LATE SPRING FROSTS AND THEIR IMPACT TO AGRICULTURE IN BULGARIA

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Abstract

The losses of agricultural production in Bulgaria, as a result of climatic anomalies and unfavorable weather conditions during the years since the beginning of the 21st century, are significant and are growing continuously. The dates of the last spring and first autumn frosts limit the potential growing season. Damage from late spring frosts is a major limiting factor for the production of agricultural products. In the last 40 years, studies on the regime and risk of occurrence of late spring and early autumn frosts with data on a sufficient number of observation points have not been done.

The aim of the study is to assess the risk of late spring frosts in the agricultural lands of Bulgaria.

The phenomenon of frost is observed in the NIMH meteorological network. Agricultural crops are affected by frost during the potential growing season. We selected the cases of frost appearance after the permanent transition of air temperatures above 10°C for 50 stations from the territory of Bulgaria. The study period is 1991-2022.

The results of this study will be useful in assessing the agroclimatic resources of a given region and planning agricultural production, especially for some spring crops and orchards.

Keywords: *late spring frost, potential growing season, length of frost-free season*

1. INTRODUCTION

Frost is a type of rain and it is an ice crystals formed by water vapor in the atmosphere at negative air temperature values. From an agrometeorological point of view, the appearance of frost is related to adverse impact of the plants and damage agriculture production. This phenomenon is the one of the most important extreme events for the temperate latitude, especially for the country from the South Eastern Europe (S. Malinovic-Milicevic et all, 2018; Papagiannaki, K et all., 2014; Micu, D et all., 2018). Mean frost dates are the additional constraint on the potential vegetation season and this is the climatological characteristic of the regions.

The most dangerous are the late spring and first autumn frosts. First of all, the spring frosts affect orchards during the initial phenological stages – buds swelling and burst, and flowering at the stone fruit trees, such as apricot, peach, and cherry. Second, frost is dangerous for the vegetable production. As a result, late spring frosts damage or significantly reduce the yields of the mentioned fruits species. The tendencies to increase the air temperature in winter (Georgieva V., V. Kazandjiev 2022) turn the frosts into the main limiting factor for the cultivation of fruit plants (Bozhkova R., D. Ivanova, 2001; Nesheva M., R. Bozhkova, 2021). In 15 of the first 22 years of this century, frost damage was observed on the territory of the country in the months of March and April mainly on the stone orchards of apricots, cherries and peaches, and during later frost (April, May) and on seed-grain trees – apples and pears. Since 2015, in every subsequent year frosts if very high intensity and huge losses have been recorded. In the Plovdiv region in 2018, at a temperature of -2°C, damage from 94 to 98% of frosted flowers was reported, and in 2019 from 68 to 100% damage to young buds at a temperature of -5°C, (Bozhkova R., ? Ivanova, 2001; Nesheva M., R. Bozhkova, 2021). That is why the prevention is of great importance for the successful cultivation of sensitive species, especially for stone orchards.

Frosts also cause serious damage to spring crops such as maize, millet, sorghum, potatoes and tobacco. Soybean is moderately resistant to late spring frosts. Resistant to spring frosts are spring vetch, chickpea, broad bean and sunflower, which can survive temperature drops to minus 5-6°C.

The appearance of frost depends from the meteorological conditions, especially when they are formed during strong cooling of the surface boundary layer as a result of clear and cold nights. Frost also depends from the orography. Probability of frost appearance is higher at the foot of mountain slopes and in high fields. Cold air is heavy, which is why it flows down and occupies the negative relief forms - valleys, hollows, etc. Very important for frost damages are their characteristics – duration and intensity. The state of plant development - the phenological phases is also important for damages. In the process of studying the cherry in the region of Plovdiv Malchev at all., 2020 found that the most sensitive to spring frosts are those in the bud bursting stage. The significance of the duration of the impact of sub-zero temperatures on the fruit buds, as well as the temperature values and the location of the flower buds, is also determined.

The first study on the regime of late spring and early autumn frosts in Bulgaria, in connection with the development of agricultural crops, was made by Lingova, 1955. The work were analyzed data about 100 stations for the period 1931-1950 and it was found that for most of the country the last spring frosts occur in May 20 - 23. A dependence between altitude and the average date of frost occurrence, as well as the probability of occurrence of frosts after certain, critical for agriculture dates, was also obtained. The duration of the frost-free period has been determined, which for almost the entire country is 120-140 days, decreasing with increasing altitude. The average number of days with frost in April and September was also determined, for the territories with an altitude above 600 m in April, frosts were reported on 4-6 days.

Bozhkov, 1962, considered the synoptic conditions during the formation of frosts and found empirical dependences for their prediction. This study of the regime of late spring and early autumn frosts in our country was made based on data for the period 1931-1960 from 54 stations. The average and final date of occurrence of the late spring and early autumn frosts, as well as the frost-free period, have been determined.

The average date of appearance of late spring frosts, varying for different stations from the end of March to the first ten days of April was determined Nikolova et al, 2020 with data from 8 stations during the period 1989-2018. The last frost was observed earlier along the Black Sea and in the most southwestern part of Bulgaria. The frost-free period is shortest in the most northwestern part of Bulgaria and the longest along the Black Sea and the southwestern part of the country.

From the review of the studies of the regime and the risk of the occurrence of late spring and early autumn frosts, it can be seen that those with data for a sufficient number of observation points have not been done in the last 40 years.

The aim of the study is to assess the risk of late spring frosts in the agricultural lands of Bulgaria under contemporary climate.

2. MATERIALS AND METHODS

2.1. Study area

The study area includes the agricultural lands in Bulgaria, extending over a territory with an attitude up to 800 m. For research we use the data from frost records in 52 meteorological stations which spatial distribution is shown on fig. 1. The arable lands on Bulgaria are located in two climatic zones – European-continental and Continental-Mediterranean (Sabev and Stanev, 1959).

According to research presented in the book - The Climate of Bulgaria, with authors St. Stanev, M. Kyuchukova, St. Lingova, 1991 found that the probability of temperatures falling below minus 3ºC in April divides the country into 5 regions according to the degree of frost danger. At these temperature values, when the vegetation of all plants is in progress, the probability of damage to agricultural crops and perennials is 100%, and the amount of damage depends on the duration of retention and impact of this negative temperature. The least frost-hazardous area covers the Black Sea area, the lands along the Danube River and the southernmost part of the Struma River catchment. The probability of observing a decrease in temperature below -3ºC is P=5% or once every 20 years. Low frost-hazardous risk areas

cover the fields of Northern Bulgaria and the Pre-Balkan area up to 400 m above sea level, without the valley fields. In these areas, the probability of a decrease in temperature below -3ºC is P=20% or once in every 5 years. The frost-danger zone extends in the northeastern part of the Danube plain, mainly in the region of Dobrudzha. Here, the probability that the temperature will drop to and below -3ºC is P=40% or once every 2-3 years. The very frost-dangerous area covers the high plain fields and the regions with an altitude of 1000-1200 m. In these areas, the probability of a late spring frost is P=40-90% or from once every 2-3 years to 9 out of 10 years. The most frost-dangerous zone is that above 1200 m above sea level when every year in April the temperature drops to and below -3ºC.

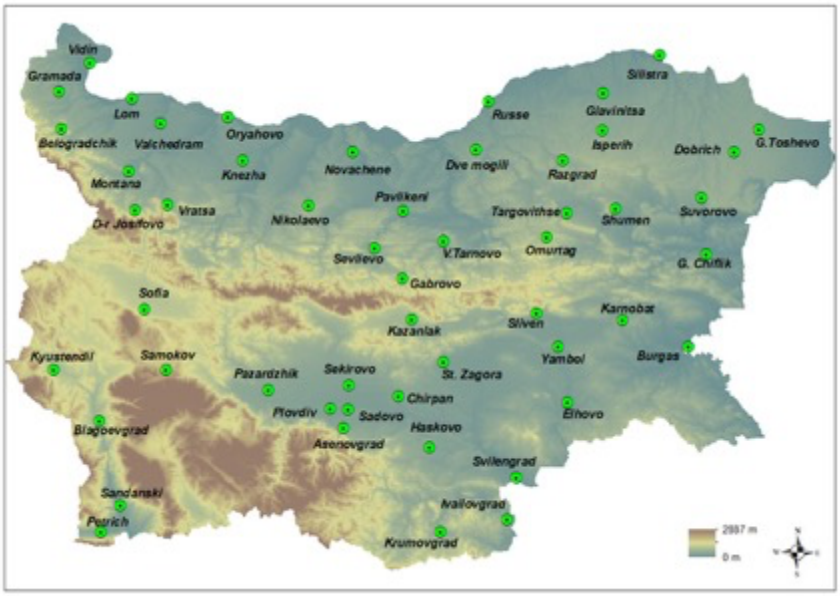

Figure 1. Spatial distribution of the stations used in investigation.

2.2. Materials

The period of investigation is 1991-2022. A data from 65 meteorological stations are used to determine the date of permanent transition of air temperature above 10ºC. The average date for the vegetation season when all plants are in active vegetation was determined. We selected the dates of the registration frost after these dates and made the investigation with these rows.

The most vulnerable from frosts are the orchards. The dates of initial phenological stages are very important to hazard assessment. The phenological data are from 17 agrometeorological stations for representative for economical regions.

Table 1. Dates of occurrence of the main phenological stages for the stone orchards

Stations	Apricot			Stations	Cherry		
	Buds swelling	Buds burst	Flowering		Buds swelling	Bud burst	Flowering
Silistra	6.03	19.03	5.04	Razgrad	19.03	25.03	10.04
Isperih	14.03	22.03	3.04	Ruse	19.03	31.03	12.04
Oryahovo	12.03	20.03	31.03	G. Toshevo	24.03	3.04	20.04
Pyce	16.03	24.03	6.04	Targovishte	16.03	22.03	11.04

Targovishte	14.03	21.03	5.04	Chirpan	13.03	20.03	11.04
Plovdiv	3.03	14.03	29.03	Plovdiv	4.03	19.03	8.04
Kyustendil	11.03	22.03	6.04	Sadovo	3.03	18.03	5.04
Petrich	7.03	14.03	27.03	Yambol	11.03	23.03	9.04
Burgas	12.03	18.03	27.03	Kyustendil	15.03	26.03	17.04
Suvorovo	8.03	19.03	7.04	Blagoevgrad	20.03	31.03	10.04
Shabla	13.03	24.03	7.04				
	Peach						
Razgrad	19.03	28.03	10.04				
Dobrich	19.03	28.03	19.04				
Targovishte	17.03	23.03	8.04				
Yambol	13.03	22.03	7.04				
Petrich	4.03	13.03	26.03				
Sandanski	24.02	10.03	31.03				
Suvorovo	13.03	25.03	9.04				

2.3. Methods

The number of cases and the average number of cases of last spring frost (LSF), first fall frost (FFF) and the length of the frost-free period (LFP) was determined. Probabilistic statistics are used to estimate the frost regime. The date with a probability of 50%, 90% and the end date in spring and the first date of the registered autumn frost was used as an indicator for determining the regime of frosts. A comparison was made between the mean and final frost dates during the study period and the period 1931-1960 (Sabev, S. et al., 1963) for stations for which data were available for both periods.

3. RESULTS

Frost is a complex phenomenon. The occurrence of frost depends on several factors - physical-meteorological, climatological-geographic and biological. The degree of damage depends on the duration of holding critical temperatures, on the intensity of the frost and on the phase in which its impact is observed. In the present study, we investigate the frost occurrence from the perspective of the risk of damage to crop plants. Under our climatic conditions, the most vulnerable to damages from frost are the fruit crops and especially the early flowering stone species - almond, apricot, peach, cherry and sour cherry. Of the field crops, the mid-early and late crops are the most vulnerable - sunflower, beet, carrots, pumpkin, soybeans, corn, potatoes, beans, cotton, rice, watermelons, melons etc. All vegetable crops are also sensitive to the spring and early autumn frosts.

The dates of the last spring and first autumn frost limit period of potential vegetative season with varying degrees. The potential growing season is connected with the permanent increase in average daily air temperature above 10°C, when all crop plants, except for heat-loving ones, are in active vegetation. Therefore, it should be emphasized that the probabilistic estimates in the study were made on data series with frost events after the permanent transition of air temperature above 10°C. For different regions of the country, this transition take place within a month. It occurs earliest in the northern Danube regions, south-central Bulgaria and the southernmost regions until 20th March. In most of the country, air temperatures during the last ten days of March permanently rise higher than 10°C. At the latest, during

the first ten days of April, this happens in the far north-eastern regions and the region of Sofia and Pernik and part of the Pre-Balkan, fig. 2.

The results of the study include the occurrence of frost after the date of permanent of air temperature transition above 10oC for each station. The number of these cases during the spring, fig. 3a is different because the frosts are mostly local events. More than hundred are the cases in the plain regions, because the permanent transition of air temperature is earlier in the spring. The average numbers of days of spring frost varies between one and seven, fig.3b. The number of the stations with one to two and from three to six average days ate relatively similar about 36-44%. There is no dependence in the distribution of the stations with similar average days of the spring frost.

The number of cases with autumn frosts, fig. 4a are more than these in the spring, and the date of permanent transition of the average daily air temperature below 10°C is shifted in late autumn. Some vegetables still have uncollected harvest. The average numbers of the autumn frost days varies from one to six (fig.4b.). Stations with frost of 1-2 days are 20% and the rest stations have an average number of days with frost 3-6.

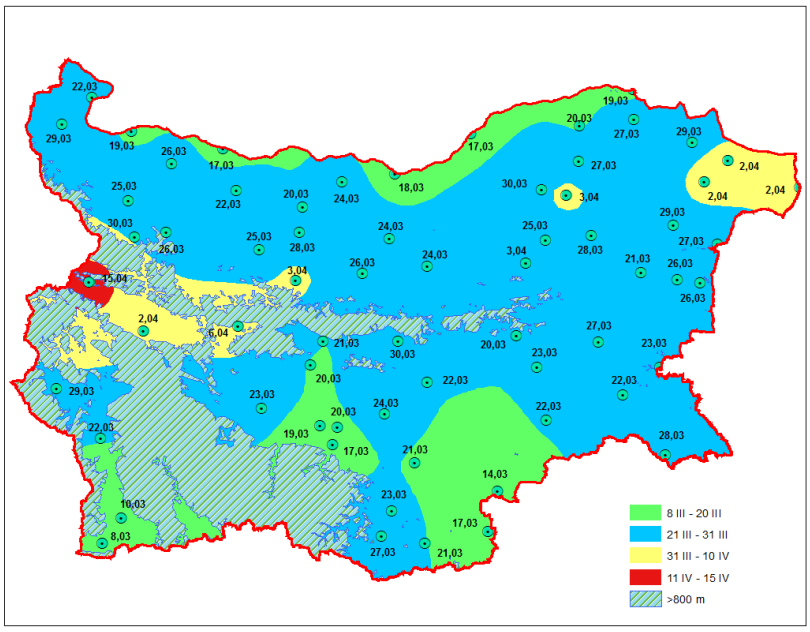

Figure 2. Average dates of the permanent transition of air temperature above 10°C.

a) b)

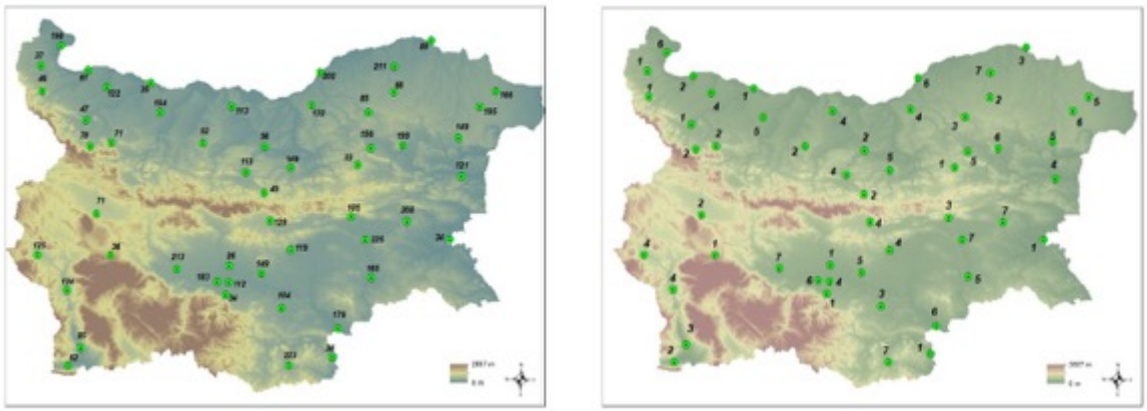

Figure 3. Number of frost cases during the spring (a), and average number of frost cases during the spring (b) after transition of the temperature above10°C.

a) b)

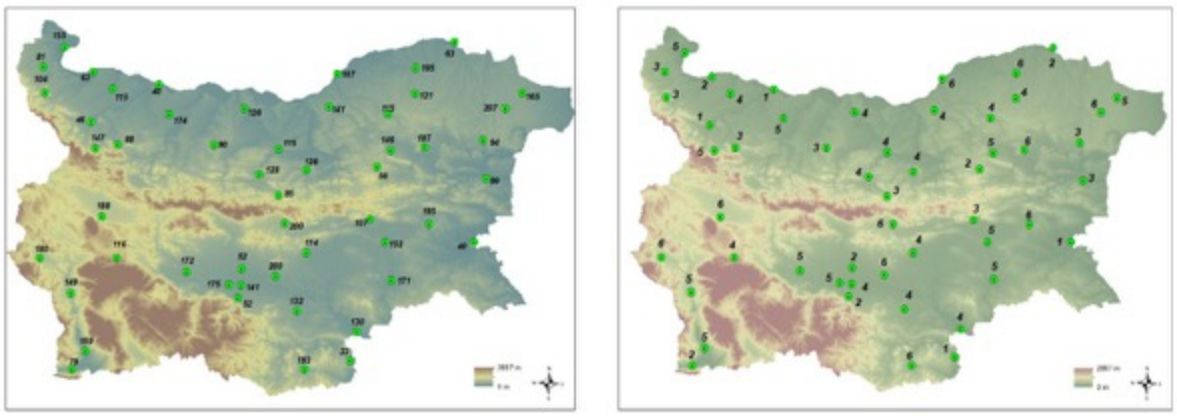

Figure 4. Number of frost cases during the autumn (a), and average number of days with frost during the autumn (b) after transition of the temperature below10ºC

The earliest date of frost is in the southernmost part of the country, Petrich – 16.03 and latest date is in Dupnitsa – 18 April. The most common average date of spring frost is during the first ten days of April – fig. 5. In the last ten days of March are the average dates in the most south regions, some stations in Thracian Valley, Burgas and some stations around Danube River. According to the date of occurrence of sensitive phenological stages - buds burst and flowering - Table 1, the development of stone fruit trees in some regions are in risk. The bud burst of stone fruits trees occurs at the sensibility from frost period. Apricot trees are most sensitive to late spring frosts. Usually, flowering in Thracian Valley and Kyustendil coincides with the frost period. Compared to the results of the last frost survey, shown in the Agro climatic Atlas of Bulgaria, 1982 the areas with an average date of frost from 20 March to 5 April are increased and cover the whole Northern Bulgaria, except the easternmost parts, and in Southern Bulgaria, except the high fields on the western part of the country.

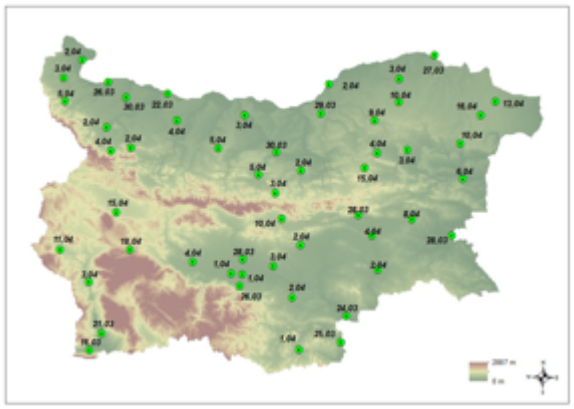

Figure 5. Average dates of spring frost occurrence.

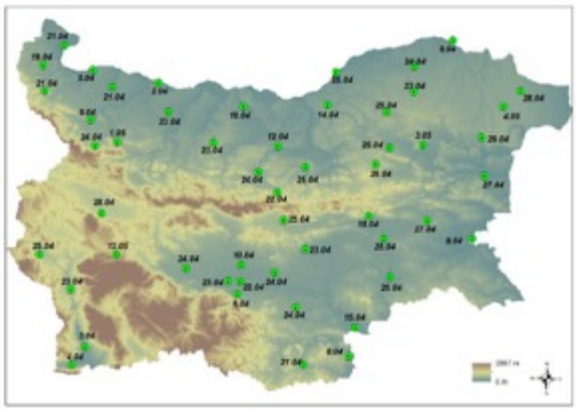

Figure 6. Dates of frost occurrence with probability one per 10 years.

The third ten days of April is the date of spring frost with a probability of once in ten years for most of the country, fig.6. During the first ten days of April, there were frost only in the western part of the country, along the Danube River and in the most Southern regions, includes the region of Burgas. In the central part of the Danube Plain and in the central part of the Thracian Valley, the frost is occurring

during the second ten days. The latest date of spring frost is in the first ten days of May in the Pre-Balkan and in the second ten days of May in Dupnitsa.

The latest spring frost dates is at the wide diapason (Fig.7.).The earliest dates are during the first two ten days of April in the region of the western reaches of the Danube River, Montana, Asenovgrad, and Burgas. During the third ten days of April the spring frost is the latest date in the Central Northern Bulgaria and part of Western Bulgaria - Sofia, D-r Josifovo, and Hissar in Southern Bulgaria. The first ten days of May is the period of occurrence of the late spring frost in the region of North Eastern Bulgaria, except for Black Sea region and Thracian Valley. During the second ten days of May spring frost is observed in the Black Sea region, and in the third ten days of May on the high fields of Western Bulgaria and Elhovo and Krumovgrad. A comparison was made of the late spring frosts dates in the period 1931-1960 (Sabev S., et all., 1963) and the contemporary period 1961-2020. This was done for some stations where the data for both periods are available. The results confirm the tendencies reported by Menzel et al., (2003) for Germany. They noted that the dates of the last spring frosts over the period 1951-2000 shifted by 0.24 d/yr-1. The results obtained for average dates from our investigation show similar tendencies. We found that mean spring frost dates occurred on average 8 days earlier and ranged from 2 to 19 days. According to the latest data, the comparison shows that in 62% of the stations, spring frosts are occur later than the previous period. These results show the increase in extreme nature and rising risk for agriculture.

The average dates of the FFF, fig. 8 are the last decade of the October and first of November. The earlier FFF is in Northern Bulgaria, except for the stations along the Danube River and some stations in the Thracian Valley. In the southern part of the country, FFF is in the first decade of November.

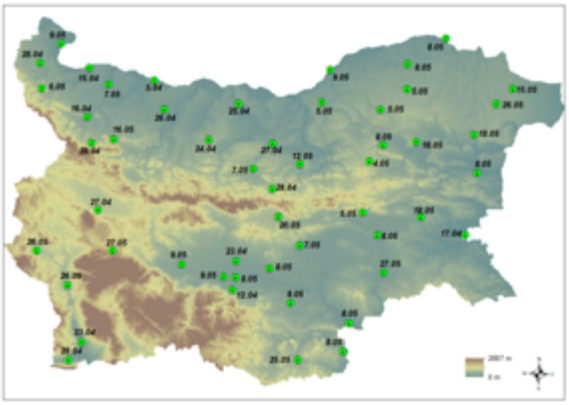

Figure 7. Dates of last spring frost occurrence.

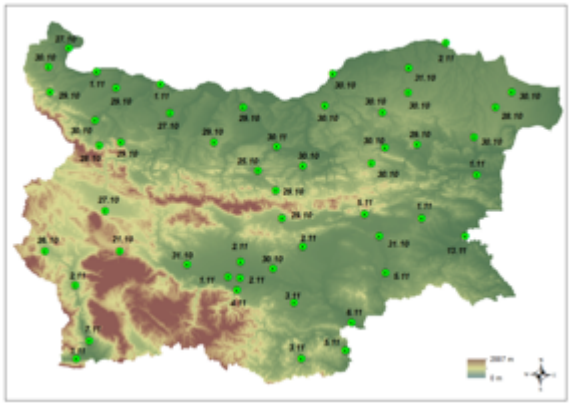

Figure 8. Average dates of autumn frost occurrence.

The most dangerous for agriculture are the early autumn frosts. In the central northern and northeastern part of the country, the earlier appearance of autumn frost is in the third ten days of September. The earliest FFF (first frost fall) is during the first and second ten days in Vidin, the North-Eastern part, and the high fields of West Bulgaria. The first ten days of October is the date of the onset of the early frost in the rest part of the country, fig. 9.

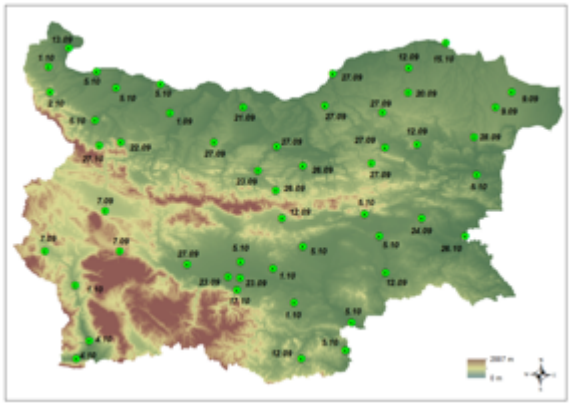

Figure 9. The earlier date of fist fall of frost (FFF) occurrence in the autumn

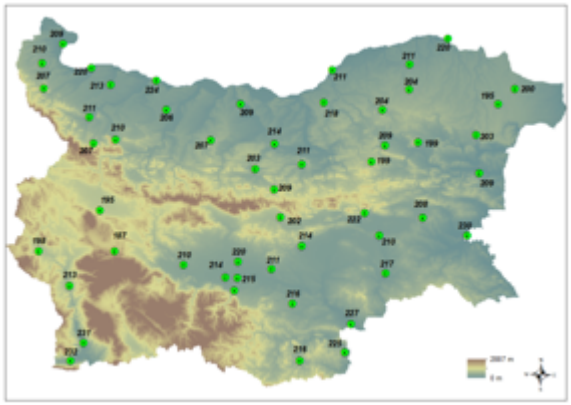

Figure 10. Average duration of the frost free period (FFP).

The duration of the frost-free period is one of the main climate and agro climatic indices for characterizing conditions in arable lands. The mean duration of the FFP varies from 187 to 232 days, fig.10. The areas with the longest FFP are Southwestern Bulgaria and those with the shortest period are the high fields.

4. DISCUSSION

As a result of our research for the period 1991-2022, data were obtained on the average, earliest and latest dates for the occurrence of late spring and early autumn frosts in the area of 52 meteorological stations of the NIMH network and located in the agricultural area of the country. We are established that the dangers to agricultural production from these phenomena are rising. As we already noted the latest dates of spring frost are occurring later in comparison with previous period. Given the raising of the air temperature during the winter and earlier start of vegetation season, the period with risk are increase. The period from frost dates with probability 9 per 10 years to the latest frost date for more than 50% from the stations those period is over 40 days and reached 66 days. The proportionally shorter is the period from average to the latest frost dates. For 70% from the stations it is more than 30 days and reaches to 56 days. This is the active vegetation season when the plants are in different stages from their development. For orchards those period cover the main phenological stages, for spring crops this is the period of germination and leaf formation. This is additional restrict for vegetation period.

In this way, the influence of climate change on the occurrence and dynamics of late spring and early autumn frosts is revealed. And frost is a phenomenon that causes damage, sometimes large and irreversible, to agricultural production - mainly to fruit trees and some cereals in the spring and mainly to vegetable production in the fall.

5. CONCLUSIONS

In conclusion, we would like to highlight a few findings:

- As a result of climate changes, there is a warming of the seasons and years, especially since 1999. This clearly outlines an increasingly earlier transition of average daily temperatures above 5 and 10°C in spring and a later transition below these values in autumn. This also determines the duration of the vegetation period, which increases over the years;
- The extended growing season for the agricultural crops does not have a positive effect, as they are vulnerable to late spring or early autumn frosts during the one to two months;

- The number of spring frosts during the studied period is in the range of 34-213. The average number of dangerous frosts for agricultural crops and orchards is up to 7;
- The number of autumn frosts during the studied period is in the range of 33-207. The average number of frosts dangerous for agricultural crops and orchards is up to 6;
- The average date for the onset of late spring frosts is from 26.03 to 16.04;
- The date for the onset of late spring frosts with a probability once per 10 years are observed from 04.04 to 04.05;
- The last spring frost in different regions of the country is observed in the period from 05.04 - 26.05;
- The earliest date of the first autumn frost in autumn is from 07.09 to 26.10;
- The duration of the frost-free period during the studied period is from 195 to 232 days.

These features of agro-climatic conditions must be considered and accounted for in the agro-climatic distribution of crops depending on the vulnerability to late spring or early autumn frosts.

They should also be taken into account by breeders when creating new varieties and hybrids of agricultural plants in order to improve their resistance to frost.

ACKNOWLEDGMENTS

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REFERENCES

1. Malinovic-Milicevic, S, G. Stanojevic, M. M. Radovanovic, 2018, "Recent changes in first and last frost dates and frost-free period in Serbia", *Geografiska Annaler: Series A, Physical Geography*, 100:1, 44-58, DOI: 10.1080/04353676.2017.1369048
2. Papagiannaki, K., Lagouvardos, K., Kotroni, V., Papagiannakis, G., 2014, "Agricultural losses related to frost events: use of the 850 hPa level temperature as an explanatory variable of the damage cost", *Nat. Hazards Earth Syst. Sci*., 14, 2375–2386, https://doi.org/10.5194/nhess-14-2375-2014.
3. Micu, D., Dragotă, CS, Havriş, LE 2018, "Climatic Parameters of Seasonal Air and Ground Frost in the Romanian Plain Region", *Aerul şi Apa: Componente ale Mediului*, 69-76. 10.24193/AWC2018_09.
4. Georgieva, V.; Kazandjiev, V.; Bozhanova, V.; Mihova, G.; Ivanova, D.; Todorovska, E.; Uhr, Z.; Ilchovska, M.; Sotirov, D.; Malasheva, P.", 2022, "Climatic Changes-Challenge for the Bulgarian Farmers".*Agriculture*, *12*, 2090. https://doi.org/10.3390/agriculture12122090
5. Bozhkova, V., Ivanova, D., 2001, "Damage to some plums and mirobalan plum cultivars from the late spring frost in 2001", *Journal of mountain agriculture on the Balkans,* 4(1), 70 -77.
6. Nesheva, M., Bozhkova, V., 2021, "Spring frost damages of plum and apricot cultivars grown in the region of Plovdiv, Bulgaria", *Sci. Pap. Ser. B Horticulture*. 65(1), 194-197.
7. Malchev, S., S Savchovska, "Vulnerability of sweet cherry cultivars to continuous periods of spring frosts in Plovdiv, Bulgaria", *Agricultural Science and Technology* 12 (4), 348-352.
8. Lingova S., 1955, "Under regime of the frosts in Bulgaria", *Papers of IHM*, t.IV, 177-196 (in Bulgarian).
9. Bozhkov, R., 1962, "Synoptic conditions for dangerous cooling down during the spring and autumn and methods for their prediction", *Papers of IHM*, t. XIII, 111-139 (in Bulgarian).

10. Nikolova, N., S. Matev, G. Rachev, D. Ivanova, 2020, "Characteristics of First and Last Frost Occurrences and the Length of Frost-free Season in Bulgaria", *Journal of environmental protection and ecology*, 22(1):85-94.
11. Sabev S., L. Stanev, 1959, "The Climatic regions of Bulgaria and their climate", *Papers of IHM*, vol.V, Sofia, Nauka I Izikustvo, p.174 (In Bulgarian)
12. St.Stanev, M. Kyuchukova, St. Lingova, 1991. The Climate of Bulgaria, Edition of BAS, ,
13. Sabev L., S. Stanev, S. Lingova, 1963, Under regime of the late spring and earlier autumn frosts in Bulgaria. Papers of IHM, vol. XV, 45-112.
14. KIPP of mapping, Main office hydrology and meteorology, 1982. "Agroclimatic atlas of Bulgaria", 117 p., Sofia