The probability of late freezes after the air temperature exceeds 10°C in the territory of the Republic of Moldova

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ABSTRACT: The agricultural sector has a major social and economic importance for the Republic of Moldova. The aim of the study is to analyze the probability of the occurrence of late frosts on the territory of the Republic of Moldova for the period of 2005-2020, a period in which, from a synoptic point of view, the most obvious effects of climate change were observed on the territory of the Republic of Moldova. Knowing the probability and risk of occurrence of these hazardous climate phenomena is important because it helps farmers decide what, when and where to plant to achieve the maximum possible crop yields. The study aims to map these dangerous manifestations throughout the territory of the Republic of Moldova. Meteorological data regarding the date of the last frost in the air were collected and selected from the archive under the State Hydrometeorological Service. Also, the factual material, regarding the date of the stable passing of the air above 10°C, were calculated in the Climatology and Environmental Risks laboratory of the Institute of Ecology and Geography. The main effort was to analyze temporally and spatially the occurrence of frosts that occurred after the stable passage of air above 10°C. As a result, maps representing the spatial distribution of these frosts were modeled. The temporal distribution was represented in the form of tables. The obtained results will be able to be extended for analysis on physical-geographical regions and territorial administrative units. The spatial and temporal trends in freeze warnings may be of interest to any number of scientists with applied climatological interests.

KEY WORDS: spring frosts, intensity frost, ontogenetic phase.

1. Introduction

Frost is an extreme meteorological phenomenon, quite difficult to manage, due to its random nature of manifestation. It has a negative influence on agricultural crops by disrupting their normal phenological development and as a result, a significant financial impact for the economy of countries where agriculture holds an important place.

Knowing the information regarding the period and where there is a risk of frosts in the spring when the air temperature has passed 10°C is particularly important for all those who practice agriculture, horticulture and many others.

A frost, which manifests itself in late spring, can damage or even kill plants in the first phenological phases of development.

Observations and phenological research carried out on perennial plants by researchers Cannell and Smith (1986) and Hänninen (1991), Colombo (1998) have shown that climate warming has favored early bud break in many trees, thus making them more vulnerable to late frosts of spring.

Unquestionable is the effect that air temperature has on vegetation. Consequently, thermal variations (inter-annual fluctuations, day-to-day variability, temperature extremes) impact the agricultural potential of a given area (Żmudzka 2004).

According to the WMO (https://library.wmo.int/), crossing the thermal threshold of 0°C, which also means the beginning of the warm period (spring), implies the activation of the biological processes of plants and continues with the crossing of the thresholds above 5°C the beginning of vegetation, above 10°C - active vegetation, the period when it takes place the formation of the elements of productivity, and "hot" (over 15°C) early summer. We would like to mention that in the interval between these two thresholds (5°C and 10°C) most of the time the positive minimum temperature (or biological zero) is also established for the formation of the rudiments of productivity, for example in the apple the formation of the floral bud. In the specialized literature, the term climatological vegetation season is also used (Frich et al., 2002). At the same time, agricultural crops due to the particularities induced by the variety, hybrid behave differently at low positive temperatures +3 - -4°C and frosts. In particular, the degree of frost exposure for agricultural plants differs both from plant to plant and from variety to variety and depends on the moment of manifestation or the ontogenetic phase, its intensity and duration and last but not least on the agricultural technological conditions applied (Miscenco, 2009). It is generally believed that inter-individual variability in spring is mainly due to genetic differences between individuals. For example, the total temperature requirement for birch bud burst differs between genotypes (Possen et al., 2014).

Resulting from the fact that in the temperate-continental regions the manifestation of dangerous frosts occurs even more than a month after the average daily temperature is passed well above 10°C, including in the territory of the Republic of Moldova, the vegetation being in an active period of development, we set out to develop and present a climatological information base on the probability of occurrence of dangerous frosts that occur during this period. To achieve this goal, we proposed the following objectives:

- identification of the stable date of passage through 10°C;
- identification of the average date of occurrence of late frosts;
- assessment of frost intensity;
- calculation of the number of days with frost of a certain intensity;
- establishing the critical period of frost manifestation well beyond the 10°C cut-off date;
- completion and analysis of information bases.

2. Study area

The study area includes the entire territory of the Republic of Moldova, located on the South-Eastern area of Central Europe, near the geographic center of the continent. It borders Romania to

the West, and Ukraine to the North, East and South (fig. 1). The Republic of Moldova has a generally favorable physical-geographic position of the territory (location in the south-western extremity of the Eastern European Plain, near the Carpathian Mountains - relief units that exert a considerable influence on the natural framework of the territory; location in the Sea basin Black, which has a certain impact on nature).

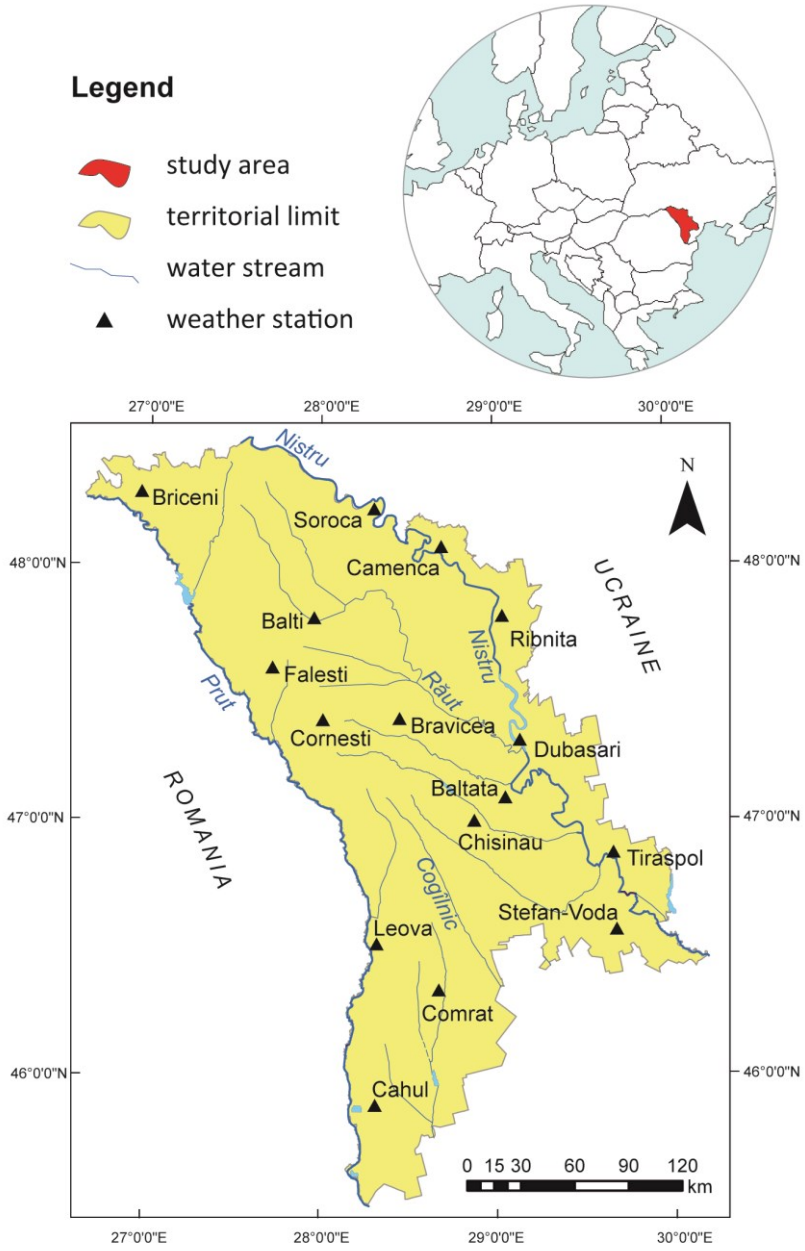

Figure 1 Delimitation of the study area and the location of meteorological stations in the studied area.

For the given study, chronological series of meteorological data recorded at sixteen weather stations were used, being representative given the geographical and climatic position of the weather stations in the area of interest.

3. Methods

This paper characterizes temporal and spatial changes of frosts in the Republic of Moldova from 2005–2020 years. This time series was used to calculate the date and average intensity of the last frost. From the 18 weather stations subordinated to the State Hydrometeorological Service (SHS), 16 weather stations were selected, which have a homogeneous data string, and without a lack of data for some non-climatic reasons.

The analysis was limited to late spring, defined as March, April, and May. A freeze event was defined as a minimum temperature below 0°C.

According to the Technical Regulations of the WMO, to evaluate the climatic parameters and their changes, either standard climatological norms (30-year periods) or average values over a period longer than 10 years are used. For the given study, we analyzed a period of 15 years, a homogeneous period of data, which has not been subjected to such an analysis before, and which allowed us to draw valid conclusions (https://library.wmo.int/).

The results were obtained based on the storage and processing of data strings in the Excel software. The data regarding the date of passing over 10°C were calculated according to the WMO methodology, within the Climatology and Environmental Risks laboratory of the Institute of Ecology and Geography (https://library.wmo.int/).

The geo-informational support for the simultaneous use of several standard programs allows the highlighting of the regional particularities of the manifestation of dangerous frosts, which to a large extent could contribute essentially to their effective use, given that dangerous frosts with a significant harmful impact on crops are characteristic of the Republic Moldova.

The statistical analysis with the establishment of the dependence of the occurrence and termination of frosts after the stable transition of the air temperature to 10°C was carried out in the Statgraphic software. With the help of this software, regression models were obtained that reflect the connection between certain indices of the frost regime (average date of occurrence and intensity) with geographical factors - longitude, latitude, absolute altitude of the place. The obtained regression equations allowed the calculation of the value of frost indices in the points of the regular network.

Cartographic analysis and modeling involved working with ArcGIS 10.8 software for cartographic modeling, indispensable components of GIS.

From the multitude of information obtained, in the formed tables, we have selected and entered only the most representative data.

4. Results and discussion

The degree of danger of dangerous frosts on agricultural crops depends on its intensity, but even under the conditions of a lower intensity, the impact of the frosts that occurred remains as high due to the number of days and the number of cases when agricultural crops were exposed to temperatures below 0°C.

About the particularities of the manifestation of the last frost after the stable passage of air through 10°C, in the spring, the data presented in (table 1) tell us, where the minimum date of manifestation, the maximum date of manifestation, the duration of frosts and their intensity, as well as the number of cases of frosts that they took place after the stable passage of the air temperature above 10°C in the spring.

Table 1 Manifestation of late frost phenomenon when the temperature exceeds 10°C occurs stable for five consecutive days (2005 - 2020), Northern region of Republic of Moldova.

Station	Date when the temperature exceeds 10°C (spring)	Maximum date (year)	Intensity (°C)	Duration (days)	Duration (cases)
Briceni	25.04	-	-	1	1
	04.04	-	-	1	1
	31.03	27.04 (2016)	-1.2	2	2
Bălți	14.04	24.04 (2005)	-0.2	2	1
	24.04	-	-	1	1
	04.04	27.04 (2009)	-0.0	9	5
	04.04	26.04 (2010)	-0.4	4	4
	24.04	-	-	1	1
	03.04	11.04 (2012)	-4.0	2	1
	30.03	-	-	1	1
	16.04	21.04 (2020)	-2.0	2	2
Camenca	13.04	-	-	1	1
	24.04	-	-	1	1
	04.04	26.04 (2009)	-0.0	3	2
	03.04	11.04 (2012)	-1.9	2	1
	17.04	-	-	1	1
	26.04	-	-	1	1
	08.04	15.04 (2020)	-1.2	2	2
Fălești	03.04	-	-	1	1
	08.04	-	-	1	1
Rîbnița	04.04	26.04 (2009)	-0.3	9	6
	04.04	27.04 (2010)	-0.1	3	3
	24.04	-	-	1	1
	03.04	-	-	1	1
	17.04	-	-	1	1
	31.03	-	-	1	1
	22.04	-	-	1	1
	16.04	-		4	3
Soroca	04.04	28.04 (2009)	-0.0	5	4
	17.04	-	-	1	1
	30.03	03.04 (2016)	-1.2	2	2
	26.04	-	-	1	1
	08.04	15.04 (2020)	-0.2	2	2

*The last frost occurred until the average air temperature was stable above 10°C.

Thus, for the northern region, during the period under analysis, the date of passing through 10°C, spring occurs predominantly in April, while frosts with an average intensity of -1.2°C were also recorded after this date, which means that the manifestation corresponds to an active period of vegetation development and respectively has a negative impact on the yield per hectare. The maximum intensity for the study period was -4.0°C and coincided with April 11 in 2012 at the Bălți weather station, which was much higher than the period of passing over 10°C, which was calculated on April 3.

The maximum duration was 9 days with frost, also recorded at the Balti weather station in 2009, during which the vegetation was exposed to temperatures lower than 0°C, and if we superimpose the value of the intensity, the table of damages that - produced these agricultural frosts in 2009, in the northern part of the country.

Table 2 Manifestation of late frost phenomenon when the temperature exceeds 10°C occurs stable (2005 - 2020), Central region.

Station	Date when the temperature exceeds 10°C (spring)	Maximum date (year)	Intensity (°C)	Duration (days)	Duration (cases)
	10.04	-	-	1	1
	18.04	03.05 (2006)	-0.5	3	1
	07.04	26.04 (2008)	-0.3	2	1
	04.04	27.04 (2009)	-0.0	8	5
Bălțata	01.04	27.04 (2010)	-1.3	4	4
	18.04	24.04 (2011)	-0.9	3	2
	03.04	11.04 (2012)	-4.8	3	2
	30.03	-	-	1	1
	22.04	-	-	1	1
	08.04	21.04 (2020)	-0.1	4	3
Cornești	13.04	-	-	1	1
	03.04	11.04 (2012)	-1.7	2	1
	04.04	-	-	1	1
Dubăsari	04.04	-	-	1	1
	03.04	-	-	1	1
	30.03	-	-	1	1
Bravicea	05.04	-	-	1	1
	31.03	-	-	1	1
	23.04	-	-	1	1
	04.04	26.04 (2009)	-0.2	4	3
	20.03	23.04 (2010)	-1.3	4	4
	19.04	-	-	1	1
	03.04	11.04 (2012)	-3.0	2	1
	17.04	-	-	1	1
	30.03	-	-	1	1
	13.04	-	-	1	1

*The last frost occurred until the average air temperature was stable above 10°C.

The manifestation of dangerous frosts for the central region of the country, during the analyzed period, shows us the following aspects: unlike the northern part of the Republic, in this region, the date of crossing over 10°C slightly moves towards March. The earliest this was calculated for March 20 in 2010, at the Bravicea weather station. Thus, the manifestation of the last frost, recorded on April 23 of the same year, with a duration of 4 days and an intensity between -1.2°C and -1.3°C, indicates a major negative impact for agricultural crops, which were surprised during the period of active vegetation. The year 2009 also stands out, when 8 days with temperatures lower than 0°C were recorded at Bălțata weather station.

In the southern part of the Republic, also the date of passing over 10°C in spring takes place predominantly in April. However, here too the frosts that occur late in the spring surprise the agricultural crops in the period of active vegetation. Here we can mention 2020, when at the Ceadîr Lunga weather station, the last frost was recorded on April 21 (about 13 days later than the date when the air temperature stably exceeded 10°C), with the intensity between -1.5 and -2.0 °C, and its duration was 3 consecutive days. Also, in the southern part of the republic, the year 2009 is the year in which in Tiraspol weather station the late spring frost was recorded for 4 consecutive days.

Table 3 Manifestation of late frost phenomenon when the temperature exceeds 10°C occurs stable (2005 - 2020), Southern region.

Station	Date when the temperature exceeds 10°C (spring)	Maximum date (year)	Intensity (°C)	Duration (days)	Duration (cases)
Leova	03.04	-	-	1	1
Ștefan	10.04	-	-	1	1
Vodă	04.04	23.04 (2009)	-0.5	2	1
	31.03	-	-	1	1
Tiraspol	09.04	-	-	1	1
	04.04	24.04 (2009)	-2.9	4	2
	02.04	27.04 (2010)	-1.7	5	5
	19.04	24.04 (2011)	-0.0	3	2
	31.03	-	-	1	1
	21.04	23.04 (2019)	-1.7	2	1
	08.04	22.04 (2020)	-0.1	3	3
Comrat	10.04	-	-	1	1
	30.03	-	-	1	1
	03.04	-	-	1	1
Ceadîr	10.04	-	-	1	1
Lunga	02.04	-	-	1	1
	08.04	-	-	1	1
	30.03	-	-	1	1
	08.04	21.04 (2020)	-2.0	3	3

* The last frost occurred until the average air temperature was stable above 10°C.

From the analysis of the data we obtained through their statistical processing, on average, the last frosts on most of the territory of the Republic of Moldova end at the same time or 1-5 days before the air temperature exceeds 10° C in the spring period. But, in some regions of the republic such as the regions with depressional relief such as the Ialpug Depression, the interfluves, the region of

the Central Moldavian Plateau, which is explained by the atmospheric activity (the penetration of air masses), also the altitude (over 400m), late frosts can also be observed after a constant transition of the daily air temperature above 10°C during the growing season of heat-loving crops (table 1 – 3, fig. 2,3).

Thus, for the analyzed period, the manifestation of the last frost was observed even after 25 days (Comrat weather station in 2009) after the stable passage of the air temperature above 10°C (tab.3). This frost had a duration of one day and an intensity of -1.8°C, and the number of cases varies between one case and 6 cases with a total of days between 1 and 9 days.

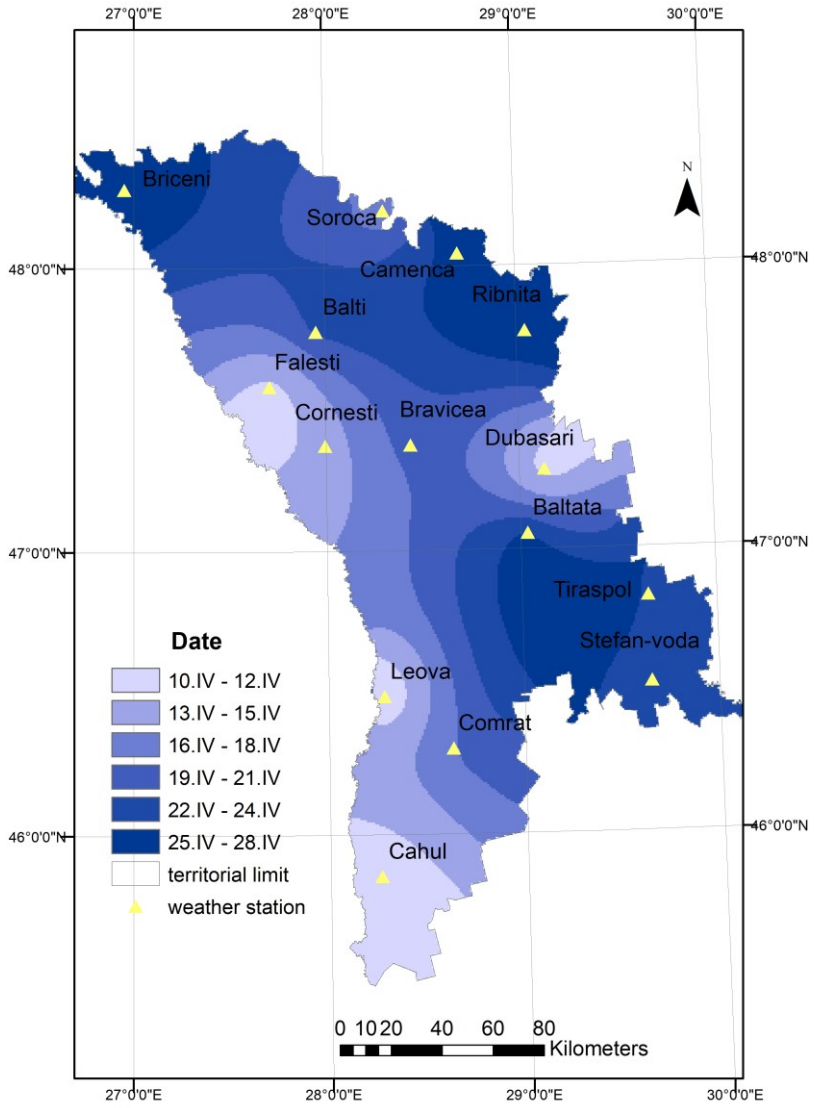

Figure 2 Date of manifestation of the last frost after the stable trend passes of mean diurnal temperature passes the mark of 10°C with increasing trend.

The most cases of frost were recorded in Râbnița municipality - 6 cases, in total 9 days with frost, the maximum intensity -0.3°C. In the municipality of Balti, 5 cases, in total 9 days, and the air

temperature dropped to -1.5°C. Likewise, 5 cases were registered in the Bălțata municipality with a total of 8 days and an intensity of -0.6°C.

The highest intensity of -4.8°C was registered at Bălțata weather station (2012) with 2 cases of frost and a total of 3 days; Bălți weather station (2012), the intensity of -4°C.

The analysis of the correlation between the indices of late frosts with latitude, geographic longitude and absolute altitude shows us that the multiple correlation coefficient between these geographical parameters and the date of installation of frosts in the spring, their intensity, represents r = 0.62 and r = 0.60, respectively.

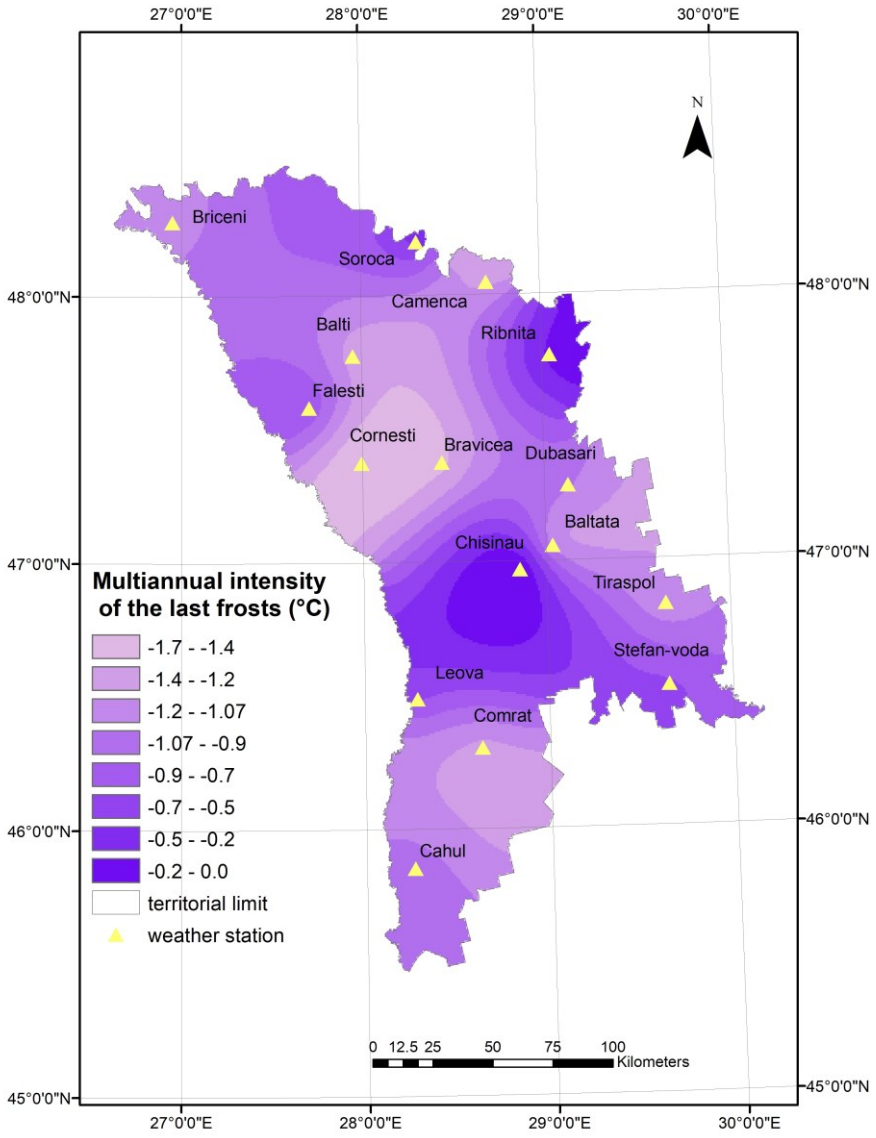

Figure 3 The intensity of the last frost after the stable passing of the average daytime temperature above 10°C.

Atmospheric circulation plays an important role in the spatial variation of air temperature (e.g. Ustrnul et al. 2010), which in turn has a large impact on numerous environmental processes. Thus, examining the spatial distribution of the date of occurrence of frosts (fig. 2) and respectively of their intensity (fig. 3) that occurred after the stable passage of the temperature above 10°C, in the spring, we can observe the increasing influence of meridional advections of cold air masses from Scandinavia.

These results are consistent with other studies conducted in the same region (Constantinov et al., 2006; Nedealcov, 2010) and come to complement and update them, but also for Romania (Bogdan, 1999; Mărculeţ et al., 2010), and on the European continent (Ustrnul et al., 2014). Globally, there is also a growing interest in studying this phenomenon. A large number of researches on the same problem are carried out on the American continent (Norby et al., 2003; Hufkens et al., 2012).

5. Conclusion

The obtained results add more updated information regarding the spatialization of frosts that occur after the stable passage of the air temperature above 10°C, in the spring for the period 2005 - 2020.

In 2009, the most days with frost were recorded throughout the territory of the republic.

The obtained results support the general trend regarding the warming of the climate by advancing towards the warm period of the year

The above-mentioned results are of both theoretical and practical interest to both farmers and researchers in several fields, and serve as a scientific basis for the development of systems for the correct territorial placement of various agricultural crops, especially thermophilic ones. This would contribute to increased agricultural productivity as well as the longevity of perennial plantations.

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