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Influence of climate warming on beginning of flowering of apple tree (*Malus domestica* Borkh.) in Lithuania

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Abstract. The paper presents summarized data of longtime (the period of 1961–2006) phenological observations of apple trees (*Malus domestica* Borkh.) in Lithuania. It has been determined that in different localities of the country apple trees start flowering on May 11–17 (± 3–5 days); the average in Lithuania is May 16. Evaluation of the changes in the dates of the beginning of apple tree flowering revealed that, due to climate warming during the last decade, apple trees start flowering 4–5 days earlier than the longtime average. The thermal regime of April strongly influences the annual changes in the dates of the beginning of apple tree flowering: the correlation coefficient between the mean monthly air temperature and dates of the beginning of apple tree flowering is -0.48 – (-0.80). The possibility to forecast the dates of the beginning of apple tree flowering based on the dates of the beginning of the flowering of European hazel (*Corylus avellana* L.) and European bird cherry (*Padus avium* Mill.) was investigated. It has been ascertained that the date of the beginning of the European bird cherry flowering is suitable for forecasting the date of the beginning of the apple tree flowering because that date significantly correlates with the beginning of the European bird cherry flowering, which is an indicator of true spring.

Keywords: apple trees, air temperature, the beginning of flowering.

INTRODUCTION

Climate produces the strongest impact upon phenological phenomena as compared with other environmental factors. The last decades of the 20th century have been described as the onset of global warming; recently the data on climate warming has become increasingly abundant. Many researchers indicate that in northern latitudes the warming will be rather sudden and, therefore, will affect the fluctuations of plant seasonal rhythm (Linkosalo et al., 2000; Anisimov et al., 2003). According to A. Menzel (2000), during the period of 1959–1996 in Europe, tree leaves started to unfold 6.3 days earlier on average, and in autumn leaves were yellowing 4.5 days later on average. Considerable changes were determined in the northeastern part of Europe. For example, in Estonia during the last decades the flowering phenophases of *Padus avium* Mill., *Malus domestica* Borkh. and *Prunus domestica* L. started an average of 8 days earlier (Ahas, 1999).

Comparison of the average dates of the beginning of flowering of 7 tree and shrub species in Lithuania during the periods of 1974–78 and 1999–2003 revealed that this phenophase occurred 4–17 days earlier (Baronienė et al., 2005). It has been determined that the plant vegetation season in Europe starts 2.7 days earlier during every decade,

and from 1969–98 it lengthened by 8 days on average (Chmielewski et al., 2000). Finnish scientists predict that plants starting their vegetation season earlier due to climate warming can be more severely damaged by spring frosts (Linkosalo et al., 2000). It is particularly dangerous for fruit trees because damaged generative organs destine poor fruit yield.

Prognoses of meteorological conditions forecast further warming of the climate. Based on various models of climate prognoses, the scenarios of the changes of air temperature and precipitation amount until the year 2050 were designed in Lithuania (Bukantis et al., 1996). It is predicted that in the middle of the 21st century average air temperature in Lithuania in winter will be by 1.2–1.3°C higher than at present; average air temperature in summer will also increase. It is likely that the altered hydrothermal conditions will affect the duration of agricultural plant vegetation periods and growth. Changes in the dates of the beginning of phenophases are especially important for agriculturists as they predetermine successful application of plant protection measures against diseases and pests.

The aim of the research is to determine the impact of the thermal regime on the beginning of apple tree flowering in Lithuania during the period of 1961–2006.

METHODS

In Lithuania, phenological observations have been performed since 1959. In the period from 1960–70 the phenological network in Lithuania included more than 200 localities throughout the country. Presently, phenological observations are performed in 23 localities (density of a network – 0.4/1000 km^2). The phenological network in Lithuania comprises the territory at 54°10' and 56°20' North latitude and 21°48' and 26°33' East longitude. In most stations observations have been carried out for more than 30 years.

In the period from 1961–2006, pheno-correspondents performed phenological observations of the beginning of flowering of *Malus domestica* Borkh. (variety of 'Paprastasis antaninis') in 20 stations situated in different regions of Lithuania, where phenological observations have been performed for more than 20 years (in 4 localities, the period of observation – 20–30 years; in 9 localities – 30–40 years; in 7 localities – more than 40 years). L. Kulienė and J. Tomkus divided the territory of Lithuania into phenoclimatic regions which differ from each other in seasonal rhythm, air temperature and precipitation (Kulienė et al., 1990). Data of phenological observations from three phenoclimatic regions of Lithuania were chosen for exhaustive analysis. The phenoclimatic regions and stations of Lithuania are as follows (Fig. 1):

1. The Region of the West Žemaičiai Plain and the Central Lithuanian Plain: Veisėjai, Seirijai, Varėna, Akademija, Lukšiai, Lekėčiai, Jūrava, Keturvalakiai, Kazlų Rūda, Šilutė;

2. The Region of the Žemaičiai Upland: Ariogala, Kruopiai, Radviliškis, Kelmė, Joniškėlis, Grūžiai, Papilė;

3. The Aukštaičiai Region: Širvintos, Trakų Vokė, Dūkštas.

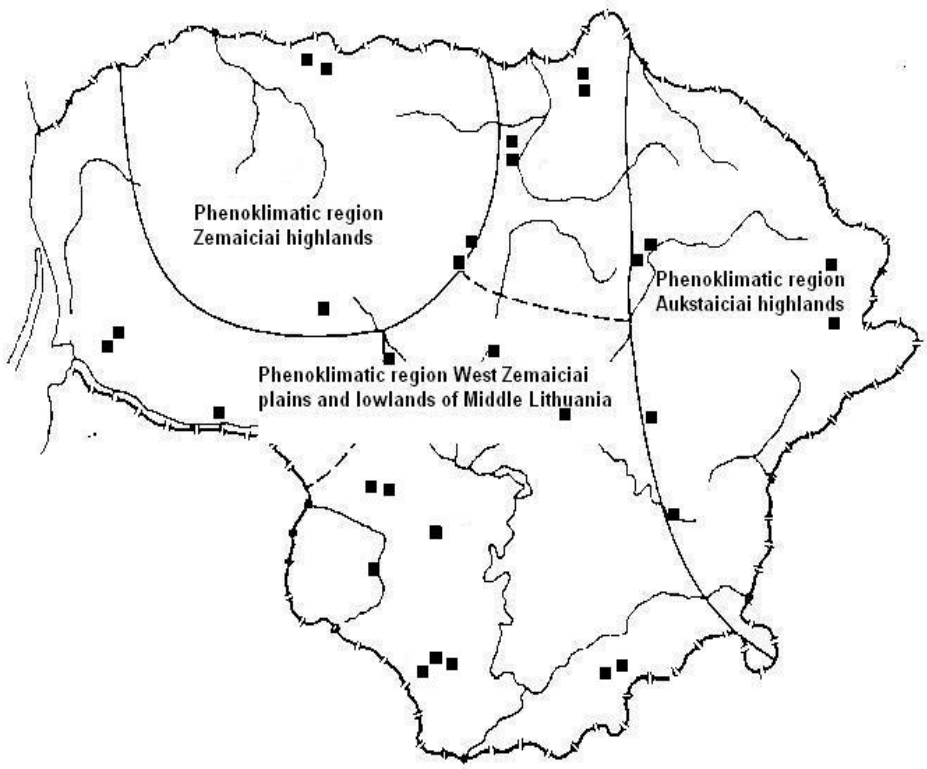

Fig.1. Phenological network and phenoclimatic regions of Lithuania.

During the research, phenological observations were carried out applying the methods for phenological supervision elaborated by Nacevičius (1975). Phenological observations were conducted in each district of Lithuania on a typical local relief, soil and vegetation on a 3–4 km diameter area. Observations were carried out every day in spring. The beginning of a phenophase is recorded when the plant development stage reaches 25% of flowers (Baronienė, et al., 2005).

Climatic data (monthly temperature) for the years 1961-2006 were obtained from the Lithuanian Hydrometeorological Service using the data of 10 meteorology stations selected closest to the nearest phenological stations.

The data was statistically processed: average date, standard error (Sx) and mean square deviation (±S) were calculated. Statistical dependence of the date of phenophase occurrence in the investigated plants upon the air temperature was determined applying the methods of correlation and regression (Dospechov, 1973).

RESULTS AND DISCUSSION

Alternation of phenophases in the course of a year proceeds consistently, rhythmically, but their dates differ every year. Changes in climatic conditions have the strongest impact upon the annual seasonal dynamics of perennial plants, especially at the beginning of their vegetation (Menzel, 2000; Wiegolaski, 1999). Perennial plants react towards the changes of abiotic factors by divergence of the development phases from the normal limits. Currently wild and cultural plants tend to start flowering earlier. From 1961–85, apple trees in the southern part of Lithuania did not start flowering until 20 May (Kulienė et al., 1990). Presently, due to climate warming, apple trees in Lithuania start flowering earlier – on May 10–17 on average (Table 1). In the southern part of the country and closer to the Baltic Sea (according to phenoclimatic regions the Region of the West Žemaičiai Plain and the Central Lithuanian Plain), the apple trees start flowering earlier than in other regions of Lithuania.

Table 1. Average long-term dates of the beginning of apple-tree flowering in Lithuania 1961–2006 m. average date

Station	Coordinate	Average date	Standard error (Sx) ±	Mean square deviation (S) ±	Coefficient of variation (V) %
Veisėjai	54°10'N 23°70'E	05.13	4	7.3	5.5
Varėna	54°25'N 24°55'E	05.11	3	4.2	3.2
Seirijai	54°23'N 23°82'E	05.15	3	6.0	4.5
Keturvalakiai	54°55'N 23°15'E	05.13	3	7.1	5.3
Trakų Vokė	54°63'N 25°10'E	05.17	3	7.3	5.4
Kazlų Rūda	54°77'N 23°50'E	05.15	4	7.4	5.5
Lukšiai	54°95'N 23°18'E	05.16	4	6.6	4.9
Lekėčiai	54°97'N 23°50'E	05.17	5	8.0	5.8
Akademija	54°40'N 23°87'E	05.15	4	7.8	5.8
Širvintos	54°05'N 24°95'E	05.17	5	8.5	6.2
Jūrava	55°12'N 22°31'E	05.14	5	8.1	6.1
Šilutė	55°35'N 21°48'E	05.14	4	7.5	5.6
Kruopiai	55°18'N 23°90'E	05.10	5	7.1	5.4
Ariogala	55°27'N 23°47'E	05.16	3	7.5	5.5
Dūkštas	55°53'N 26°33'E	05.16	4	7.1	5.3
Radviliškis	55°48'N 23°15'E	05.16	3	7.4	5.4
Kelmė	55°63'N 22°93'E	05.17	3	7.3	5.4
Joniškėlis	56°03'N 24°17'E	05.16	3	7.4	5.5
Grūžiai	56°11'N 24°16'E	05.16	3	7.1	5.3
Papilė	56°15'N 22°80'E	05.17	4	7.8	5.7

According to variation of hydrothermal conditions, the territory of Lithuania is divided into three phenoclimatic regions. The Region of the West Žemaičiai Plain and the Central Lithuanian Plain is the largest; its plain relief is favourable for warm air advection from southwest, south and southeast. In this phenoclimatic region spring

starts 0–3 days earlier compared with the average of many years for the whole of Lithuania. In the Žemaičiai Upland and Aukštaičiai Regions the upland areas are rather large and the absolute pitch has significant influence upon seasonal development of plants; therefore the phenophases start later there (Kulienė et al., 1990).

The impact of the thermal regime upon annual changes of the beginning dates of apple tree flowering is highly significant. Due to climate warming during the last decade, i.e. since 2001, apple trees in Lithuania have started flowering 8 days earlier on average than in 1961–80 (Fig. 2). Furthermore, negative anomalies from the longtime average dates of the beginning of apple tree flowering were more frequent during the period of 1981–2006 and exceeded 10 days in 1989, 1990, 1993, 2000 and 2002. Similar results were obtained while investigating phenological regularities of other plant species both in Lithuania and other countries.

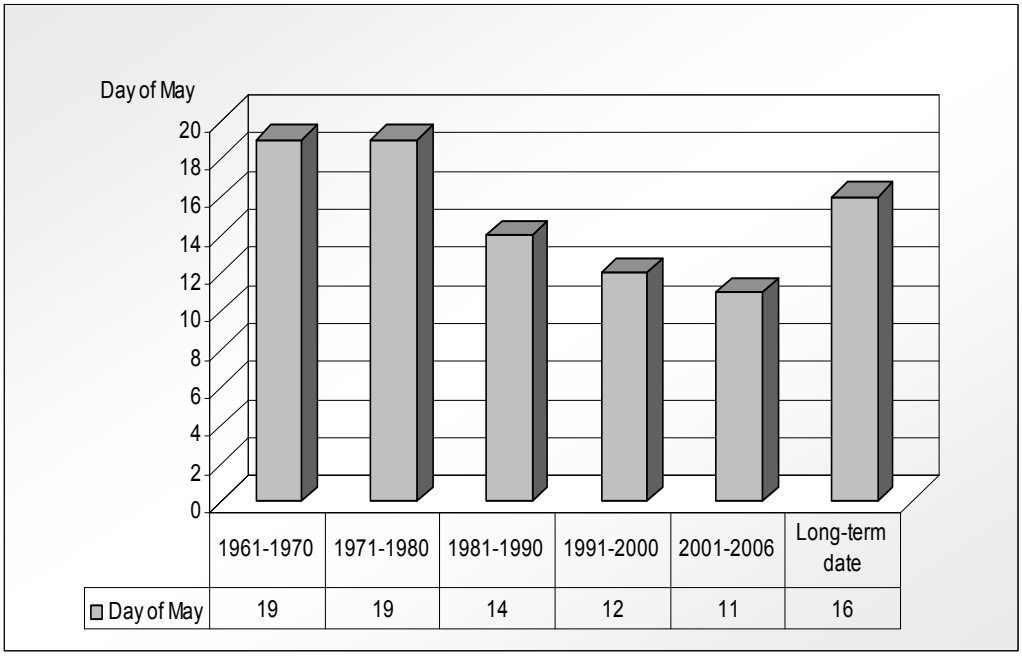

Fig. 2. Average date of beginning of flowering of apple trees in Lithuania during the different periods. 1961–2006 average date.

The research performed in Lithuania revealed that larger variation in the dates of the occurrence of phenophases is characteristic of plants that flower early in spring. For example, deviations from the average dates of the beginning of flowering of European hazel in 1989 and 1990 occurred on 40–45 days (Baronienė et al., 2005). European hazel, which is an indicator of early spring in Lithuania, also starts flowering earlier near the Baltic Sea and in the southern part of the country than in other parts of the country (Romanovskaja, 2003). Although apple trees start flowering much later, during true spring, the same regularities in the occurrence of phenophases regarding the territory are determined. The occurrence of phenophases of most plants is related to changes in air temperature. Under the influence of climate warming in Western Europe and in the whole Baltic Sea region, phenological phenomena of early spring, such as

the beginning of European hazel flowering, starts 0.3–0.4 days earlier every year, and the later flowering plants (e.g. apple trees, lilacs), 0.1–0.3 days earlier (Ahas et al., 2002). It has been determined that in Lithuania the date of the beginning of European hazel flowering depends upon the mean temperature during February and March (r = - 0.76 – (-0.84)) (Romanovskaja et al., 2007). According to research results obtained in Germany, leaf unfolding and flowering of various plants in spring and summer depend upon the temperature of the previous month (R^2 between 0.65 and 0.85) (Menzel, 2003). These statements encouraged us to investigate and evaluate the impact of the mean monthly temperature of winter and spring months upon the flowering of orchards in different localities of Lithuania. Analysis of statistical data reveals only weak correlation between the dates of the beginning of apple tree flowering and mean daily temperatures of January and February in many localities (r < -0.5). The impact of air temperature beginning in March upon the beginning of apple tree flowering is more evident. The correlation coefficient between the dates of the beginning of apple tree flowering and mean monthly temperature in March was r = - 0.37 – (-0.59), in April – r = -0.48 – (-0.80) (Table 2). Therefore, the beginning of apple tree flowering is predetermined by the thermal regime of spring (March and April); depending upon the temperature changes during these months, the beginning of flowering date can also change. The research results confirm the presumption that the time of the apple tree flowering is predetermined not so much by temperatures of the previous winter but of the previous spring (Kulienė, 1983). Since 1987 the average monthly temperature of April has frequently exceeded the standard temperature in Lithuania (Fig. 3).

Table 2. Correlation between dates of beginning of flowering of *Malus domestica* (y) and average temperature of April (x).

Station	Number of correlation pair	r	Equation of regression
Veisėjai	31	-0.57**	y = -2.7283x + 149.54
Varėna	25	-0.50*	y = -2.0127x + 142.85
Seirijai	31	-0.59**	y = -2.8737x + 152.46
Keturvalakiai	40	-0.69**	y = -3.268x + 154.92
Trakų Vokė	46	-0.70**	y = -3.0556x + 155.37
Kazlų Rūda	46	-0.70**	y = -3.5618x + 159.08
Lukšiai	23	-0.61**	y = -3.5159x + 157.28
Lekėčiai	33	-0.69**	y = -4.4588x + 165.15
Akademija	46	-0.60**	y = -2.9166x + 153.35
Širvintos	35	-0.52**	y = -2.4786x + 152.71
Jūrava	29	-0.66**	y = -3.2356x + 156.69
Šilutė	38	-0.80**	y = -3.7948x + 158.09
Kruopiai	21	-0.48*	y = -2.0204x + 142.89
Ariogala	46	-0.65**	y = -3.3923x + 155.64
Dūkštas	33	-0.71**	y = -3.1657x + 153.55
Radviliškis	40	-0.67**	y = -3.2668x + 155.36
Kelmė	43	-0.66**	y = -3.2925x + 156.24
Joniškėlis	46	-0.66**	y = -3.1323x + 154.66
Grūžiai	46	-0.65**	y = -2.8012x + 152.71
Papilė	38	-0.63**	y = -3.047x + 153.17

- - correlation significant at 95% probability level

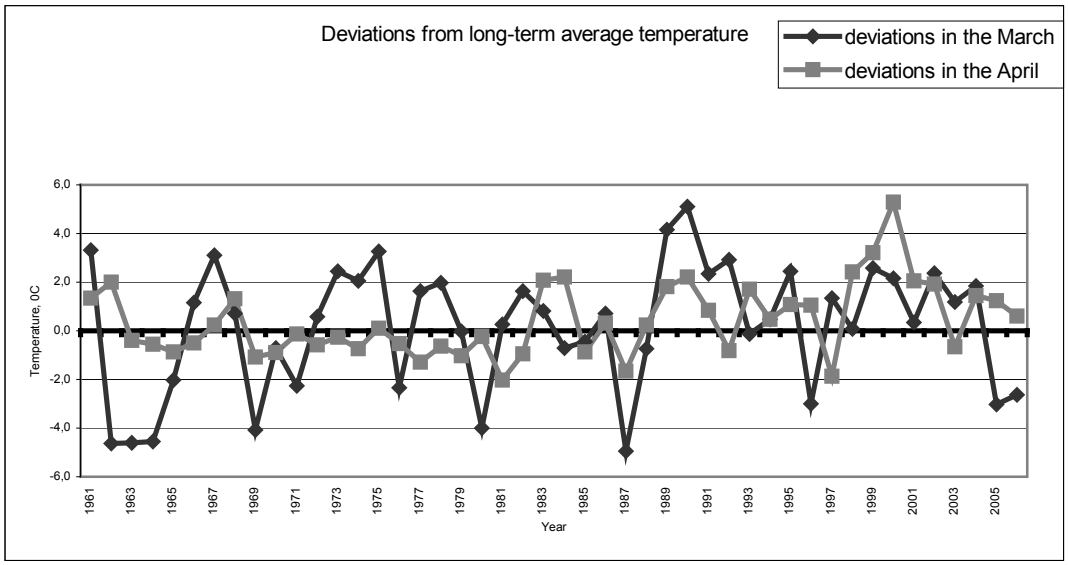

Fig. 3. Deviations from long-term average temperature in March and April 1961-2006 in 10 meteorological stations of Lithuania

April 2000 was extremely warm, with average monthly temperature 5.3°C higher than the long-term norm. Considering variable weather in March, from 2000 the average monthly temperature showed lower positive and higher negative deviations from long-term temperature compared to April. The average annual air temperature is 6.2°C in Lithuania (Galvonaitė et al., 2007). However, due to climatic warming, it rose by 0.8°C from 1991–2003. Meteorological data revealed an increased average air temperature in almost all months (except October, November and December) in Lithuania (Table 3). Higher temperature alterations were observed in January, February, March and April. Namely the thermal regime in these months triggers the beginning of flowering of the majority of plants. The phenological investigations revealed that during the last decade in Lithuania the apple trees started flowering averagely 4–5 days earlier than the longtime mean values (May 16). It is quite possible that with further climate warming the apple trees might start flowering even earlier.

For gardeners it is particularly important to know the date of the beginning of orchard flowering in advance. Forecasting of the majority of phenological phenomena is related to changing weather, but the dates of the beginning of phytoindicators' phenophases are also frequently employed in forecasting (Kulienė, 1983; Kulienė, et al., 1990; Shnelle, 1961; Shulc, 1981). Wild plants have been chosen as the indicators in forecasting the beginning of fruit-tree flowering. It has been determined that the dates of the beginning of flowering of all fruit-tree species strongly correlate with the dates of the beginning of leaf-unfolding of birch (*Betula pendula* Roth.) (R^2 = 0.61 to 0.91); those of the beginning of pear tree (*Pyrus communis* L.) and apple tree (*Malus domestica* Borkh.) flowering correlate with the date of the beginning of leaf-unfolding of beech (*Fagus sylvatica* L.) (R^2 = 0.62 to 0.66) (Bergant et al., 2003).

In our investigations, for forecasting the dates of the beginning of apple tree flowering, the dates of the beginning of European hazel (*Corylus avellana* L.) and European bird cherry (*Padus avium* Mill.) flowering were chosen. The correlation between the dates of the beginning of apple tree and European hazel flowering was most often weak and statistically significant, but not in all localities (Table 4). The length of time between the phenophases of these plants is rather long – 51 days; therefore European hazel is not the most suitable indicator in forecasting the date for the beginning of apple tree flowering. These investigations show that another indicator, i.e. the beginning of European bird cherry flowering, is more suitable for such forecasting. The period between the beginning of flowering of European bird cherry and apple trees is 8 days on average. Statistical data show strong statistical correlation between the phenophases of these plants, significant at 99 % significance level.

When flower-buds of fruit trees open, plant pests spread particularly actively (Kulienė et al., 1990). Precise forecasting of the date of the beginning of apple tree flowering allows successful application of plant protection measures that significantly reduce the losses caused by plant diseases and pests.

Table 3. The alterations of the average temperature in Lithuania during 1961-2003. (Galvonaite et al., 2007)

Month												Average
01	02	03	04	05	06	07	08	09	10	11	12	of year
Period of 1961-1990												
-5.1	-4.6	-0.7	5.4	11.9	15.4	16.7	16.2	11.9	7.2	2.0	-2.4	6.2
Period of 1991-2003												
-2.2	-2.3	0.7	7.1	12.3	15.5	18.2	17.3	12.1	6.7	1.4	-2.6	7.0

Table 4. Statistical dependence of phenological spring of plants indicators and started dates of flowering *Malus domestica*

1961–2000 date

Station	Coefficients of correlation		
	Between flowering of *Corylus avellana* and *Padus avium*	Between flowering of *Corylus avellana* and *Malus domestica*	Between flowering of *Padus avium* and *Malus domestica*
Šilutė	0.64**	0.63**	0.88**
Dotnuva	0.53**	0.17	0.55**
Lazdijai	0.48**	0.53**	0.77**
Akmenė	0.53**	0.38*	0.62**
Kelmė	0.58**	0.40*	0.85**
Ukmergė	0.49**	0.31	0.83**
Trakų Vokė	0.66**	0.59**	0.85**

* - correlation significant at 95% probability level

** - correlation significant at 99% probability level

CONCLUSIONS

1. In various localities of Lithuania apple trees of autumnal varieties start flowering on May 11–17 (± 3–5 days). The regularities of the beginning of apple tree flowering in different localities do not differ from phenological regularities of other spring-flowering plants, i.e. apple trees start flowering earliest in the southern part of Lithuania and at the seaside.

2. The average date of the beginning of apple tree flowering in Lithuania is May 16. Due to climate warming during the last decade apple trees in Lithuania start flowering 4–5 days earlier than the longtime average.

3. The thermal regime of April significantly influences annual changes in the dates of the beginning of apple tree flowering, i.e. the correlation coefficient between the mean monthly air temperature and dates of the beginning of apple trees flowering is r = -0.48 – (-0.80).

4. The date of the beginning of flowering of European bird cherry (*Padus avium* Mill.), the indicator of true spring, is suitable for forecasting the date of the beginning of apple tree flowering Strong dependence was revealed between the dates of the beginning of flowering of apple trees and European bird cherry – correlation coefficient from 0.55 to 0.88.

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