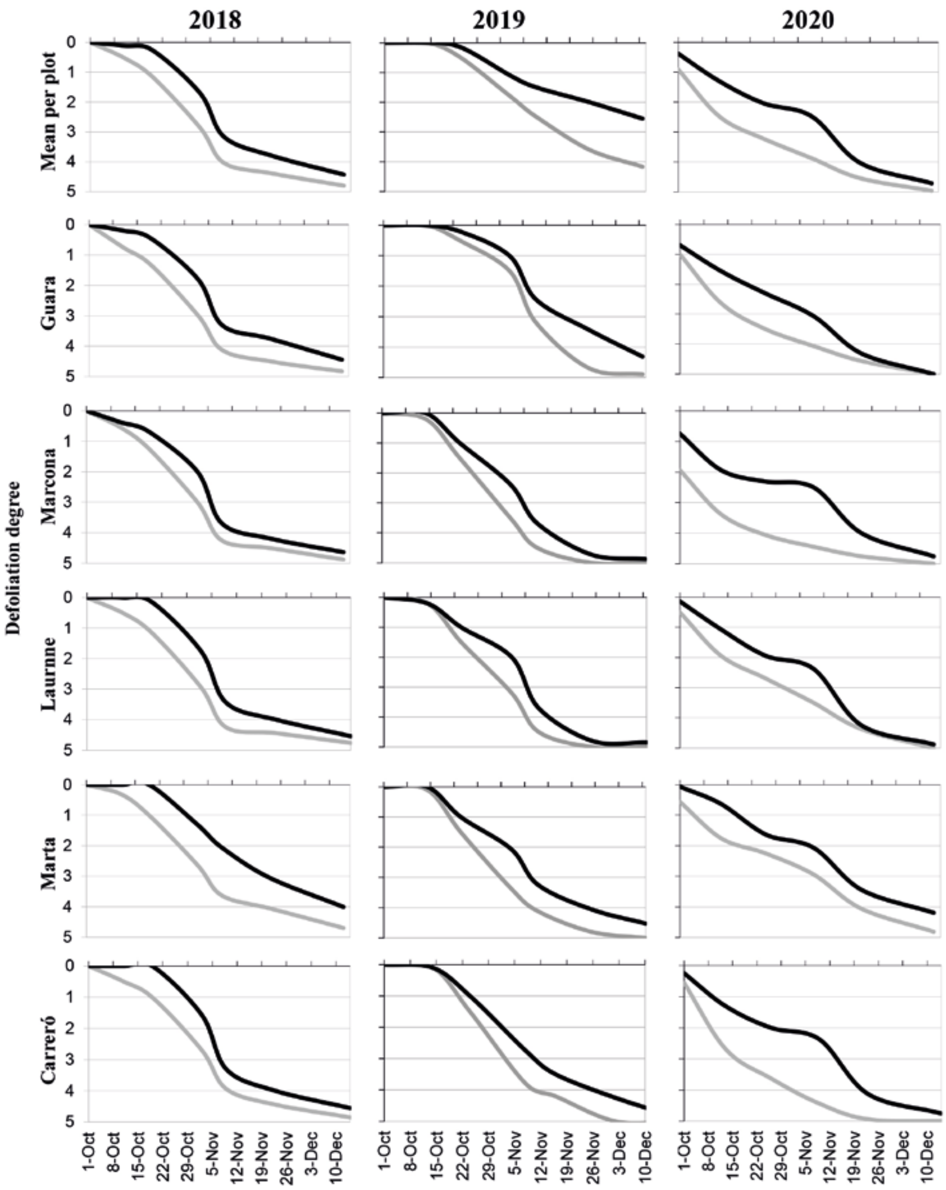

Figure 3. Kinetics of defoliation of 'Guara', 'Marcona', 'Lauranne', 'Marta', and 'Carreró' almond cultivars in 2018, 2019 and 2020 in orchards under organic (grey dashed line) and conventional (black line) management systems under drip irrigation in the Valley of Guadalquivir River.

'Marcona' was significantly the most susceptible cultivar to aphid attack in both management systems, not significantly differing from 'Carreró'. 'Lauranne' and 'Guara' were the most tolerant, showing scarce incidence in the organic and conventional orchards in all years analyzed (Fig. 4).

Tree growth, foliar analyses and production

Table 6 shows the tree growth and vigor, estimated as TCSA in cm^2, for each cultivar in the two production systems from 2017 to 2020, as well as the TCSA increase in that period. Data reveal that all cultivars showed significantly higher values of TCSA in conventionally grown almond trees than in organically managed ones in all years. The growth increase in the analyzed period was also higher in the trees grown in the conventional plot for all cultivars. In 2017, there were no significant differences in vigor among cultivars within the organic production system. As the trees developed, differences in growth among cultivars were appreciated: 'Marta' was the cultivar that showed the highest growth dynamics, displaying the highest TCSA values and the highest growth increase in both production systems. 'Lauranne' was the cultivar that showed the least difference between the two production systems. Likewise, 'Marcona' and 'Carreró' were the cultivars that presented the lowest growth increase under organic and conventional management, respectively, in all years studied (Table 6).

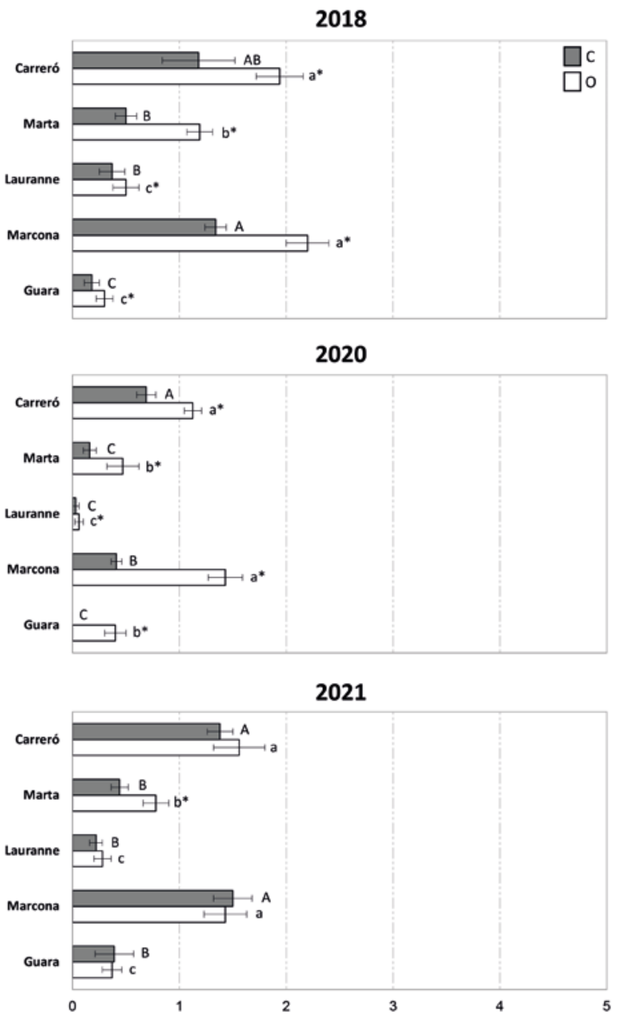

Figure 4. Maximum severity index of aphid attack, estimated on a 0-5 scale, on different almond cultivars in organic (white bar) and conventional (grey bar) systems in 2018, 2020 and 2021. Different letters indicate significant differences among cultivars under conventional (uppercase) and organic (lowercase) management, and asterisks indicate significant differences between types of management at $p \leq 0.05$.

N and P leaf contents for each cultivar in the two production systems from 2018 to 2021 are shown in Table 7. N concentration ranged from 2.01 to 2.97% and from 2.25 to 3.02% in organically and conventionally managed tress, respectively, not showing significant differences among management systems except for specific cultivars in different years. 'Lauranne' was, in general, the cultivar with the highest N leaf content in both management systems. P concentration ranged from 0.08 to 0.17% and from 0.09 to 0.19% for the organic and conventional management, respectively. Significant differences in P content between trees under conventional and organic management were only observed in 2018, with higher values displayed by organically managed almond trees. In the three following years, no significant differences in leaf P concentration were observed between both management systems except for 'Lauranne', which displayed a higher leaf P content under conventional management in 2021.

Almond in shell and kernel productions (measured as kg per tree) were significantly higher in the conventional orchard than in the organically managed one, for all cultivars and all years studied, except for 'Lauranne' cultivar in 2021 (Table S1 [suppl]). On average, the production of almond in shell from organic plot was 26% of that of conventional plot in 2020 and increased to 57% in 2021. A similar trend showed the kernel production whose value in the organic plot was 28% of that of the conventional plot in 2020, and increased to 55% in 2021.

The difference in size of the trees between both plots have been considered for efficiency calculations. So, Table 8 shows the almond in shell and kernel productions normalized with the size of the trees (TCSA in cm^2) to obtain PE and YE, respectively. PE of the organic plot was 41% of that of the conventional one in 2020 and increased to 85% in 2021. In the same way, YE of the organic plot was 32% and reached 83% of that of the conventional plot in 2020 and 2021, respectively. Regarding PE per almond cultivar, differences between both managements were observed for all cultivars in 2020, with significantly higher values for the trees grown under conventional system. In 2021, significant higher PE values were only observed for 'Marta' and 'Marcona' under conventional management. 'Lauranne' showed the best performance in terms of PE under organic and conventional systems in the two seasons analyzed. 'Guara' also exhibited high PE, not significantly differing from that of 'Lauranne' in 2021. Regarding YE, no significant differences were observed between both managements for cv. 'Lauranne' in the two years studied, and significant higher YE values were observed for conventionally managed 'Guara', 'Marcona' and 'Marta' in 2020 but only for 'Marta' in 2021.

Kernel yield of organic plot, calculated as the percentage of seed with respect to the weight of the fruit with shell, was 91 and 97% of that of the conventional plot in 2020 and 2021, respectively (Table 8). Regarding kernel yield per almond cultivar, 'Guara' was the cultivar that showed the higher kernel yield under organic and conventional management in the two years studied. Differences between both managements were only observed for this cultivar in 2020 which rendered 32% and 40% of kernel yield under organic and conventional systems, respectively. The rest of cultivars showed similar kernel yields under both managements in the two seasons. Marcona was the cultivar that showed the lowest kernel yield under both managements.

Discussion

The organic production system is widely accepted by farmers and consumers due to the quality and food safety of its products and the minimal impact produced on the environment (Pfiffner & Niggli, 1996; Hole *et al.*, 2005;

Table 6. Kinetics of tree growth estimated as trunk cross section area (TCSA) in cm^2 of almond cultivars under organic (O) and conventional (C) management from 2017 to 2021, and increase (Δ) of TCSA in the period 2017-2021.

Year	Plot management	Almond cultivar				
		Guara	Marcona	Lauranne	Marta	Mean
2017	O	13.61a	18.95a	18.28a	18.95a	17.45
	C	21.00a*	26.41ab*	23.48ab	27.49b*	24.60
2018	O	34.05a	32.62a	39.56ab	45.73b	37.99
	C	68.44a*	72.29a*	62.04a*	92.84b*	73.90
2019	O	77.46ab	62.79a	83.65b	105.94c	82.46
	C	148.93b*	146.74b*	123.47a*	204.71c*	155.96
2020	O	143.48b	107.99a	142.82b	172.34c	141.66
	C	222.38b*	231.71b*	189.54a*	313.58c*	239.30
2021	O	175.24b	139.14a	172.46b	211.44c	174.57
	C	255.47ab*	268.74b*	221.63a*	349.65c*	273.87
Δ 2017-2021	O	161.63	120.19	154.18	192.49	157.12
	C	234.47	242.33	198.15	322.16	249.28

For each year, the asterisk indicates significant differences between the two management systems. Per lines, different letters indicate significant differences among cultivars at $p \leq 0.05$.

Busari *et al*., 2015). In addition, organic agriculture has been shown to increase soil fertility, control erosion, and enhance biodiversity (De Leijster *et al*., 2020). However, the organic system shows some weaknesses in terms of its production yield and ability to control pests and diseases (Leake, 1999; Weibel *et al*., 2007; De Ponti *et al*., 2012). Furthermore, evidence on the agronomic behavior of almond commercial varieties under organic management is scarce, even more on trees subjected to drip irrigation. In this work, we compared the phenology, growth, leaf reserves and pest susceptibility of five irrigated almond cultivars grown under organic and conventional management in the Guadalquivir River Valley during four consecutive seasons. Production of almonds was also measured for the last years of study. The region has a Type C Mediterranean climate, according to the Köppen classification, suitable for almond cultivation. A progressive increase in the average temperature of the location (measures from January to March) was observed, with an increase of 2.98 ºC in the 2018-2021 period. This could be the cause of the advance of flowering observed for all cultivars in both systems, as previously reported in almond and other fruit trees (Fujisawa & Kobayashi, 2010; Grab & Craparo, 2011; El Yaacoubi *et al*., 2019). Flowering is an important stage in the phenological cycle strongly dependent on temperature of the previous months (Rattigan & Hill, 1986). Early flowering can also expose almond trees to spring frost risks, with the consequent loss of fruiting and productivity (Sakar *et al*., 2017). In this sense, global warming is one of the circumstances to consider for selecting varieties that could adapt to climate change without compromising production yields. The relative humidity of the studied location remained unchanged, and the rainfall diminished throughout the four studied seasons, although this did not directly affect the water availability of trees as they were under drip irrigation system. However, the chilling requirement, which determines the breakage of the dormancy of the shoots, experimented a drastic decrease of about 44% in the period studied, and reached in 2020 and 2021 values below the need of some of the studied varieties such as 'Marcona' and 'Lauranne' (428 chilling hours) (Egea *et al*., 2003; Alonso *et al*., 2005). Alterations in temperature and rainfall are one of the consequences of the climatic change which directly affect the phenology and productivity of crops (Kang *et al*., 2009; Lorite *et al*., 2020).

Flowering started earlier in all cultivars of the conventional plot compared to organically managed trees, although the onset of flowering tended to equalize between the two regimes over time. In addition, conventionally managed almonds showed longer flowering periods, higher flower density, and more delayed seasonal leaf falling than almonds grown under organic management. Differences in the dynamics of almond defoliation among different years is clearly influenced by temperature, among other factors. So, warmer temperatures during the defoliation period could slow down it. The dynamics of defoliation of almond trees presented a monotonic negative trend, similar to that observed in a study about the effect of climate on the tree health of different forest species (Popa *et al*., 2017).

These differences in phenological stages between both management systems could be attributed to differences in vigor that reached higher values in conventionally managed trees since the establishment of the orchards. Vigor differences are frequently attributed to the type of fertilization applied. In general, a controlled and more balanced fertilization in the conventional regime represents a great difference with the organic production system. Despite the use of alternate oat/vetch and broad beans covers, with good nutritional supply, as well as the use of compost animal manure in the organically managed plot, differences

Table 7. Leaf nitrogen and phosphorus content of almond cultivars under organic (O) and conventional (C) management from 2018 to 2021. Data were average of 32 trees (4 trees per repetition, and 8 repetitions) for each cultivar.

Leaf reserve	Year	Plot management	Almond cultivar				
			Guara	Marcona	Lauranne	Marta	Mean
N (%)	2018	O	2.37a	2.10b	2.60a	2.32ab	2.35
		C	2.33ab	2.33b	2.47a	2.25b	2.34
	2019	O	2.24b	2.37a	2.50a	2.41ab	2.38
		C	2.54b*	2.42b	2.71a	2.68a*	2.59
	2020	O	2.29b	2.01c	2.53a	2.33ab	2.29
		C	2.27b	2.35ab*	2.28b*	2.52a	2.36
	2021	O	2.57b	2.56b	2.97a	2.69b	2.70
		C	2.98a*	2.91a	3.02a	2.73a	3.16
P (%)	2018	O	0.22b	0.26a	0.25a	0.23b	0.24
		C	0.18a*	0.18a*	0.18a*	0.19a*	0.18
	2019	O	0.09a	0.08a	0.09a	0.09a	0.09
		C	0.10a	0.09a	0.11a	0.11a	0.10
	2020	O	0.14b	0.17a	0.15ab	0.14b	0.15
		C	0.15a	0.15a	0.16a	0.15a	0.15
	2021	O	0.16ab	0.15ab	0.17a	0.14b	0.15
		C	0.18ab	0.17ab	0.19a*	0.15b	0.17

The asterisk indicates the existence of significant differences between both types of management, and different letters indicate the existence of significant differences among cultivars, $p \leq 0.05$.

in phenology, growth, and productivity persist between both systems. Some works have evidenced that compost application is a promising practice to improve both economic and environmental performance of almond organic cultivation (De Leijster *et al*., 2020), but further research on compost composition and soil nutrient analysis after application of compost and green covers are needed to reach a balanced fertilization. Organic management have been frequently associated with low N use efficiency because N must be previously mineralized to plant-available inorganic forms. The mineralization, together with the immobilization process, depends on various factors and can lead to an asynchrony between N supplies and crop demand. This problem does not usually occur under conventional management in which easily available N fertilizers are applied and are more synchronized with the crop demand. On the contrary, the P leaf content showed similar or higher values in organic almonds despite de higher available P content present in conventional soil at the beginning of the assay. These results could be explained by the characteristics of the soil and the role played by the higher organic matter in organic soils. In calcareous soils (such as the one in the present study) much of the P added via mineral fertilization suffers high retention, mainly precipitated as calcium phosphate, making it unavailable to plants. However, it is known that the application of organic material to soil may increase P availability through diverse mechanisms (Herencia *et al*., 2007). Nevertheless, values of leaf N and P content suggest that both treatments provided adequate N and P supply by comparison of the data with previously established leaf composition standards of reference (Beaufils, 1973). Therefore, the physiological differences found between treatments could not be directly attributed to the fertilization type (Pérez-Romero *et al*., 2017; Kobierski *et al*., 2020).

Data on the incidence of pests and diseases, especially aphids, reveal some possible causes of this different behavior. The control of pests and diseases is certainly more difficult to achieve in the organic management, especially some biological agents like aphids, rusts, and red leaf blotch. Cultivar 'Marcona' suffered the most severe attack of aphids (*Hyalopterus amygdali*) specially in the organic plot, where natural compounds used for its control, based on potassium soap and pyrethrins, were less effective than imidacloprid, the chemical pesticide used in the conventional management system. In this work we have demonstrated that 'Marcona' was the most susceptible cultivar to aphid attack in all years studied even under conventional management. These attacks led to a situation of almost complete defoliation of 'Marcona' trees in the months of June to August mainly, affecting the normal growth of the trees. Probably for this reason, 'Marcona' was the cultivar that showed the lowest production compared to the rest of the cultivars, despite having one of the longest flowering intervals and the highest density of flowers. 'Marcona' is a very widespread cultivar in Spain due to the quality of its fruit, although its early flowering (that can be affected by spring frosts) and its susceptibility to pests and diseases could decrease its production in both conventional and organic management (Donatelli *et al*., 2017).

Table 8. Production (PE) and yield (YE) efficiency and kernel yield of almond cultivars under organic (O) and conventional (C) management in 2020 and 2021.

Cultivar	2020						2021					
	PE [1]		YE [2]		Kernel yield [3] (%)		PE [1]		YE [2]		Kernel yield [3] (%)	
	O	C	O	C	O	C	O	C	O	C	O	C
Guara	1.41b	3.78c*	0.45b	1.20b*	32	40	4.52b	4.74a	1.52a	1.72a	34	36
Marcona	0.56c	1.27d*	0.17c	0.40c*	24	23	1.98c	2.57c*	0.50b	0.81b	26	26
Lauranne	2.71a	5.64a*	0.83a	1.59a	33	35	5.73a	5.72a	1.72a	1.77a	30	31
Marta	1.89b	5.08b*	0.60b	1.30b*	32	33	1.44c	2.86b*	0.43b	0.75c*	30	32
Mean	1.64	3.94	0.51	1.12	30	33	3.42	3.97	1.04	1.26	30	31
Ratio O/C	0.41		0.32		0.91		0.85		0.83		0.97	

[1] Production efficiency: (kg almond in shell tree^{-1} TCSA^{-1})*100. [2] Yield efficiency: (kg kernel tree^{-1} TCSA^{-1})*100. [3] Kernel yield: percentage of seed with respect to the weight of the fruit with shell. Data were average of 32 trees (4 trees per repetition, and 8 repetitions) for each cultivar. The asterisk indicates the existence of significant differences between both types of management, and different letters indicate the existence of significant differences among cultivars, $p \leq 0.05$.

The more severe attack of aphids observed in the organically managed trees, probably determined their higher defoliation degree. Defoliation exerts a high influence on the growth and photosynthetic compensation of the plant, which in turn determines the yield and nutritional quality of the crop (Iqbal *et al*., 2012). The relationships and effects of pest and diseases, defoliation, phenological development and growth of trees seem to be involved in the lower almond production of the ecologically managed plot, which was 26% of that obtained in the conventional plot in the first year of study and recovered to 57% the following season. Similar results (31%) were obtained on another study on comparative production of Japanese plums grown under organic and conventional management in the same location, although such a low ratio was only recorded in the first crop evaluated and grew above 70% from the second crop on (de Ponti *et al*., 2012; Arroyo *et al*., 2013). However, PE and YE, which consider the production of almond in shell and kernel relative to the size of the trees, experienced a big increase over time, with PE and YE of the organic plot 85 and 83% of those of the conventional in the last year of study. So, for the establishment of an organic orchard it would be appropriate to use a conventional management during the first seasons, until trees reach an adequate size that can cope with the debilities of the organic management.

Regarding productivity, 'Lauranne' was, in general, the cultivar that showed the best performance under organic and conventional management and the one which exhibited a more similar behavior under both systems. The high productivity of this variety could be attributed to several characteristics: i) it presents a delay in the onset of flowering that could protect it from winter and spring frosts, ii) together with 'Guara', 'Lauranne' was the most tolerant cultivar to aphid attack; and iii) this cultivar had the highest N leaf content under both management systems.

Kernel yield of the almond varieties under the organic management was very similar to that of those grown under the conventional system. So, research should be focused on enhancing the productivity of organic farming by using sustainable and equilibrated fertilization and looking for efficient and sustainable alternatives to chemical treatments products. Although organic almonds reach a higher market price, which could compensate the loss of production, other aspects should be considered by farmers to calculate the profitability of the conventional and organic management. Overall, the production cost of the organic plot was about 20% higher than that of the conventional plot, considering the same pruning and irrigation practices, due to the higher cost of the compost, green cover and straw applications, and the difficulty in the management of pests and diseases in the ecological plot.

This work compares physiological functions, aphid susceptibility, and productivity of different almond cultivars subjected to organic and conventional management systems in irrigated experimental orchards located in the Guadalquivir River Valley (Seville, SW Spain). Overall, we can conclude that almond trees grown under organic management showed lower values of physiological and production variables, although both managements tend to equalize over time, especially in some cultivars better adapted to organic farming. Since the nutritional reserves of leaves did not differ between the trees under both managements, we suggest the ineffectiveness of the phytosanitary products used in the ecological system as one of the main causes of the difference in productivity between the two systems. Research focus should be on the development of sustainable but effective pests and diseases control methods.

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Authors' contributions

Conceptualization: Francisco T Arroyo, Nieves Capote, Juan F Herencia.
Data curation: Francisco T Arroyo, Nieves Capote, Juan F Herencia.
Formal analysis: Francisco T Arroyo, Nieves Capote, Juan F Herencia.
Funding acquisition: Nieves Capote.
Investigation: Francisco T Arroyo, Nieves Capote, Juan F Herencia.
Methodology: Francisco T Arroyo, Juan F Herencia
Supervision: Nieves Capote.
Writing – original draft: Francisco T Arroyo, Nieves Capote.
Writing – review & editing: Francisco T Arroyo, Nieves Capote.

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