International Journal of Biometeorology (2020) 64:1263–1271
https://doi.org/10.1007/s00484-020-01903-2

ORIGINAL PAPER

Timing of phenological stages for apple and pear trees under climate change in a temperate-continental climate

Emil Chitu[1] · Cristian Paltineanu[2]

Received: 3 October 2019 / Revised: 20 March 2020 / Accepted: 22 March 2020 / Published online: 2 April 2020

Abstract

The study examines the consequences of climate change in *Malus* (apple) and *Pyrus* (pear) on four phenological stages: bud swelling (code 51 BBCH Monograph), budburst (code 53), beginning of flowering (code 61), and end of flowering (code 69) in the temperate-continental climate of southern Romania. The hypothesis tested is how much the onset dates (TOD) of phenology stages moved earlier due to climate change. Weather and phenological data were collected from 1969 to 2018 and were statistically processed. There was an increase in air temperature (T) during the first 5 months in the year, with a significant rise in March and April; significant linear relationships show an advance in TOD with the years elapsed. Inverse linear relationships were found between TOD, maximum (T_{max}), mean (T_{mean}), minimum (T_{min}) temperature, and sunshine hours (Sh). The relationships between TOD and T_{max} were the strongest. The early stages of flowering phenology are advancing more strongly than later flowering stages. For apple, in the last 50 years, there was an advance of 13.8 days for stage 51, 14.8 days for stage 53, 10.7 days for stage 61, and only 7.3 days for stage 69; for pear trees, the advance was lower: 10 days for stage 51, 9 days for stage 53, 6.7 days for stage 61, and only 2.1 days for stage 69. These findings, which might be extrapolated to similar environments, have important consequences in fruit growing, like the occurrence of climate accidents due to late frost, insect pollination, and application of pesticides and irrigation water.

Keywords Bud swelling · Budburst · Beginning and end of flowering · Air temperature · Sunshine hours · Climate change

Introduction

The observed trend of warming at a global or local scale can have serious implications on living organisms. At continental scale, over Eurasia between 1850 and 2005, mean annual air temperatures from Coupled Model Intercomparison Project 5 (CMIP5) increased by about 0.074 °C per decade and will probably increase by 0.08–0.72 °C per decade during the years 2006–2100, depending on future emission pathways (Peng et al. 2019); these authors also predicted an increase of 1.68–6.41 °C during 2081–2100 compared with the period 1986–2005.

In Europe, Guedon and Legave (2008) reported an annual temperature rise of 1.1–1.3 °C in France in the cropping regions mainly since the late 1980s, while Blanke and Kunz (2017), investigating a 60-year-long period of climate data in Bonn/Germany, reported a warming trend since 1988, when the air temperature increased by 0.6 °C until 2015. In the same country, Waldau and Chmielewski (2018) examined a period of 65 years (1951–2015) and reported an increase in mean annual air temperature of March–May period by 1.9 °C. There is also a trend of warming and aridity combined in some Mediterranean countries, e.g., Spain (Paniagua et al. 2019). Due to climate change manifested with warmer winters and earlier springs, temperate fruit crop adaptation in many places will be at risk in the coming decades (Wenden et al. 2017).

In Romania, some data on climate for the investigated region were first reported about two decades ago (Paltineanu et al. 2000), and the trend of warming emphasizing some consequences on rainfed or irrigated crops has been noted by Paltineanu et al. (2011, 2012, 2016a). More recently,

✉ Cristian Paltineanu
cristian_paltineanu@yahoo.com

Emil Chitu
emilchitu@gmail.com

[1] Research Institute for Fruit Growing, Pitesti-Maracineni, ICDP, judetul, Pitesti, Arges, Romania

[2] National Research Institute for Soil Science, Agrochemistry and Environment Bucharest - ICPA, Bd-ul Marasti, No. 61, Sector 1, Bucharest, Romania

Dobrinescu et al. (2015) and Busuioc et al. (2015) noted the increasing trend in air temperature during the 1962–2010 period in Romania, while Chitu et al. (2015) emphasized the increased variability of seasonal and annual extreme temperature trends of the latest three decades.

In Europe, studies from the beginning of the twenty-first century in Germany have revealed that phenological phases of natural vegetation, as well as fruit trees and field crops, showed a trend of chronological advance in the year due to warming (Chmielewski et al. 2004). Menzel et al. (2006) analyzed the phenological response to climate change for many species. Sunley et al. (2006) revealed a significant declining trend in winter chill occurring with reduced spring frost mainly in southern regions of England, with agronomic implications. In France, Atauri et al. (2010) also observed a chronological advance of mean flowering dates in apple and pear trees due to an increase in temperatures from January to April, corresponding to the period of heat requirement completion for buds. More recently, Chmielewski et al. (2011) created models to evaluate blossom for a wider range of apple cultivars, emphasizing that the beginning of apple blossom has moved forward since 1989 due to climate change. In the UK, Atkinson et al. (2013) reported declining chilling and its impact on temperate perennial crops. Advances in flowering stages of apple trees have also been noted in a northern European climate (Rivero et al. 2017). Trying to generalize data and develop a theoretical approach, Darbyshire et al. (2017) created phenology models for climate adaptation at a global scale regarding apple flowering.

In some neighboring countries with temperate-continental climate, Drkenda et al. (2018) found out an increasing trend in air temperature and investigated the impact of climate change on phenological stages in apple and cherry fruit trees, reporting advanced flowering dates for these species.

Although this warming trend has been reported in some regions, currently, the in-depth regional knowledge of warming is insufficient, particularly regarding the implications of warming on fruit tree phenology and growing. Flowering phenology of agricultural plants might be important for fruit tree growing in the management of tree pollination and fruit set, as well as in fighting against late frosts, in pesticide application and irrigation scheduling.

The purpose of this paper is to analyze the impact of climate change on the dates of the onset of phenological stages of apple and pear trees in a continental climate of central and southeastern Europe since the middle of the twentieth century; another objective is to determine which climate variable correlated strongest with the time to the onset date (TOD, days) of phenological stages, and if all stages of flowering phenology are advancing equally, with the aim to use this knowledge in fruit growing.

Materials and methods

Study site

The study has been carried out in apple and pear tree orchards located at the Research Institute for Fruit Growing (RIFG) in Pitesti-Maracineni, southern Romania. The study site is characterized by a humid temperate-continental climate, with a mean annual temperature (T_{mean}) of 9.9 °C, a precipitation (P) of 680 mm, and an annual climatic water balance (CWB = P – ETo, with ETo as Penman-Monteith reference evapotranspiration) of − 20 mm for the 1969–2018 period, Fig. 1. T_{mean} ranges during winter from − 3.6 to 2.9 °C in December, from − 5.9 to 4.3 °C in January, and from −7.1 to 5.7 °C in February. In spring, T_{mean} varies from − 1.1 to 8.9 °C in March, from 6.8 to 15.1 °C in April, and from 12.6 to 18.6 °C in May.

The weather data were collected in the RIFG fenced meteorological platform during 1969–2018 (50 years). From 1969 to 2008, there was a continuous recording of data with instruments read by a meteorologist four times a day. This platform has the following geographical latitude, longitude, and altitude coordinates: 44.8982° North, 24.8674° East, and an altitude of 285 m above sea level. In 2006, weather measurements from meteorologists were carried out in parallel with readings form automatic weather stations, WatchDog 900ET from Spectrum Technologies Inc. Since 2008, another automatic weather station, iMETOSag from Pessl Instruments GmbH, was used to collect weather data, and from 2015, an additional weather station, WatchDog 2900ET from Spectrum Technologies Inc. was used as well. There were three replicates of each measuring instrument to check the accuracy of the data collected, and an analysis of data quality was performed by comparing the RIFG data with the weather data taken at a nearby station (5 km distance, Pitesti city) from the national meteorological network. We found highly significant relationships between all climate variables.

The weather variables used in the present study, from January 1 to May 31, were mean (T_{mean}), maximum (T_{max}), and minimum (T_{min}) daily air temperature measured by classic thermometers at 2 m height in the meteorological shelter from 1969 to 2008, and from the values recorded at 10-min intervals by sensors in the automatic weather stations since 2008; daily sunshine hours (Sh) measured by a Wild heliograph till 2008, and by the help of BF2 and BF5 sunshine sensors from Delta-T Devices Ltd. since 2008; relative humidity (%), wind speed, and precipitation measured by specific devices to determine reference evapotranspiration and climatic water deficit. We used the International System of Units (SI) for all weather variables.

The soil is an aric antrosol, with a loamy to loamy-sandy texture, while soil pH is moderately acid, with a large range from topsoil to subsoil. Details on other soil chemical and

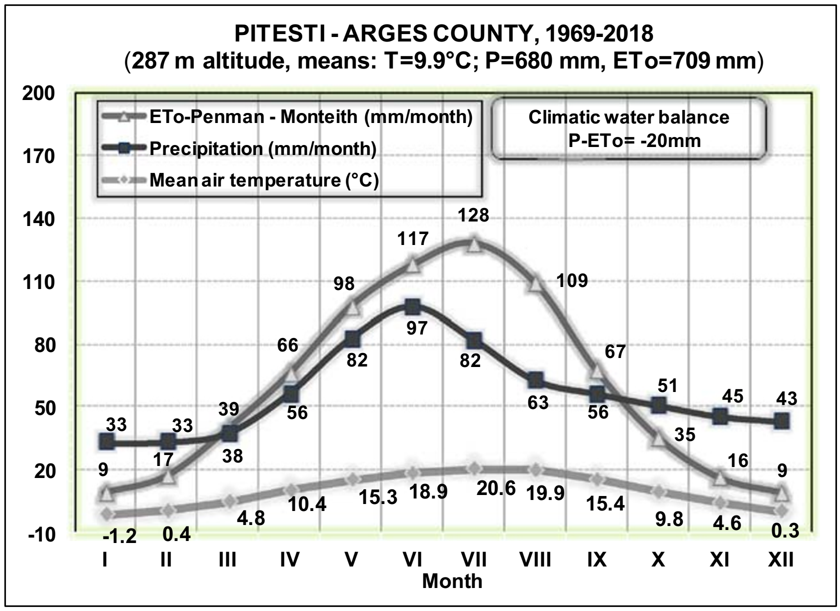

Fig. 1 Climate diagram showing mean monthly values for air temperature (T), precipitation (P), Penman-Monteith reference evapotranspiration (ETo), and P-ETo, annual values, for the study region, 1969–2018

physical properties were reported in previous papers (Paltineanu et al. 2016b). The soils studied are profound enough to allow a proper development of tree roots, irrespective of grafting on classical vigor rootstocks (Paltineanu et al. 2016d and 2016e) or low vigor rootstocks (Paltineanu et al. 2016c).

The landscape conditions of the region are similar to other important areas of the southeastern and central parts of Europe, such as Hungary, northern Bulgaria, eastern Serbia, Moldova, and western Ukraine.

Data collection and processing of phenological stages

The phenological stage database consists of observations made for apple and pear trees, with two representative cultivars, one cultivar of each species. The cultivar/rootstock combinations are Golden Delicious (*Malus domestica Borkh.*) grafted on MM106 and Curé (*Pyrus communis* L.) grafted on seedlings, grown in RIFG orchards for 45 years (1969–1976 and 1982–2018) in the case of apple trees and 42 years (1970–1976, 1982–2008 and 2011–2018) in the case of pear trees. The gaps are generally because the old studied orchards were land-cleared, and new orchards with the same cultivar/rootstock combinations were established under similar soil and climate conditions in nearby plots. These two cultivars have long been used in fruit growing in Romania as well as other Balkan and central European countries (Legave et al. 2008; Chițu et al. 2013; Lepaja et al. 2015; Schmidt and Kellerhals 2012).

For this study, the first four phenological stages were used for apple and pear trees according to BBCH Monograph (2001). These stages are inflorescence buds swelling (code 51), budbursts (code 53), beginning of flowering (code 61), and end of flowering (code 69).

More than three (between 3 and 10) mature trees of various ages (older than 8 years) grown in a classical system with mowed sod strips between tree rows and cultivation and herbicide application in inter-rows have been studied. The planting distance was 4 m × 3 m.

The chilling requirement of trees is usually met in the winter months. For the 2008–2018 period, when direct readings from an automatic weather station were made, the chill hours (0 to 7 °C) calculated by the help of a chilling hour model (Weinberger 1950) were 952 ± 126.1 h from November 1 until January 31. However, chill hours show great differences between species and cultivars (Measham et al. 2014; Rai et al. 2015). Because chilling requirements are assumed to generally be met until January 31, the time to the onset date (TOD) of the four phenological stages has been considered February 1. Thus, based on the course of air temperatures, TOD represents the number of days from February 1 until the starting day of each of the four phenological stages considered here, for every year.

Statistical analysis of the data

The means of the climate variables for each of these four phenological stages have been calculated for both species, with the means from February 1 to the onset of each stage. Regression equations between TOD, the elapsed years, and climate variables have been calculated using the SPSS14.0.0 software (program made by LEAD Technologies, Inc.) and also Microsoft Excel. The number of data was different for all stages. According to the data shape distribution, fitted regression equations and their statistical coefficients have been calculated. Both linear and non-linear relationships have been tried, and in most of the cases, the highest values of the correlation coefficients have been found for linear equations, and this equation type has been used for all variables. The relationship slope or regression coefficient (a), from the TOD = ax + b linear equation type, has been used to show the increase/decrease in TOD from 1 year to another for all climatic variables presented (T_{mean}, T_{max}, T_{min}, and Sh). To evaluate the strength of the average decade trend of increasing/decreasing for the climate variables studied depending on time, the regression coefficients have been multiplied by 10 (years).

Results

Dynamics of the climate variables characterizing the warming trend for the 1969–2018 period

The climate variables that characterize the warming trend are air temperature and sunshine hours. Table 1 shows a trend of increase in T_{mean}, T_{max}, T_{min}, and Sh. The increase in T_{mean}, T_{max}, T_{min}, and Sh over the January through May period is not constant. The changes in these climate variables, evaluated by linear regression equations and statistically assured by the error probability ($p \leq 0.05$), occurred during spring time, specifically in March and April. The average increase in T_{mean} was 0.67 °C/decade in March and 0.42 °C/decade in April, respectively. The increase in T_{max} was 0.71 °C/decade in March only, and the increase in Sh was 0.4 h day^{-1} in April.

Table 1 Statistics of the linear regression equations between T_{mean}, T_{max}, T_{min}, Sh, and time for the first 5 months of the investigated years (1969–2018) to evaluate the average decade trend calculated from the regression coefficients of these equations (multiplied by 10 years), probab. is probability, r^2 is the determination coefficient, and the horizontal bar length obeys the proportion between months within each climate variable

Climate variable	Month	r^2 (%)	Probab. of error r^2 (Sig.)	Average trend per decade
Mean air temperature (°C)	January	1.2	0.468	0.18
	February	6.7	0.085	0.51
	March	15.1	0.008	0.67
	April	11.5	0.023	0.42
	May	3.7	0.205	0.19
Maximum air temperature (°C)	January	3.0	0.259	0.32
	February	6.3	0.097	0.61
	March	9.8	0.037	0.71
	April	7.5	0.069	0.44
	May	1.3	0.452	0.15
Minimum air temperature (°C)	January	0.1	0.828	-0.06
	February	1.7	0.390	0.27
	March	7.8	0.064	0.36
	April	1.9	0.362	0.15
	May	3.5	0.222	0.15
Sunshine hours (h day^{-1})	January	5.0	0.143	0.18
	February	1.6	0.407	0.14
	March	5.1	0.140	0.20
	April	20.1	0.002	0.40
	May	0.5	0.646	0.06

In March, 15.1% of the T_{mean} oscillations (with $r^2 = 0.151$**) as well as 9.8% of T_{max} oscillations ($r^2 = 0.098$*) were attributed to the elapsed time (year). In addition to the relatively sharp increase in T_{mean} and T_{max} of about 3 °C for the period studied, the annual oscillations toward the regression line were low. In April, 11.5% of the increase in T_{mean} and 20.1% of the rise in Sh were also attributed to the elapsed time.

Correlations between TOD of phenological stages and the elapsed years

There are correlations described by regression equations between TOD of the four phenological stages studied and the years elapsed from 1969 to 2018 for both species (Table 2). The number of years with observations and measurements is different for the four stages. All these linear relationships show an advance in TOD with years; for apple, TOD in stages 51 and 61 decreases significantly and stage 53 distinctly significantly with the years elapsed, while stage 69 showed no significant decrease. The TOD advance for pear trees was non-significant in relation to the time elapsed due to a high data scattering.

According to our phenological data of the 1969–2018 period, for apple, the average occurrence dates of stage 51 is March 19 ± 10.9 days, of stage 53 is March 29 ± 10.8 days, of stage 61 is April 24 ± 8.8 days, and of stage 69 is May 04 ± 8.0 days, while for pear trees stage 51 generally occurs in March 18 ± 11.3 days, stage 53 in March 29 ± 9.6 days, stage 61 in April 18 ± 8.5 days, and stage 69 in April 28 ± 8.1 days. Stages 51 and 53 have similar occurrence dates, while stages 61 and 69 differ substantially between the two fruit tree species.

Table 2 Regression coefficients (a and b) of TOD for the phenology stages in the case of apple and pear trees depending on time (x), 1969–2018, from the linear relationships (TOD = $ax + b$); the correlation coefficient r is shown and also the number of years with observations (n)

Species	Stage no.	n	a	b	r	Significance
Apple	51	35	− 0.2817	610.2	0.40	$p \leq 0.05$
	53	42	− 0.3026	660.9	0.41	$p \leq 0.01$
	61	45	− 0.2184	519.2	0.36	$p \leq 0.05$
	69	42	− 0.1450	392.8	0.28	Not significant
Pear	51	34	− 0.2075	460.2	0.28	Not significant
	53	41	− 0.1873	430.7	0.29	Not significant
	61	40	− 0.1393	355.3	0.23	Not significant
	69	39	− 0.0444	176.4	0.08	Not significant

In the tables and graphs, the coefficient of correlation (r) is significant for the error probability $p \leq 0.05$, distinctly significant ($p \leq 0.01$), highly significant ($p \leq 0.001$), or not significant, respectively

Correlations between TOD of the phenological stages and some climate variables

Correlations have been found between TOD of the phenological stages and some climate variables: T_{max}, T_{mean}, T_{min}, and Sh for the February through May periods, with each stage from February 1 to the onset of each individual stage (Fig. 2 and Table 3). All four studied stages occurred earlier with warmer temperatures. The obtained relationships are linear and inverse, and show an advance of TOD with an increase in these climate variables for all the four stages studied.

From the climate variables investigated, the TOD relationships involving T_{max} presents the highest r values, between 0.72 and 0.89 for apple trees, and between 0.68 and 0.85 for pear trees, Fig. 2. The next highest r values from the climate variables studied is for T_{mean}, closely followed by Sh, Table 3. However, there was no shortening of blossoming time with rising temperatures when correlating the mean temperatures between BBCH61 and BBCH69 stages with TOD for the same periods for both fruit tree species; on the contrary, we found direct correlations, with $r = 0.34$, $p < 0.05$ for apple trees and $r = 0.27$ for pear trees.

Discussion

The warming trend

In the study region, the warming trend was previously shown by Paltineanu et al. (2012), Chitu et al. (2015) and Busuioc et al. (2015). This trend is now updated and confirmed, specifically for March and April, when T_{mean} increased on average by about 1.2 °C (resulted from 0.67 °C × 1.8 decades) and 0.8 °C (0.42 °C × 1.8 decades), respectively, (Table 1), from the beginning of the twenty-first century. In the same months, T_{max} increased by 1.3 °C and 0.8 °C (Table 1), respectively, and Sh rose by 0.72 h day^{-1} (0.4 h × 1.8 decades) in April (Table 1), versus the same reference time. In France and Switzerland, Guedon and Legave (2008) noted a warming trend in February and March by about 1.6 °C, specifically later than the 1988.

The annual increase in temperature seems to be largely extended in Europe, as stressed many scientists (e.g., Chmielewski et al. 2004; Peng et al. 2019; Drkenda et al. 2018). However, the annual air temperature has risen differently in various European locations compared with that of the last century, e.g., by 1.4 °C in Ljubljana, Slovenia, by 1.2 °C in Čačak, Serbia, and by 1.7 °C in Klein-Altendorf near Bonn, Germany (Drkenda et al. 2018). The rise in temperature in March and April is expected to determine an earlier start in vegetation of the trees and the exposure of flowers to late freezing. Wypych et al. (2016) have also reported a significant increase in the length of the frost-free season, up to 10 days per decade in the western parts of Europe. Nevertheless, even if there is a warming trend, Tomczyk et al. (2019) have reported that the number of frost days in spring increased from the west to the east of central Europe for the 1966–2015 period, and these anomalies affect more seriously the eastern part of this geographical region. After these authors, the cause is related to a higher than average air pressure at sea level over the prevailing area of the Euro-Atlantic sector.

Correlations between TOD, the elapsed years, and some climate variables

The regression equations depicted in Table 2 show the advance of phenological stages during the 45 years of

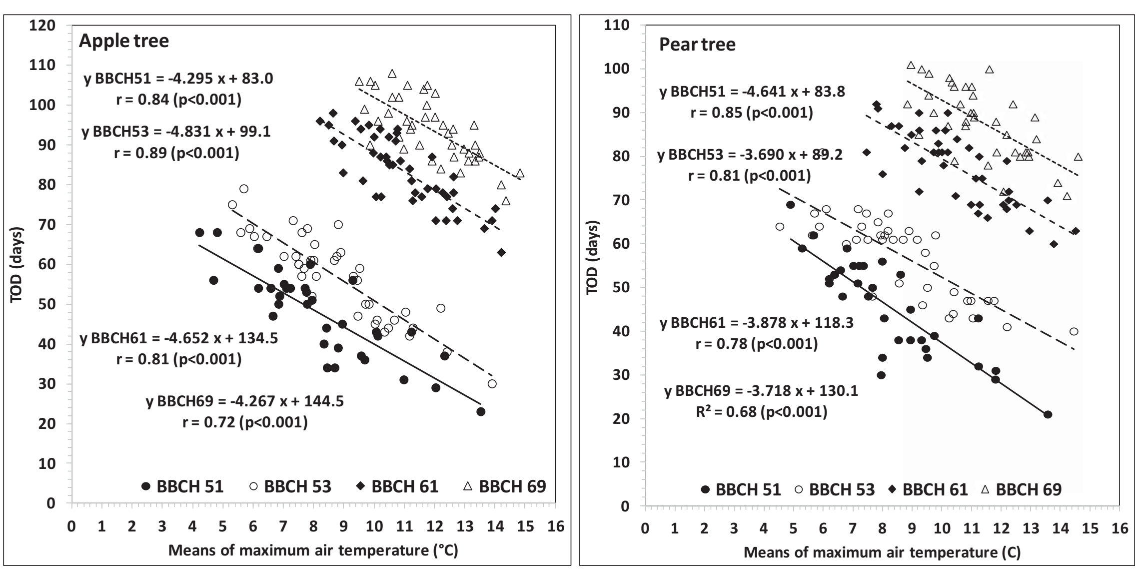

Fig. 2 Linear relationships between the time to onset date (TOD) of phenological stages and the means of maximum air temperature, T_{max}, from February 1 to the onset date of each of the four phenology stages, apple and pear trees, 1969–2018

Table 3 Regression coefficients (a and b) of the linear relationships between the time to onset date of phenological stages (TOD) and T_{mean}, T_{min}, and Sh, (with TOD = $ax + b$) for apple and pear trees, 1969–2018; the used climate data were only for the corresponding months of each phenological stage, i.e., from February 1 until the onset of each stage, and the correlation coefficient r is also shown as well as the number of years with phenological observations (n)

Climate variable/species	Stage no.	n	a	b	r	Significance
Apple trees						
T_{mean}	51	35	−4.853	59.6	0.72	$p \le 0.001$
	53	42	−5.995	74.2	0.81	$p \le 0.001$
	61	45	−5.151	108.7	0.68	$p \le 0.001$
	69	42	−4.354	118.9	0.57	$p \le 0.001$
T_{min}	51	35	−2.884	41.4	0.45	$p \le 0.01$
	53	42	−4.204	50.0	0.54	$p \le 0.001$
	61	45	−2.763	83.2	0.35	$p \le 0.05$
	69	42	−2.335	95.4	0.30	$p \le 0.05$
Sh	51	35	−5.387	73.2	0.50	$p \le 0.01$
	53	42	−6.191	86.1	0.55	$p \le 0.001$
	61	45	−7.421	122.0	0.61	$p \le 0.001$
	69	42	−4.942	120.5	0.42	$p \le 0.01$
Pear trees						
T_{mean}	51	34	−5.600	58.3	0.78	$p \le 0.001$
	53	41	−4.456	69.4	0.77	$p \le 0.001$
	61	40	−4.291	96.44	0.66	$p \le 0.001$
	69	39	−3.945	108.5	0.57	$p \le 0.001$
T_{min}	51	34	−3.751	37.2	0.53	$p \le 0.01$
	53	41	−3.477	50.7	0.58	$p \le 0.001$
	61	40	−2.719	76.1	0.37	$p \le 0.05$
	69	39	−2.926	88.5	0.40	$p \le 0.05$
Sh	51	34	−4.802	68.8	0.46	$p \le 0.01$
	53	41	−3.493	73.7	0.36	$p \le 0.05$
	61	40	−5.459	105.3	0.53	$p \le 0.001$
	69	39	−3.332	105.3	0.31	Not significant

Note that a is the slope and b is the intercept for the regression equation obtained, while p is the error probability

observations for apple trees and 42 years for pear trees. The highest TOD advance, shown by slope of the regression line, occurred for stage 53, followed by stage 51, stage 61, all significantly, and for stage 69, non-significant, for apple trees, as well as for stages 51 and 53 for pear trees, yet non-significant. This advance might be attributed to the highest significant increase in air temperature in the region that occurred, as discussed, during March and April, with the highest rise in March, stage 53 being essentially covered by 29 March, in addition to the cold period of winter, for both species. Stage 51 is generally covered by the cold period of the year when the increase in temperature is not strong, and only by the first part of March (days 18 and 19 for pear and apple, respectively), while stages 61 and 69 occur on average in April for pear, and April and the first part of May for apple.

In the continental climate of the southern Romania, there was thus an advance for all four phenological stages for apple from 1969 until 2018 as follows: 13.8 days for stage 51, 14.8 days for stage 53, 10.7 days for stage 61, and only 7.3 days for stage 69, with the last one non-significant. For pear trees, the advance of the phenological stages from 1970 to 2018 was lower than the one for apple trees, and occurred as follows: 10 days for stage 51, 9 days for stage 53, 6.7 days for stage 61, and only 2.1 days for stage 69, also non-significant due to a large data scattering. Flowering starts by about 6 days earlier for pear trees than apple trees.

As seen from Table 3, the highest correlation coefficients between TOD and the climate variables were generally found for T_{max}, followed by T_{mean}, Sh, and T_{min}. No other climate variable was found to correlate with TOD. Even if the phenological advance for pear trees was not significant versus the time elapsed, because the increased air temperature and the strong correlation between TOD, T_{mean} and T_{max}, that advance might probably become significant in the future. Similar results have been recently found for two other fruit species in the region, i.e., sweet and sour cherry trees (Paltineanu and Chitu 2020).

Compared with other countries in the central and southeastern part of Europe, the start of flowering (stage 61) in the study region advanced with a similar magnitude (about 11 days for apple trees and 7 days for pear trees, according to the relationships shown in Table 2) as that of the neighboring Serbia (10 to 14 days for Golden Delicious cv. at Čačak town) and the farther Germany (7 to 10 days at Bonn) versus the past century, as reported by Drkenda et al. (2018).

In the western part of Europe, Sunley et al. (2006) and Atkinson et al. (2013) reported declining chilling and its impact on temperate perennial crops especially in the southern part of England. Guedon and Legave (2008) also noted advanced flowering dates in apple and pear trees in France and Switzerland as an effect of global warming, specifically later than 1988, and Chmielewski et al. (2011) for apple in Germany.

This trend of advanced flowering stage in central and southeastern Europe was also noticed in a northern climate by Rivero et al. (2017), who found a close relationship between the flowering stage of the Gravenstein apple cultivar and April–May temperatures over a long period (1946–2016). Notwithstanding, in warmer semi-arid environments (Morocco), El Yaacoubi et al. (2019) noted a longer dormancy period as an effect of climate change for apple trees. The advance pattern of the phenological stages for apple trees and pear trees seems to generalize not only in Romania but also in many parts of Europe.

One of the most important finding of this work is that the early stages of flowering phenology are advancing more strongly than later flowering phenology stages. There are also climatic-related changes of the blossoming time as difference between stages 69 and 61 for both fruit tree species. For apple trees, blossoming time significantly increased when related to T_{max} ($r = 0.46$, $p \le 0.01$), T_{mean} ($r = 0.40$, $p \le 0.01$), and Sh ($r = 0.38$, $p \le 0.05$), whereas for pear trees, the direct linear relationships found between these variables were not significant. As previously shown, when only using the variables between these two stages, we unexpectedly did not find any shortening of blossoming time with rising temperatures for both fruit tree species.

Thus, a very important consequence of this advanced trend for the phenological stages in apple and pear trees is the occurrence of climate accidents as late frost. Climate accidents became more frequent in the last decades because of the extreme and high-amplitude oscillations of air temperatures during the spring, mainly in April when flowering occurs, and as previously reported by Chitu et al. (2015) and Busuioc et al. (2015). Similar observations have been made in other European countries by Drkenda et al. (2018). According to Chitu et al. (2011), climate accidents also became more frequent in the recent decades for other fruit tree species in the region.

Another consequence refers to insect pollination; during warm springs, flowering is not always in harmony with insect activity, mainly during rainy and cold days. As a result, fruit set is then poor, and fruit yield as well.

Among other consequences of the advancing of phenological stages is the earlier application of pesticides on trees. Farmers should also take into account additional treatments to impede development of specific pests and diseases, as well as to adjust irrigation scheduling and harvesting time.

Romania's continental climate is not much different from other European countries, specifically neighboring or not far countries (Hungary, northern Bulgaria, eastern Serbia, Moldova, western Ukraine, eastern Slovakia, etc.). That is why the results of the present paper could be extrapolated to other countries or regions in Europe or elsewhere with similar environment. If the global changes continue, important changes in orchard management are needed for these two fruit tree species.

Conclusions

There was an increase in air temperature during the first 5 months of the year for the 1969–2018 period, mainly in March and April; sunshine hours also increased significantly in April.

There were significant linear relationships showing an advance in the onset dates of three out of four phenological stages (TOD) with the years elapsed for apple trees, and no significant relationships for pear trees due to a large data scattering.

Linear and inverse relationships were found between TOD for all the four stages investigated, T_{max}, T_{mean}, T_{min}, and Sh for the corresponding periods, for both tree species. The relationships between TOD and T_{max} present the highest r values.

The early stages of flowering phenology are advancing more strongly than later flowering phenology stages.

One of the most important consequences of this advanced trend for the phenological stages in apple and pear trees is the occurrence of climate accidents as late frost, i.e., the increase in their frequency and severity. Other consequences refer to the difficulty of insect pollination and fruit set, to earlier application of phytosanitary treatments and irrigation water, and to the advance in the harvesting date.

The advance pattern of the phenological stages for apple trees and pear trees seems to generalize in many parts of Europe with a continental climate. The knowledge obtained here could be used by farmers in other countries or regions with similar environment. If global warming continues, this advance might probably be more serious in the future.

Funding information The authors received financial support from the Romanian Ministry of Research and Innovation: Project PN-III-P1-1.2-PCCDI-2017-0721 – INTER-ASPA.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethics statement The authors declare that the work complies with the current laws of the country in which it was performed, Romania.

References

Atkinson CJ, Brennan RM, Jones HG (2013) Declining chilling and its impact on temperate perennial crops. Environ Exp Bot 91:48–62. https://doi.org/10.1016/j.envexpbot.2013.02.004

Atauri IGC, Brisson N, Baculat B, Seguin B, Legave JM, Calleja M, Farrera I, Guedon Y (2010) Analysis of the flowering time in apple and pear and bud break in vine, in relation to global warming in France. Acta Hortic 872:61–68. https://doi.org/10.17660/ActaHortic.2010.872.5

Blanke MM, Kunz A (2017) Cherry phenology as bioindicator for climate change. Acta Hortic 1162:1–7. https://doi.org/10.17660/ActaHortic.2017.1162.1

Busuioc A, Dobrinescu A, Birsan MV, Dumitrescu A, Orzan A (2015) Spatial and temporal variability of climate extremes in Romania and associated large-scale mechanisms. Int J Climatol. https://doi.org/10.1002/joc.4054

Chitu E, Giosanu D, Mateescu E (2015) The variability of seasonal and annual extreme temperature trends of the latest three decades in Romania. Agric Agric Sci Procedia 6:429–437. https://doi.org/10.1016/j.aaspro.2015.08.113

Chitu E, Sumedrea D, Chitu V, Topor E, Paltineanu C, Dumitru ML, Ionita AD, Filipescu L (2011) Phenological and climatic modelling of the late frost damage in apricot orchards under the changing climatic conditions of south-eastern Romania. Acta Hortic 919:57–64. https://www.ishs.org/ishs-article/919_7. Accessed 26 March 2020

Chițu V, Braniste N, Militaru M, Chițu E (2013) Effect of treatment with prohexadione-ca product on pear fruits shelf life. Acta Hortic 981:573–580. https://doi.org/10.17660/ActaHortic.2013.981.92

Chmielewski FM, Müller A, Bruns E (2004) Climate changes and trends in phenology of fruit trees and field crops in Germany, 1961–2000. Agric For Meteorol 121:69–78

Chmielewski FM, Blumel K, Henniges Y, Blanke M, Weber RWS, Zoth M (2011) Phenological models for the beginning of apple blossom in Germany. Meteorol Z 20(5):487–496. https://doi.org/10.1127/0941-2948/2011/0258

Darbyshire R, Farrera I, Martinez-Lüscher J, Berenhauser Leite G, Mathieu V, El Yaacoubi A, Legave JM (2017) A global evaluation of apple flowering phenology models for climate adaptation. Agric For Meteorol 240–241:67–77. https://doi.org/10.1016/j.agrformet.2017.03.021

Dobrinescu A, Busuioc A, Birsan MV, Dumitrescu A, Orzan A (2015) Changes in thermal discomfort indices in Romania and their connections with large-scale mechanisms. Clim Res 64:213–226. https://doi.org/10.3354/cr01312

Drkenda P, Musić O, Marić S, Jevremović D, Radičević S, Hudina M, Hodžić S, Kunz A, Blanke MM (2018) Comparison of climate change effects on pome and stone fruit phenology between Balkan countries and Bonn/Germany. Erwerbs-Obstbau 60(4):295–304

El Yaacoubi A, Oukabli A, Hafidi M, Farrera I, Ainane T, Cherkaoui SI, Legave JM (2019) Validated model for apple flowering prediction in the Mediterranean area in response to temperature variation. Sci Hortic 249:59–64. https://doi.org/10.1016/j.scienta.2019.01.036

Guedon Y, Legave JM (2008) Analyzing the time-course variation of apple and pear tree dates of flowering stages in the global warming context. Ecol Model 219(1–2):189–199. https://doi.org/10.1016/j.ecolmodel.2008.08.010

Lepaja L, Kullaj E, Lepaja K, Shehaj M, Zajmi A (2015) Fruit quality parameters of five pear cultivars in western Kosovo. J Int Sci Publ: Agriculture and Food. 2:245–250. ISSN 1314-8591 (Online) . https://www.academia.edu/22370883/Fruit_quality_parameters_of_five_pear_cultivars_in_Western_Kosovo. Accessed 26 March 2020

Legave JM, Farrera I, Almeras T, Calleja M (2008) Selecting models of apple flowering time and understanding how global warming has had an impact on this trait. J Hortic Sci Biotechnol 83(1):76–84. https://doi.org/10.1080/14620316.2008.11512350

Measham PF, Quentin AG, MacNair N (2014) Climate, winter chill, and decision making in sweet cherry production. HortScience 49(3):254–259

Menzel A, Sparks T et al (2006) European phenological response to climate change matches the warming pattern. Glob Chang Biol 12(10):1969–1976. https://doi.org/10.1111/j.1365-2486.2006.01193.x

Paltineanu C, Chitu E (2020) Climate change impact on phenological stages of sweet and sour cherry trees in a continental climate environment. Sci Hortic 261. https://doi.org/10.1016/j.scienta.2019.109011

Paltineanu C, Chitu E, Mateescu E (2011) Changes in crop evapotranspiration and irrigation water requirements. International Agrophysics 25(4):369–373

Paltineanu C, Chitu E, Mateescu E (2012) New trends for reference evapotranspiration and climatic water deficit. International Agrophysics 26:159–165. https://doi.org/10.2478/v10247-012-0023-9

Paltineanu C, Septar L, Chitu E (2016a) Temperature profile in apricot tree canopies under the soil and climate conditions of the Romanian Black Sea Coast. Int J Biometeorol 60(3):401–410. https://doi.org/10.1007/s00484-015-1037-3

Paltineanu C, Tanasescu N, Chitu E (2016b) Pattern of soil physical properties in intensive plum and apple orchards on medium and course textured soils. Soil Tillage Res 163(C):80–88. https://doi.org/10.1016/j.still.2016.05.013

Paltineanu C, Chitu E, Tanasescu N, Apostol G, Pufu MN (2000) Irrigation water requirements for some fruit trees specific to the Arges-Vedea river basin, Romania. Acta Hortic 537:113–119

Paltineanu C, Nicolae S, Tanasescu N, Chitu E, Ancu S (2016c) Investigating root density of plum and apple trees grafted on low-vigor rootstocks to improve orchard management. Erwerbs-Obstbau 59:29–37. https://doi.org/10.1007/s10341-016-0293-7

Paltineanu C, Septar L, Gavat C, Chitu E, Oprita A, Moale C, Calciu I, Vizitiu O, Lamureanu G (2016d) Characterizing root density of peach trees in a semi-arid Chernozem to increase plant density. International Agrophysics 30(1):67–74. https://doi.org/10.1515/intag-2015-0079

Paltineanu C, Septar L, Gavat C, Chitu E, Iancu M, Oprita A, Moale C, Lamureanu G, Calciu I, Stroe VM (2016e) Spatial distribution of apricot roots in a semi-arid environment. Agrofor Syst 90:469–478. https://doi.org/10.1007/s10457-015-9869-8

Paniagua LL, García-Martín A, Moral FJ, Rebollo FJ (2019) Aridity in the Iberian Peninsula (1960–2017): distribution, tendencies, and changes. Theor Appl Climatol 138:811–830. https://doi.org/10.1007/s00704-019-02866-0

Peng X, Zhang T, Frauenfeld OW, Wang K, Sun W, Luo J (2019) Evaluation and quantification of surface air temperature over

Eurasia based on CMIP5 models. Clim Res 77:167–180. https://doi.org/10.3354/cr01549

Rai R, Joshi S, Roy S, Singh O, Samir M, Anil Chandra A (2015) Implications of changing climate on productivity of temperate fruit crops with special reference to apple. J Horticult. https://doi.org/10.4172/2376-0354.1000135

Rivero R, Sonsteby A, Heide OM, Mage F, Remberg SF (2017) Flowering phenology and the interrelations between phenological stages in apple trees (Malus domestica Borkh.) as influenced by the Nordic climate. Acta Agric Scand Section B-Soil Plant Sci 67(4): 292–302. https://doi.org/10.1080/09064710.2016.1267256

Schmidt H, Kellerhals M (2012) Progress in temperate fruit breeding: proceedings of the Eucarpia fruit breeding section meeting held at Wädenswil/Einsiedeln. Book Springer Science & Business Media, 472 pages

Sunley RJ, Atkinson CJ, Jones HG (2006) Chill unit models and recent changes in the occurrence of winter chill and spring frost in the United Kingdom. J Hortic Sci Biotechnol 81(6):949–958. https://doi.org/10.1080/14620316.2006.11512181

Tomczyk AM, Szyga-Pluta K, Bednorz E (2019) Occurrence and synoptic background of strong and very strong frost in spring and autumn in central Europe. Int J Biometeorol 64:59–70. https://doi.org/10.1007/s00484-019-01793-z

Waldau T, Chmielewski FM (2018) Spatial and temporal changes of spring temperature, thermal growing season and spring phenology in Germany 1951-2015. Meteorol Z 4(27):335–342. https://doi.org/10.1127/metz/2018/0923

Weinberger JH (1950) Chilling requirements of peach varieties. Proc Am Soc Hortic Sci 56:122–128

Wenden B, Mariadassou M, Campoy JA, Quero-Garcia J, Dirlewanger E (2017) Statistical analysis of trends in sweet cherry flowering data across Europe. Acta Hortic 1160:215–220. https://doi.org/10.17660/ActaHortic.2017.1160.31

Wypych A, Ustrnul Z, Sulikowska A, Chmielewski FM, Bochenek B (2016) Spatial and temporal variability of the frost-free season in Central Europe and its circulation background. Int J Climatol 37(8): 3340–3352. https://doi.org/10.1002/joc.4920

Growth stages of mono-and dicotyledonous plants - BBCH Monograph, 2nd Edition, (2001) Edited by Uwe Meier, Federal Biological Research Centre for Agriculture and Forestry, 158 p