Features development of olive trees during the growing season in the Southern coast of the Crimea

Svetlana Korsakova[1*], and *Pavel* Korsakov[1,2]

[1]The Nikitsky Botanical Gardens – National Scientific Center of the RAS, 298648, Nikita, Yalta, Russian Federation

[2] Agrometeorological station of Nikitsky garden, 298648 Yalta, Russian Federation

Abstract. Estimate climatogenic changes in phenorhythms of *Olea europaea* L. during the growing season in Southern coast of the Crimea carried out. The study used data of olive trees phenological observations and data climatic parameters during 1947–2020. It was established that in the 'Nikitskaya' cultivar during studied period of climate change the steady bias tendency to shift to earlier budbreak dates and fruit maturity has been observed since the 80s, the flowering has been since the 90s of the XX century, first leaves separated has been since the beginning of the XXI century and it differs in the highest rates. For the last 2001–2020 the tendency to shift earlier spring phenophases of budbreak and first leaves separated has increased 1.5–2 times. Phenological models using as input variable temperature and photoperiod were developed to predict dates beginning of full flowering 'Nikitskaya' olive cultivar. Forecast accuracy amount to 2.7–4.1 days. The expected future change those dates to end of XXI century are also shown.

1 Introduction

The olive (*Olea europaea* L.) is one of the most long-term and ancient species among evergreen subtropical fruit crops grown in the Crimea [1]. This a very sensitive species with regard to temperature, so the plant's thermal requirements strongly regulate the different phases of the life cycle of the olive [2].

Given the impacts of the climate change on plant phenology modeling the onset and peak dates of different phenological stages using climatic variables became an important issue in recent years [3–6]. Most of the phenological models described by many authors have revealed temperature as the best external variable to predict flowering time of the olive, nevertheless, photoperiod may also have an influence, less than temperature [4, 7].

The object of our work was to estimate climatogenic changes in phenorhythms of olive trees during the growing season and development of phenological models to forecasting date beginning of 'Nikitskaya' olive cultivar full flowering in Southern coast of the Crimea.

---

* Corresponding author: korsakova2002@mail.ru

2 Material and methods

The 'Nikitskaya' olive frost-resistant cultivar has a continuous field phenological data collected for over 70 years observations was selected as an object for the research. The study used a 74-year database (1947–2020) of olive trees phenological stages records and climatic parameters. The study site (44°31′ N, 34°15′ E) is located on the territory of the Nikitsky Botanical Gardens – National Scientific Center (Southern coast of the Crimea (SCC). The area has a Mediterranean type climate with moderately humid winters, hot and dry summers. The annual mean temperature (1930–2015) is 12.6 °C and the annual average rainfall is 592 mm [8].

Data for the main meteorological variables were obtained from an agrometeorological station Nikitsky Sad, managed by Roshydromet and located nearest (about 50 m) at the olive orchard planted.

Phenological observations were carried out in 10 olive trees once every 2 days during the growing season of olive trees development. In order to identify the phenological stages during field observations the international standardised BBCH scale for olive [9] was used. In this study the following five BBCH phenophases were analysed: budbreak (correspond on this scale to BBCH 01), first leaves separated (BBCH 11), full flowering (BBCH 65), end of flowering (BBCH 68) and fruit maturity (BBCH 81).

The 6 models were applied to predict the beginning dates of full flowering, which were different for difficulty level and types of responding functions to signals from the environmental (air temperature, photoperiod): GDD, BC_{DOY}, SIG_{DOY}, UNI_{DOY}, $SEQBC_{DOY}$ and UNIChill [3, 5, 6]. The GDD model described a linear plants response to temperatures above baseline (*Tb*). Phenological models parameters were identified by the evolutionary optimization method using the Microsoft Excel add-on SolveXL [10]. For verification of phenological models were used odd years data and for validation were used even years data. Estimation of the model approximation accuracy was made on the four performance indicators basis such as Determination coefficient (R^2), Root Mean Squared Error (RMSE), corrected Akaike information (AICc) and Bias (Θ) criterion [10].

Mean daily temperature inputs to predict the date beginning of full flowering for the future climatic period (from 2021 to 2099) were calculated for an ensemble of the five climatic models from CMIP5 [10]. Then 20-year-averaged projections of coordinated changes in thermal condition and date beginning of flowering were built for the climatic scenarios (RCP2.6, RCP4.5 и RCP8.5).

3 Results and discussion

Analysis of climatic variations for the SCC over the period 1947–2020 showed that, since 1947, local spring, summer and autumn temperatures have increased by around 1.5–2.2 °C (Table 1). The rainfall has only by around 15–18 mm, but it was not statistically significant. During the 1947–1971, the increase in temperatures was less marked, and there was even a drop their in spring–autumn during the 1972–1987. Since 1988, there has been a phase of the most intense increase in temperatures at all climatic seasons, which continues up to the present. Over the past thirty years, the rate of warming has increased by 3–4 times and amounted to 0.6–0.8°C per decade. The highest rates of temperature rise in the first decades of the XXI century were observed in the spring and summer seasons. Statistically valid rising the amount of rainfall for the analyzed long-term period was observed only in spring during 1947–1987.

The increase in temperatures during 1947–1971 and 1988–2020 coincided with phenological trends more early developments throughout the growing season, while the decline in temperature during 1972–1987 coincided with a delay in the onset of the

vegetative and reproductive phenophases (Fig. 1). There was a significant fluctuation in the onset of phenophases over the years. The largest amplitudes of variability in the onset of phenophases date under the SCC conditions which reach 60 or more days were identified for the phases of budbreak, first leaves separated and fruit maturity. The variability of the flowering phases timing is almost two times less and doesn't exceed 30–35 days. The analyze of the long-term phenomonitoring research results for 1947–2020 showed the steady trend towards earlier periods of budbreak and fruit maturity in the "Nikitskaya" cultivar has been observed since the mid-1980s, flowing since 1990s and first leaves separated since the beginning of the XXI century. It has the highest rates (Fig. 1, Table 2).

Table 1. Long-term trend analysis the slopes of the linear regression (yearly advance (–) or delay) of parameters mean air temperature (T, °C) and rainfall (R, mm) on seasons of the year in the Southern coast of the Crimea.

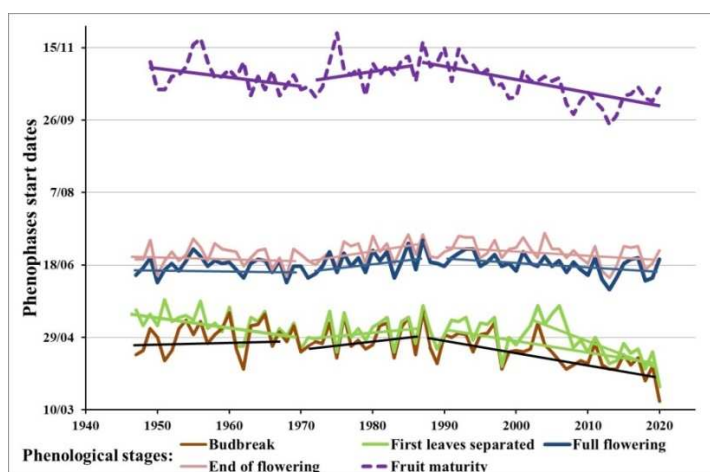| Period, years	Climatic parameter	Season of the year			
		Winter	Spring	Summer	Autumn
1947–2020	T (°C)	0.01	**0.02****	**0.03****	**0.02***
	R (mm)	0.23	0.20	0.24	0.21
1947–1971	T (°C)	0.05	0.02	–0.01	0.03
	R (mm)	0.43	**2.68***	0.27	2.45
1972–1987	T (°C)	0.04	–0.09	–0.06	–0.04
	R (mm)	3.65	**6.36***	0.43	–2.60
1988–2020	T (°C)	**0.07****	**0.06****	**0.08****	**0.08****
	R (mm)	1.70	–1.11	–0.17	–1.16
2001–2020	T (°C)	0.08	**0.08***	**0.08***	0.06
	R (mm)	–2.21	–2.44	0.73	–4.49

*p<0.05;** p<0.01

Fig. 1. Interannual changes the phenological stages of olive trees and temporal trends for various phenophases for the periods 1947–1971, 1972–1987, 1988–2020 and 2001–2020.

The comparative trends evaluation for the periods of 1988–2020 and 2001–2020 has showed that the 1.5–2 time trend towards earlier onset of certain spring phenophases has strengthening over the last 20 years, for example, for budbreak and first leaves separated (Table 2).

The flowering is one of the most important the processes in the olive reproductive cycle of yield formation, so the knowledge of floral phenology responses to weather variations is very useful for good crop management and the optimization of agronomic tasks [4]. It is known

that the variability of flowering olive trees phenorhythmics is basically conditioned by fluctuations in mean daily air temperatures which determines their as main forecast indicators. Parameters of the six models different in difficulty level and types of phenological models functions were optimized using air temperature and photoperiod (Table 3).

Table 2. Long-term trend analysis the slopes of the linear regression (yearly advance (–) or delay) the date of start phenological phases (days) of 'Nikitskaya' olive cultivar in the Southern coast of the Crimea.

Period, years	Phenological phase				
	Budbreak	First leaves	Full	End of	Fruit
1947–2020	**–0.29****	**–0.28****	–0.01	0.02	**–0.27****
1947–1971	0.16	**–0.68****	–0.08	–0.11	–0.56
1972–1987	0.52	0.50	0.57	0.73	0.75
1988–2020	**–0.80****	**–0.76****	**–0.31****	**–0.28***	**–0.97****
2001–2020	**–1.23****	**–1.98****	–0.39	–0.53	**–0.79***

*p<0.05;** p<0.01

Table 3. Parameters models for forecasting beginning of full flowering of 'Nikitskaya' olive cultivar in the Southern coast of the Crimea.

Parameter		Phenological model					
		GDD	BC_{DOY}	SIG_{DOY}	UNI_{DOY}	$SEQBC_{DOY}$	UNIChill
$t0$, date						01.Nov.	01.Dec.
T_b, °C		7.3	5.2	19.4	18.1	6.4	18.2
$F*$, °C		620	1472	33	39	44	35
T_{opt}, °C						2.5	8.6
$C*$, °C						1006	59
$t1$, date		01.Jan.	01. Jan.	**04.Feb.**	**16. Jan.**	**07.Feb.**	**04.Feb.**
C			1.501			0.917	
a					–0.162		–0.177
$b1$					–0.0030		–0.8096
$b2$					–0.1973		1.6236
Verification results	N	27	27	27	27	27	27
	R^2	0.74	0.73	0.76	0.75	0.74	0.77
	RMSE, days	3.8	4.1	3.8	3.7	4.0	3.7
	AIC_c	72.64	77.09	73.86	73.86	77.37	76.60
	θ, days	–0.6	0.5	0.5	–0.4	0.5	0.6
Validation results	N	28	28	28	28	28	28
	R^2	0.80	0.80	0.82	0.81	0.82	0.84
	RMSE, days	3.3	3.0	2.9	2.9	2.8	2.7
	θ, days	–1.4	–0.1	–0.3	–0.7	–0.2	–0.1

Optimized model parameters are highlighted in bold.

Models' quality evaluation based on using the four basic criteria showed that all models satisfactorily describe the reproductive structures development process in olive but higher accuracy of approximation was reached using the SIG_{DOY}, UNI_{DOY} and UNIChill models describing sigmoidal dependence of the phenological processes dynamics on temperature. The RMSE values of the forecast in model calculations are insignificantly different and amount to 2.7–4.1 days (Table 3). But the systematic bias value changes from –0.1…0.6 days in the BC_{DOY} and UNIChill models calculations to –0.6…–1.4 days in the GDD model calculation. Based on cumulative results of the quality evaluation and the phenological models results of validation for forecasting beginning full flowering dates there has been selected the UNIChill model which has shown better forecast accuracy, the amount of fit and the smaller amount of bias.

Built according to three climatic scenarios projections by the agreed changes in thermal conditions and flowering dates of 'Nikitskaya' olive cultivar on the SCC are presented in the figure 2. The calculation results showed that when implementing the first two scenarios (RCP2.6 и RCP4.5) which involve an increase in temperatures on the SCC ones an average of 1–2 °C, it is expected that compared to the period 2001–2020 the magnitude of shifts in full flowering to earlier dates until the end of the 21st century in average will be 3–6 days and in the case of the RCP8.5 scenario implementation it will be 14 days due to high rate of temperature rise.
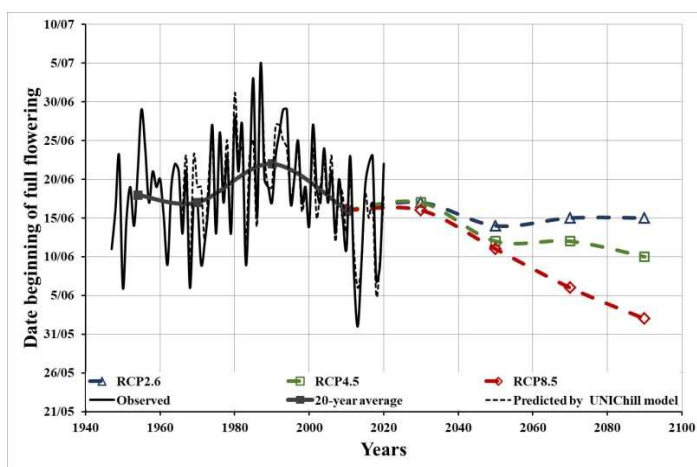

Fig. 2. Observed (solid lines) and predicted by the UNIChill model (dotted lines) date beginning of full flowering of 'Nikitskaya' olive cultivar in the Southern coast of the Crimea under the future climate scenarios RCP2.6, RCP4.5 and RCP8.5.

High enough accuracy of the air temperature data in modern weather forecasts is effective to use the developed models in order to predict short and medium term of the olive flowering and it also could be used to predict the response of 'Nikitskaya' cultivar to global increase of temperature.

References

1. L. F. Myazina, T. B. Gubanova, Bull. of the State Nikitsky Botan. Gardens, **128** (2018)

2. A. Ramos, H. F. Rapoport, D. Cabello, L. Rallo, Sci. Hortic., **231** (2018)

3. I. Chuine, J. Theor. Biol., **207** (2000)

4. J. Rojo, R. Pérez-Badia, Int. J. Biometeorol., **59** (2015)

5. C. Olsson, S. Olin, J. Lindström, A. M. Jönsson, Ecol. Evol., **7** (2017)

6. S. P. Korsakova, P. B. Korsakov, N. A. Bagrikova, Science in the south of Russia, **16**(3) (2020)

7. H. Garcia-Mozo, F. Orlandi, C. Galan, M. Fornaciari, B. Romano, L. Ruiz, C. Diaz de la Guardia, M. M. Trigo, I. Chuine, Theor. Appl. Climatol., **95** (2009)

8. A. Pashtetsky, Y. V. Plugatar, O. Ilnitsky, S. Korsakova, Acta Hortic., **1263** (2019)

9. F. Sanz-Corte´s, J. Martı´nez-Calvo, M. L. Badenes, H. Bleiholder, H. Hack, G. Lla´cer, U., Ann. Appl. Biol., **140** (2002)

10. S. P. Korsakova, Proceedings of the Karadag Scientific Station named after T. Vyazemsky, **2**(6) (2018)