TENDINȚELE PROBABILITĂȚII DE DĂUNARE PRIN ÎNGHEȚURI TÂRZII LA VIȘIN ÎN ULTIMII 25 DE ANI ÎN ROMÂNIA

TRENDS OF SOUR CHERRY LATE FROST DAMAGE PROBABILITY IN THE LAST 25 YEARS IN ROMANIA

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Abstract

A patented warning method for late-frost damage in orchards based on phenoclimatic simulation was used to analyze the late-frost damage probability (LFDP) trends for sour cherry in Romania for the decades of 2013-2022 and 2000-2009. Areas with the lowest LFDP were identified in the south, and southeast, as well as in narrow north-eastern and western sectors (p≤16%, i.e. damage may occur less than once every seven years). Above 30% LFDP was found in the west (Lipovei Hills), the north of the Western Plain and Transylvanian Depression, the south of Western Carpathians, Getic and Curburii Sub-Carpathians, and especially in areas located in the south-eastern part of the Transylvanian Depression, with an LFDP>40% (damage more frequently than once every 2.5 years). Compared to the decade 2000-2009, no changes in LFDP were observed in the Getic Plateau, the west of the Romanian plain, and southeast of the Dobrogea Plateau. Areas with the most unfavorable evolution were located in the eastern part of the Transylvanian Depression (where LFDP increased by 10-12%) and the east of the Moldavian Plateau (LFDP of 9-10%). The study warns of the danger represented by the increase of the frequency and intensity of the damages caused by the late frosts under the conditions of the climatic changes of the last 25 years.

Cuvinte cheie: accidente climatice, soiul 'Crișana', umflare muguri, dezmugurire, începutul înfloririi, sfârșitul înfloririi
Key words: climatic accidents, 'Crisana' cultivar, bud swelling, budburst, beginning of flowering, end of flowering

1. Introduction

Sour cherry (*Prunus cerasus* L.) is a fruit species grown mainly in temperate continental climates, in eastern and central Europe, Asia (SE), and the United States (NE) (Schuster et al., 2026), valorized primarily by processing (Stan et al., 2024; Sokół-Łętowska et al., 2020; Milošević and Milošević, 2020; Corneanu et al., 2021). Through the long shelf life, quality, and diversity of the derived products (Ropelewskaet al., 2023; Kotliar et al., 2025), sour cherry contributes significantly to the sustainable use of fruit resources.

The growers' interest in sour cherries places Romania in 14th place in the world in terms of cultivated area (2,570 ha) and in 12th place in terms of production (29,000 t). In addition, the investments in modern sour cherry orchards ensured Romania's 5th place worldwide with a productivity of 112,724 hg/ha (FAO, 2022). Although the main fruit species grown in Romania is plum (Butac, 2021; Butac et al., 2022), according to INS data (2014–2024), the sweet-sour cherry group ranks fourth in surface and third in production in Romanian fruit growing, confirming the species' constant economic importance. The annual fluctuations of sour cherry fruit production and quality reported by previous studies (Chivu et al., 2018; Marin, 2024; Mihut et al., 2024; FAO, 2025; INS 2014-2024) are caused by the interaction between genetic factors, orchard technology, and environmental conditions, especially during critical periods of plant organ development. Among them, climatic factors exert a complex and more pronounced effect on growth and fruiting than genetic or technological ones (Paltineanu and Chitu, 2006; Chitu and Paltineanu, 2006).

Climate warming, produced in particular by increasing daytime temperatures, has led to an advance in spring phenological stages (Fu et al., 2016; Meng et al., 2020; Mo et al., 2023; Tao et al., 2021; Kim et al., 2024), a trend also observed in South-Eastern Europe in the main fruit tree species (Chmielewski et al., 2004; Vogel, 2022). According to IPCC climate scenarios (2023) and EEA analyze (2024), an increase in average annual temperature of 1.5–2.4ºC is anticipated until 2050, which could

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explain further phenological advances reported in South-East Europe. Moreover, climate models project additional advances of 12–23 days in the period 2050–2085 for species such as plum, apple, and pear, depending on the climate scenario and region (Menzel et al., 2020; Coppola et al., 2021; Sugiura, 2025). In South-Eastern Europe, including Romania, these trends are confirmed by multi-year observations and phenoclimatic models, which warn of the increased sensitivity of early fruit species to temperature variations in March and April (Paltineanu & Chitu, 2006; Chitu and Paltineanu, 2006; Chitu et al., 2011; Bandoc et al., 2022).Several studies (Chitu and Paltineanu, 2020; Zhong et al., 2023; Daramola et al., 2024; Liu et al., 2024) have shown that, although maximum temperatures continue to rise, nighttime minimum temperatures during March and April have increased at a noticeably slower rate. These conditions led to warm spells followed by temperature drops below the critical thresholds for fruiting organs (Chitu et al., 2011; Lamichhane, 2021; Drepper et al., 2022). This thermal asymmetry explains why late frost events may become more frequent and more destructive, even in a general context of climate warming (EEA, 2024; FAO, 2023).

The agroclimatic models applied in the last decade also confirm in Romania an increase in the risk of late frost, especially in the low hilly and plain areas of the south and east (Paltineanu and Chitu, 2006; Mazilu et al., 2025). Since fruit tree species are perennial and the life span of an orchard is 15-20 years, the identification and mapping of areas with high risk of late frost, together with detailed phenological and climatic monitoring, become indispensable tools for the adaptive management of fruit orchards and for maintaining the stability of cherry production in the conditions of current climate changes.

2. Material and methods

The dynamic of minimum and maximum air temperatures in February, March, and April, in 10 years, during 2000-2009 and 2013-2022 periods (ºC) was analyzed. The floral organs damage probability for 'Crișana' sour cherry cultivar was calculated in four phenological intervals delimited by the phenophases Code 51 BBCH, 53 BBCH, 61 BBCH, 69 BBCH and 71 BBCH Monograph, using OSIM patent no. RO127444/30.11.2010 - "System and method for warning about the effects of late frosts in orchard through pheno-climatic simulation". For this purpose, a database of phenological observations of 57 years (1969-2025) was used to study the dynamics of the first four spring phenophases, i.e. bud swelling, budburst, beginning of flowering, and end of flowering for sour cherry (*Prunus cerasus* L.) 'Crisana' cv. in Maracineni, Arges County, Romania. Based on these data, the probability of each phenophase occurring was calculated. The entire method was presented in another papers (Chitu and Paltineanu, 2006; Chitu et al., 2008 and 2011). The occurrence date of the first phenological phases of the generative organs, i.e. bud swelling (51 BBCH), budburst (53 BBCH), flowering onset (61 BBCH), and end of flowering (69 BBCH) was presented during the 2000-2009 and 2013-2022 period (ºC).

Critical temperatures used for sour cherry generative organs were considered according to Murray (2011): -3.3ºC for bud swelling – budburst, -2.2ºC for budburst -flowering onset, -2.2ºC for flowering onset-end of flowering, and -1.5 for the end of flowering-young fruit interval. Mean, maximum, and minimum daily temperatures between February 1st and May 31st for the 2000-2022 period were used to calculate the probability of critical temperatures for sour cherry generative organs in the four phenophases. The phenophases' probability and critical temperatures' probability for sour cherry floral organs were compared between 2013 and 2022 for Maracineni, Arges County.

It was established that floral organs can be damaged only when the phenophase and critical temperature for this phenophase occur simultaneously. To calculate the damage probability for sour cherry floral organs, the protocol previously described by Chitu and Paltineanu (2006) and Chitu et al. (2011) was followed. The dynamics of the floral organs damage probability, as a consequence of the late frosts, for 'Crișana' sour cherry cultivar during 2000-2009 and during 2013-2022 decade were compared in Maracineni, Argeș for each decade in the February-May interval. To expand results to the entire Romanian territory, data from the other 28 weather stations have been used.

3. Results and discussion

An analysis of the maximum temperatures' evolution in February, March, and April, carried out for 28 localities in Romania in the periods 2000-2009 and 2013-2022 (Fig. 1-3), highlighted the warming of February, covering the entire territory, of at least 0.9ºC per decade. A more pronounced warming was observed in the west, north-west, and central areas of the country, where a maximum temperature increase of 1.5ºC and 2.0ºC per decade occurred. The weakest increase in maximum temperatures, of 0.9-1.3ºC per decade, was mainly concentrated in three small areas placed in the west of the Romanian Plain, Getic Plateau and Getic Sub-Carpathians, the northwest of the Romanian Plain (around Buzau), and in the north of the Moldavian Plateau (centered on Suceava, Fig. 1). The warming trend continued in March (by up to 1ºC per decade, Fig. 2), except for the south of the country, in the Oltenia Plain and south of the Central Sector of the Romanian Plain and Dobrogea, where maximum temperatures dropped

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slightly, by up to 0.3ºC per decade. At the opposite pole, the highest increase in maximum temperatures (by 0.6-0.9ºC per decade) was found in an area that goes up from the northeast of the Tarnavelor Plateau and the Transylvanian Plain, crossing the north of the Somesan Plateau, toward the northern part of the Western Plain. In April, marked by an average evolution of maximum temperature of about 0.3ºC per decade (Fig. 3), two regions with opposite trends stood out: the northern half of the Western Plain and Western Hills, where cooling occurred by up to 0.4ºC, and the Dobrogea Plateau, where maximums rose by 0.9ºC. This warming, especially the February warming, stimulates an earlier onset of sour cherry vegetation onset, followed by an advance of subsequent phenophases.

To understand the climatic context under which the vegetation onset, budburst, and flowering of the sour cherry occurred, an analysis regarding the dynamics of minimum temperatures during February-April was also carried out, and the area's most exposed to the risk of late frosts were highlighted. As shown in Fig. 4-6, February was marked by an increase in minimum temperatures, which, similar to maximums, covered the entire country. Basically, February minimums increased by 0.8-2.0ºC per decade (values very close to the 0.9-2.0ºC per decade found for maximum temperatures). The most pronounced increase in February minimum covered almost the entire Transylvanian Hilly Depression and the northern half of the Western Plains and Hills. The weakest increase (by 0.8-1.3ºC per decade) was observed in the east of the country, as well as in the west of the Romanian Plain.

This aspect is particularly important because, as the maps of the minimums, in March and especially in April (Figs. 5 and 6), present, in the northwestern sector, after a warmer February, two months of lower minimums followed. Moreover, the most intense decrease was recorded in April, when the floral organs had already acquired a phenological advance and become susceptible to damage caused by even a 2-3ºC drop below zero. Susceptibility to damage caused by late spring frosts is even higher, as, in sour cherry, the thermal threshold between 10% and 90% damage probability is only 1-2ºC (Murray, 2011; Stepulaitienė & Stanys, 2013; Longstroth, MSU Extension).

In general, in March the minimum temperatures oscillated close to their multi-year values and, as shown in Fig. 5, it was possible to distinguish three areas with slight cooling (up to 0.4ºC) located in the Transylvanian Plain, the northern parts of Somesului Plain and Silvania Hills, and in the south of the Western Hills.

The analysis of April minimum temperature trends highlights the risk areas, where the minimum values decreased by up to 0.6ºC during 2013-2022 compared to the 2000-2009 decade, following prior increases in February maximum temperatures. These areas were mainly located in the northern half of the country, in Hunedoara County, and in the north-east of the Tarnavelor Plateau. Additionally, areas located in the Timis Plain (centered on Timisoara), in the northern Silvaniei Hills, around Iasi, and a small zone around Târgu Jiu were identified, showing more moderate decreases in minimum temperatures - up to 0.4ºC.

The increase in maximum temperatures during February-April resulted in the last 57 years in earlier vegetation onset and accelerated progression of next phenophases (Code 51 BBCH, 53 BBCH, 61 BBCH, and 69 BBCH). To better understand both the phenophase tendency and the intensity of this shift, the dynamics of the beginning of bud swelling, budburst, flowering onset, and the end of flowering were graphically represented for the period 1969-2025 (Fig. 7).

It was therefore highlighted that the beginning of bud swelling and budburst were more strongly (and significantly) advanced compared to the beginning and end of flowering. Thus, in 2025, the vegetation onset occurred 21 days earlier, and budburst began 13 days earlier than in 1969. The beginning and end of flowering registered advances of 8 and 4 days, respectively.

A comparison made for the decade 2013-2022 between the probability that the floral organs undergo the transition between the onset of two phenophases (bud swelling- budburst, budburst - flowering onset, beginning and end of flowering, and end of flowering-fruit set) and the probability of the simultaneous occurrence of minimum temperatures below the damage threshold of the respective phenophase is shown in Fig. 8.

Of particular interest are the areas that overlap. A complete overlap can be observed between the probability that the sour cherry undergoes the interval between the beginning of bud swelling to budburst and the probability of minimum temperatures reaching critical values for floral organs (-3.3ºC). The significance of this overlap is that throughout this phenological interval, there is a risk of damage caused by late frost.

A similar situation was observed for the period between budburst and the beginning of flowering, although in this case, the last pentad of the phenophase was free of risk (the probability of critical temperatures was zero). The first five pentads of the period between the beginning and the end of the flowering were under the threat of minimum temperatures equal to or below the critical threshold (-2.2ºC), while the frost-free interval extended to three pentads in this phase. It was also observed that the period of occurrence of the critical minima (-1.5ºC) was limited to the three pentads corresponding to the onset of the phenophase.

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The comparative analysis of the probability of damage to the floral organs for each phenological interval from February 1 to May 31 in the two periods, 2000-2009 and 2013-2021 (Fig. 9) indicated a slight increase in the probability of damage before budburst starting with the fifth pentad of the analyzed interval and peaking in the tenth pentad, with an increase of 4.9%. Slight oscillations were observed thereafter, consisting of a reduction in the probability of damage between budburst and flowering onset, between the second and the fourth pentads of March, followed by an increase in the probability of damage until the second pentad of April. After this point, although lower compared to the first analyzed decade, the risk of damage caused by late frosts persisted until the fifth pentad of April. An increase in the damage probability during the flowering period was also noted, especially at the beginning of flowering, in the second pentad of April, when the probability rose from 0.3% to 0.8%, followed by a decrease towards the end of the phenophase. Finally, a higher probability of damage occurrence was recorded after fruit set, associated with the earlier onset of this phenophase, culminating in a rise from 0.7% to 2.4% during the fifth pentad of April.

The geostatistical interpolation of the probability of the late-frost damage probability (LFDP) in the sour cherry cultivar 'Crisana' across Romania, calculated for 28 localities (Fig. 10), revealed that during the period 2000-2009, the areas where climatic accidents occurred most frequently (once every five years) were mainly concentrated in the eastern part of the Oriental Carpathians and in the eastern and southeastern parts of Transylvania. The most favorable areas, where damaging late frosts occurred only once every ten years, were located in the southwestern half of the Romanian Plain and along a strip in the eastern part of the country, extending from Iasi County to Galati and continuing into the Dobrogea Plateau.

During the period 2013-2022, the risk of damage increased across almost the entire country (Fig. 11). Moreover, the areas where the probability of damage was below 10% (corresponding to late frost occurring less frequently than once every ten years) in the first analyzed period had diminished in the last decade of the study, becoming concentrated mainly in Mehedinti, Constanta, and Tulcea counties. At present, areas with a LFDP ranging from 18 to 24% (indicating late frost damage once every four to six years) prevailed. Finally, an increase in the damage probability up to 40% was also observed in the western part of Moldova and in Transylvania (corresponding to damaging frost events once every three years).

As an overall view, Fig. 12 illustrates this increasing trend in the LFDP in sour cherry, 'Crisana' cultivar during 2013-2022 compared to the decade 2000-2009. The map highlights both the areas where the frequency and intensity of climatic accidents increased most strongly (marked in red) and those with the most moderate evolution (marked in blue). Most of the country showed a moderate increase in the LFDP, of up to 3%, mainly in the southern half of Romania and the Western Plain, along with a small region in the northeastern part, centered on Suceava. In the south, two areas could also be distinguished where LFDP remained stable (in the Getic Plateau and the Oltenia Plain, as well as the southeastern part of the Dobrogea Plateau). In the remaining regions, LFDP increased by 5-9% and even by up to 15% within a limited area, located in the northern part of the Tarnavelor Plateau and the southeastern part of the Transylvanian Plain.

Since Romania is predominantly covered by areas where the LFDP exceeded one event every five years, and this probability showed an increasing trend, careful site selection for future sour cherry orchards is essential, along with the choice of cultivars (those with a later onset of vegetation or higher frost tolerance) and the implementation of protective measures.

To reduce losses caused by late frosts, a series of measures is recommended, grouped into three categories according to their timing and specific characteristics: (i) passive or technological measures, (ii) active or thermal measures, which compensate for heat loss from the air layer or plant tissues, and bio-technological measures (Drepper et al., 2022) or biological interventions that increase plant resilience (Liu et al., 2025).

Passive protection measures include actions implemented well before the occurrence of the damaging event, some starting as early as the orchard establishment phase (such as site selection, choice of species and cultivars, installation of barriers to prevent the flow of cold air from the slopes, and to facilitate the drainage of cold air). Other measures could be integrated into routine orchard management (soil preparation to enhance heat storage, fertigation, crown training and pruning, whitewashing of trunk, phytosanitary treatments). Although passive protection measures against late frosts do not provide fully effective antifreeze protection by themselves, they have the advantage of being less expensive and can enhance the effectiveness of active protection measures.

Bio-technological measures act directly on plants and are applied when a warning indicates the imminent occurrence of climatic accidents. They include treatments with cryoprotective substances that raise the freezing point of tissues, delay the formation of ice crystals (Eskandari et al., 2020), and stabilize cell membranes (Wisniewski and Arora, 2019), as well as treatments with foam products that reduce evaporation and tissue dehydration (Moroni et al., 2020).

Active protection measures against late spring frosts are applied during the climatic event (or shortly before the climatic accident). They require large financial investments and, in some cases, personnel available for intervention and machinery maintenance, but also a very good understanding of the application conditions – including the type of frost (radiative or advective), the critical thermal thresholds for floral organs, and the appropriate timing for activating or stopping the protection system (Drepper et al., 2022). These measures include micro-sprinkling, air heating and ventilation, tree covering, and application of insulating foams. Their effect could be even better when two such methods are combined (such as heating and ventilation or heating and micro-sprinkling). Given the diversity of local microclimates, the proper management of an anti-frost intervention requires an agrometeorological station equipped with temperature sensors both in and outside the radiation shield, as well as a wet-bulb thermometer.

Among the listed methods, a number of studies (Anconelli et al., 2002; Drepper et al., 2022; Liu et al., 2025; Pan & Hu, 2025) indicated that crown micro-sprinkling represents an affordable and effective frost protection technique. The amount of water distributed by micro-sprinkling at the canopy level depends on air temperature, wind speed (Tadic et al., 2023), water temperature (Jones, 2006), and the precision of micro-sprinklers. Targeted micro-sprinkling saves about 30% of the amount of water (Pan & Hu, 2025). Micro-sprinklers operating at one rotation per three minutes with six minutes of stopping and delivering 2-4 mm/h of water, are sufficient to increase ambient temperature from -4ºC to about -1.0ººC (Jones, 2006; Pan & Hu, 2025). Therefore, buds anti-freeze protection is assured, without causing damage by excessive ice accumulation on branches (Liu et al., 2025). Sprinkler system should be activated before the wet bulb temperature drops to the critical temperature and must be deactivated after the temperature rises above this threshold and direct solar radiation reaches the tree's canopy. In addition, micro-sprinkling can also serve additional purposes beyond frost protection, such as reducing crown temperature during periods of heat stress, delaying flowering, preventing fruit drop and fruit sunburn damage, and improving fruit coloration. Frost protection is significantly increased when two such methods are combined (Drepper, 2022; Liu et al., 2025).

4. Conclusions

Climate warming driven by rising maximum temperatures has become increasingly pronounced over the last 25 years. The increase in maximum temperatures during February-April has accelerated the vegetation onset in sour cherry (*Prunus cerasus* L.) by three weeks, budburst by almost two weeks, the flowering onset by eight days, and the end of flowering by four days. Meanwhile, minimum temperatures in the spring have remained almost unchanged, which, in correlation with the phenological advance, implies a higher frequency and intensity of late frost events. The analysis of the damage probability trends for the generative organs of sour cherry, caused by late frosts in Romania, was carried out for the decades 2013-2022 and 2000-2009 using a patented warning method, based on pheno-climatic simulation. The results indicated that, during 2013-2022, areas with the lowest probability of late frost damage were concentrated in limited regions in the south-western half of the country (Oltenia Plain and the southern part of the Strehaia Plateau) and in the south-eastern extremity (the Dobrogea Plateau). Across most of Romania, late frost damage currently occurs once every 4-6 years compared to once at 6-8 years in 2000-2009. This study identified areas with a higher risk of damage associated with minimum temperatures falling below the critical threshold for the generative organs, emphasizing the need to implement appropriate protection measures and provide a basis for future zoning of sour cherry.

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Figures

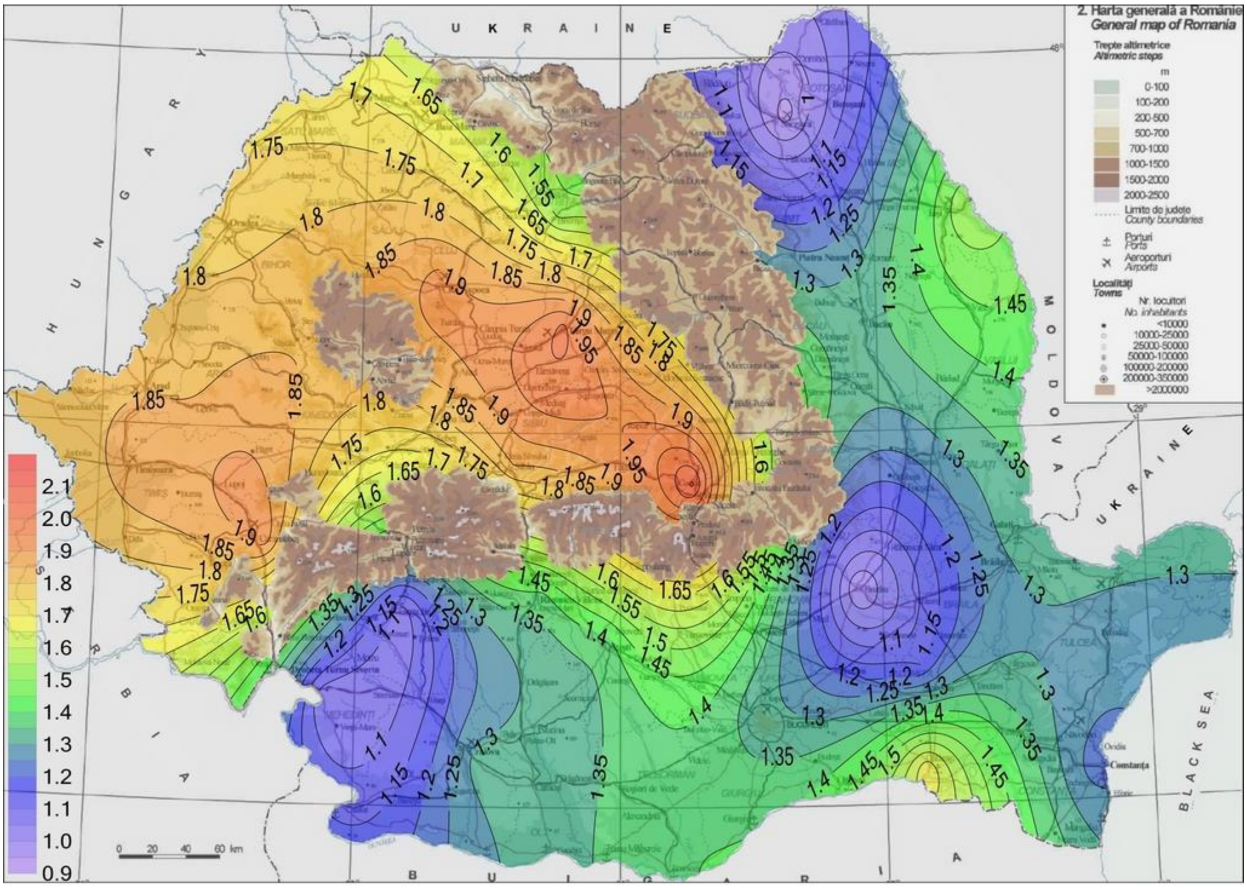

Fig. 1. Dynamics of maximum air temperatures in February, in 10 years, during 2000-2009 and 2013-2022 period (ºC)

 DOI 10.33045/fgr.v41.2025.04

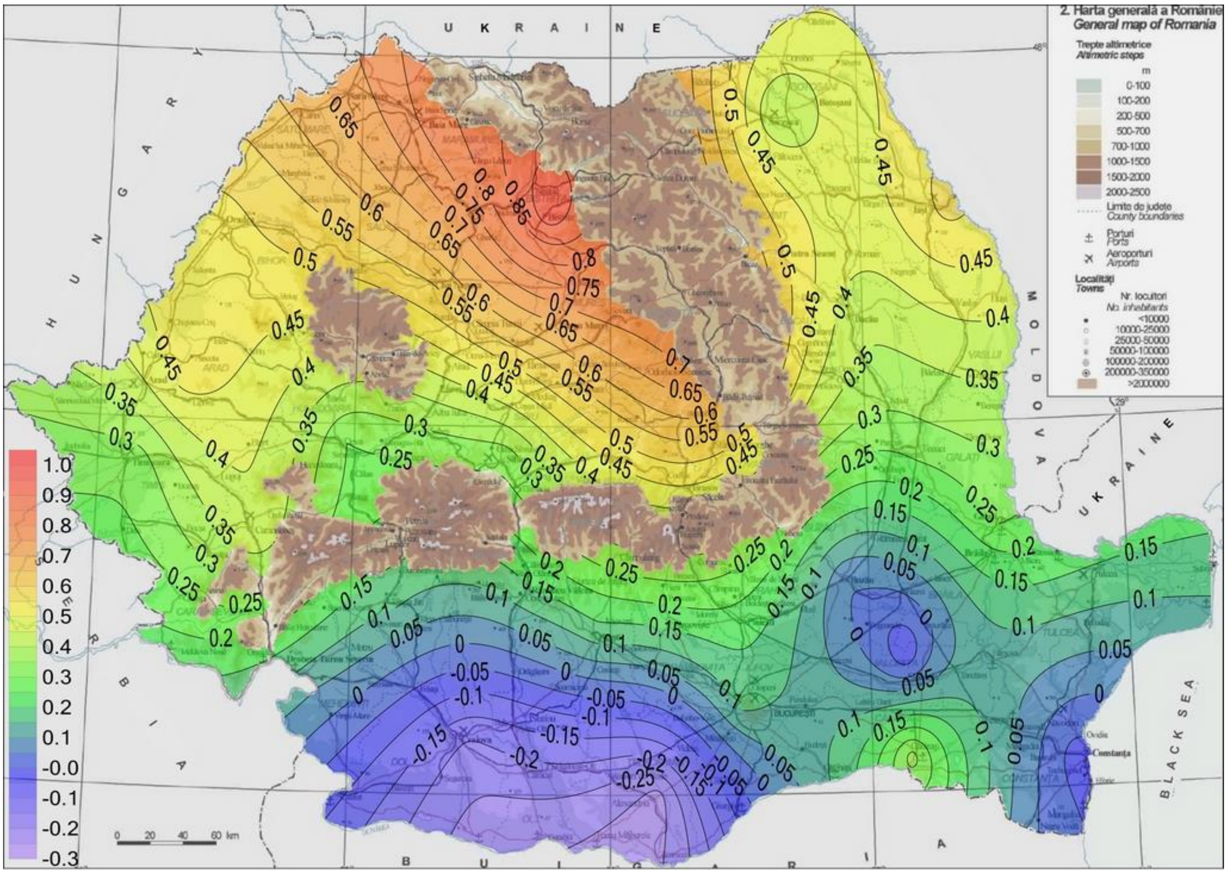

Fig. 2. Dynamics of maximum air temperatures in March, in 10 years, during 2000-2009 and 2013-2022 period (ºC)

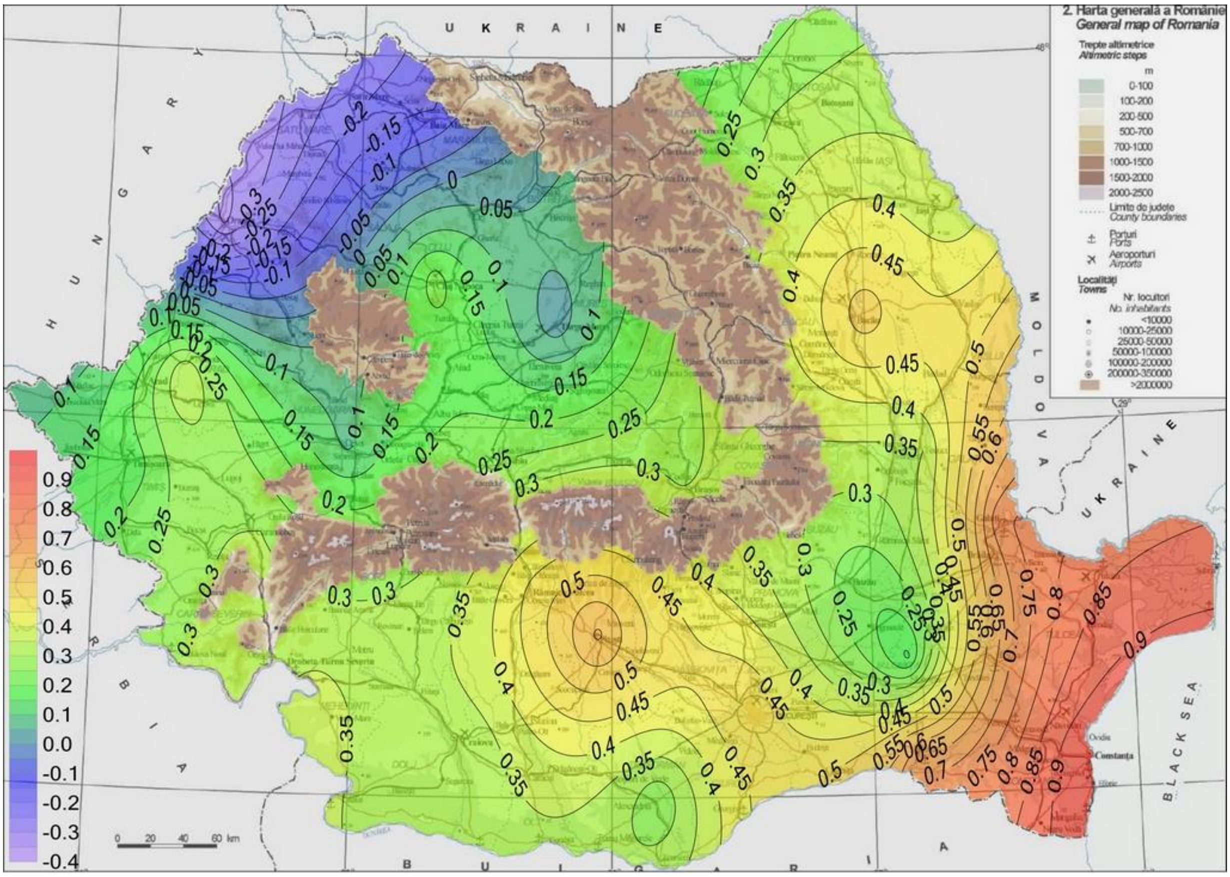

Fig. 3. Dynamics of maximum air temperatures in April, in 10 years, during 2000-2009 and 2013-2022 period (ºC)

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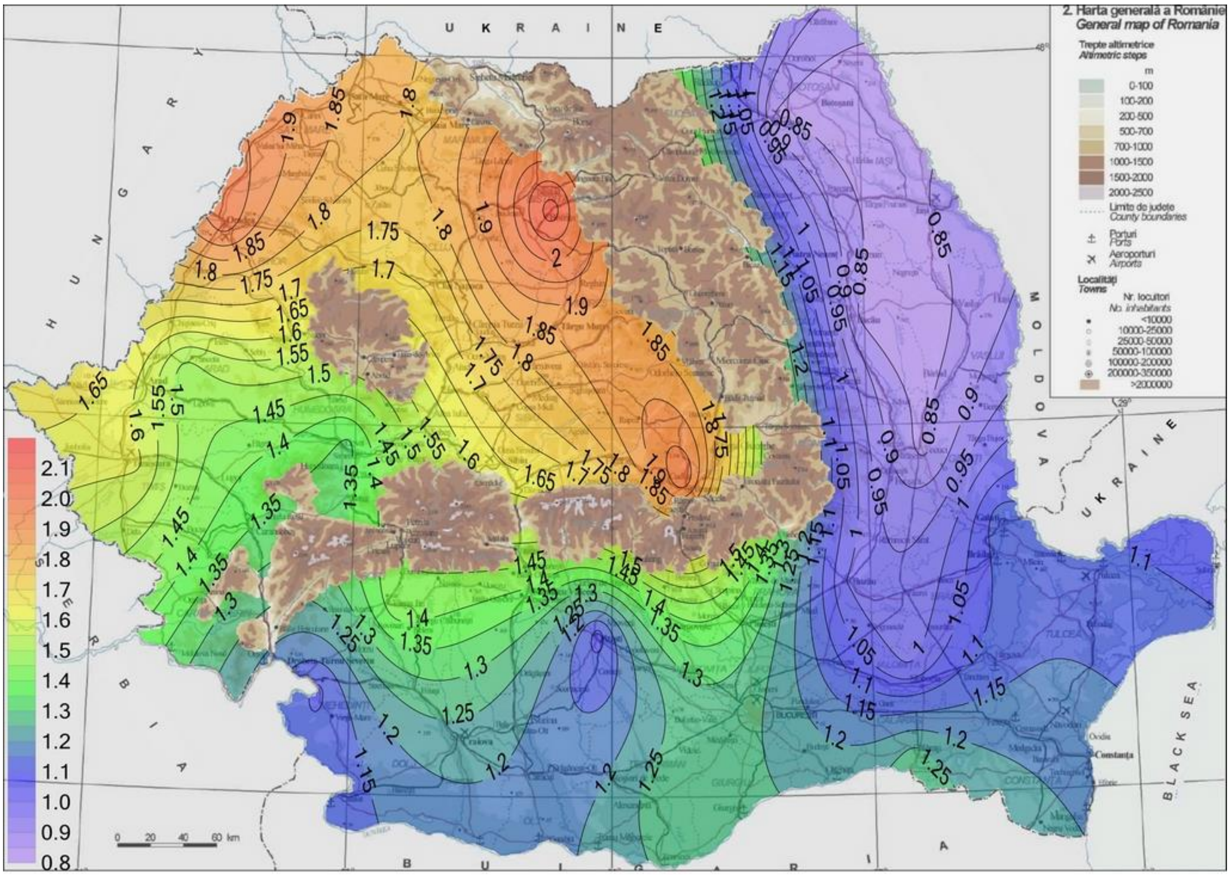

Fig. 4. Dynamics of minimum air temperatures in February, in 10 years, during 2000-2009 and 2013-2022 period (ºC)

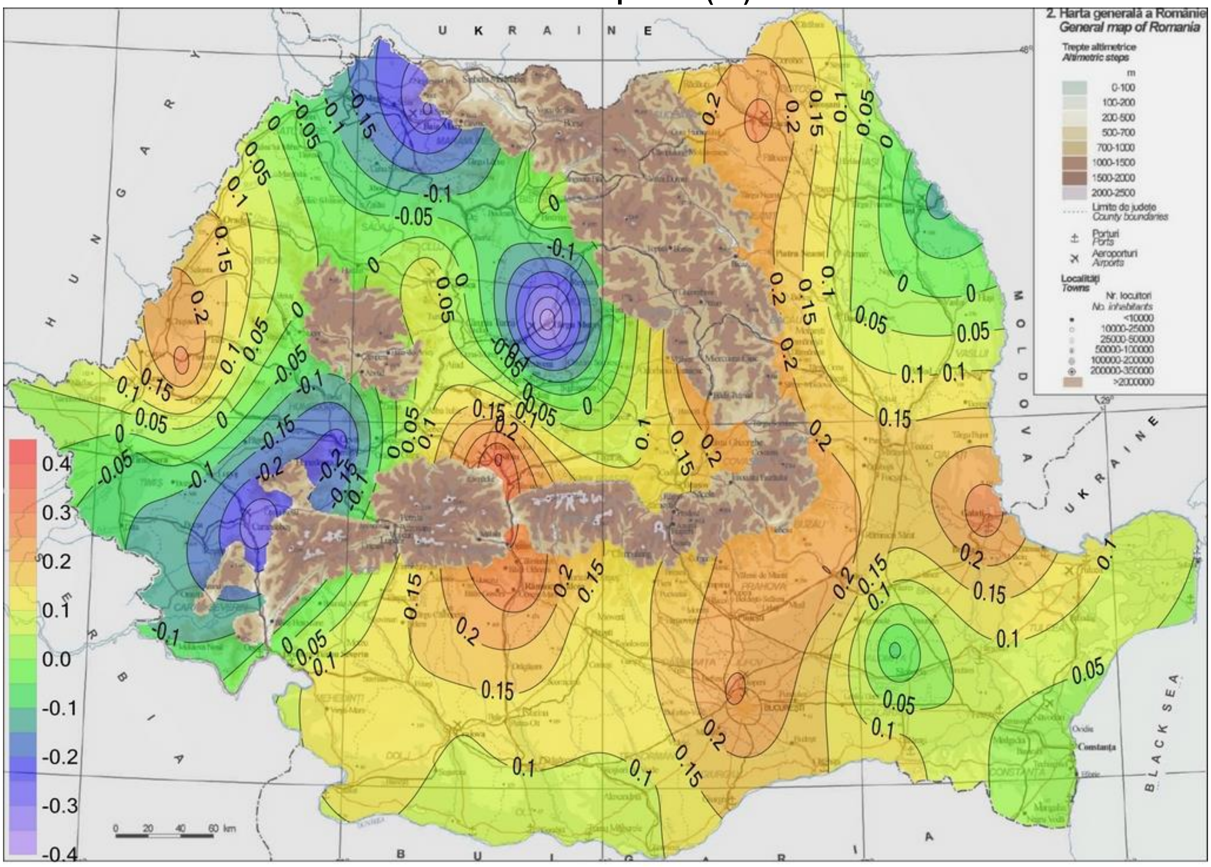

Fig. 5. Dynamics of minimum air temperatures in March, in 10 years, during 2000-2009 and 2013-2022 period (ºC)

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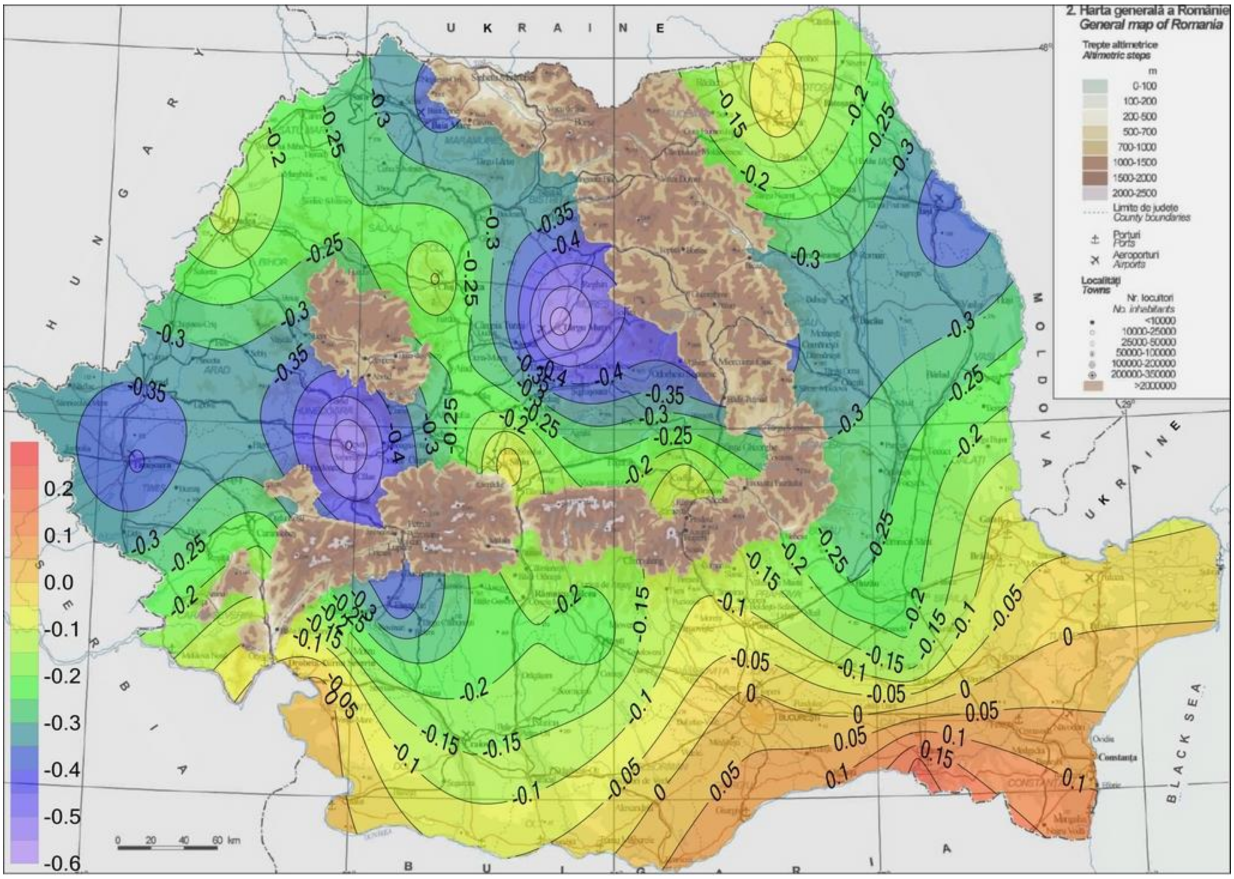

Fig. 6. Dynamics of minimum air temperatures in April, in 10 years, during 2000-2009 and 2013-2022 period (ºC)

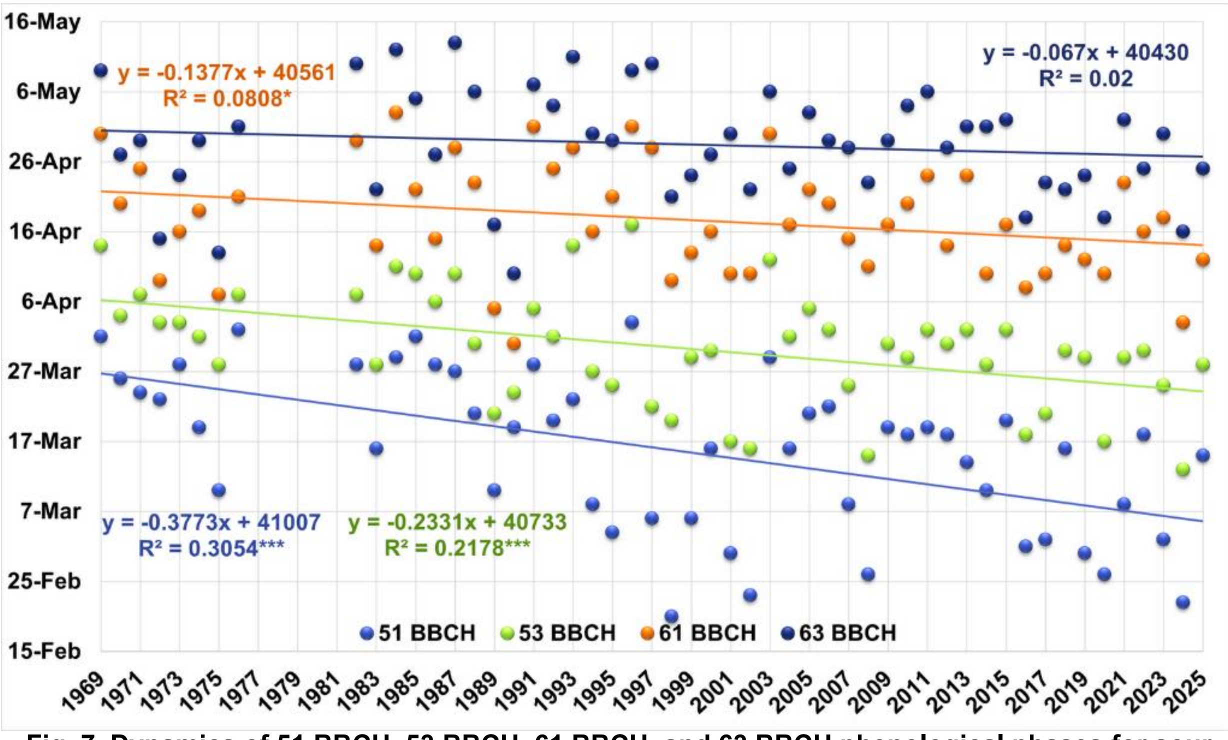

Fig. 7. Dynamics of 51 BBCH, 53 BBCH, 61 BBCH, and 63 BBCH phenological phases for sour cherry ('Crisana' cv.) during 1969-1976 and 1982-2025 period (ºC)

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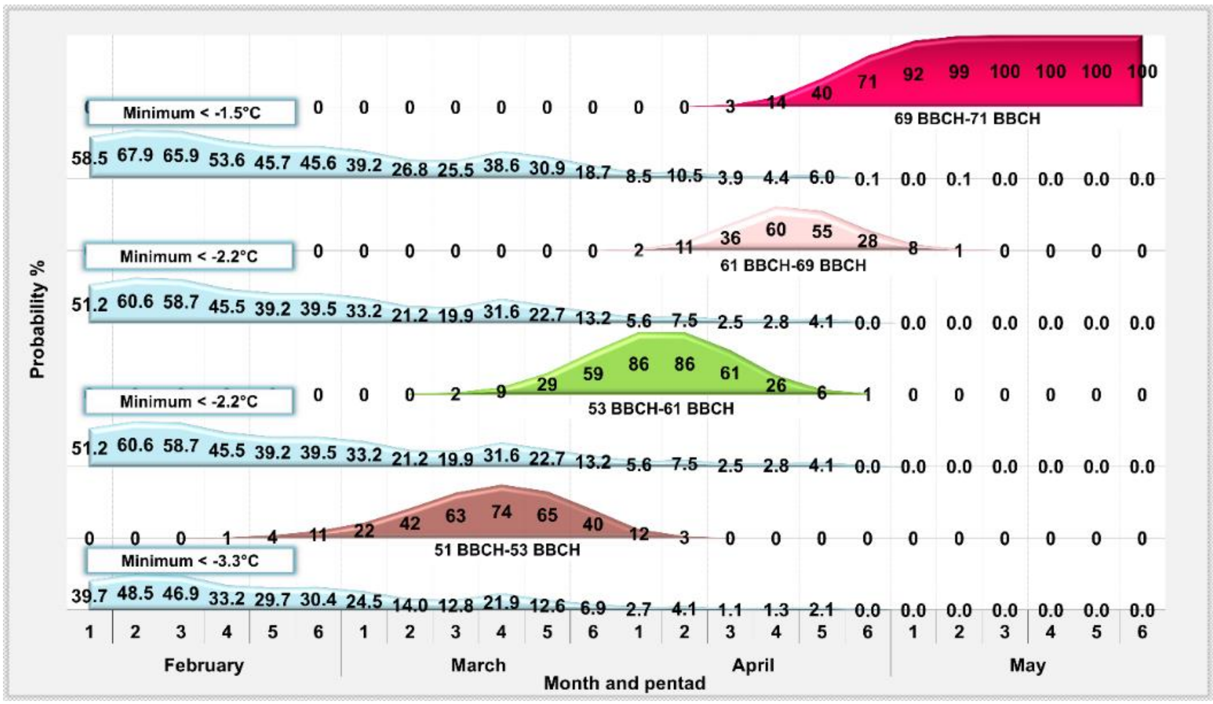

Fig. 8. Pentadal dynamics of the probability of the phenological phases and corresponding critical temperatures, in the 'Crisana' sour cherry cultivar during 2013-2022 (%, Maracineni Arges County)

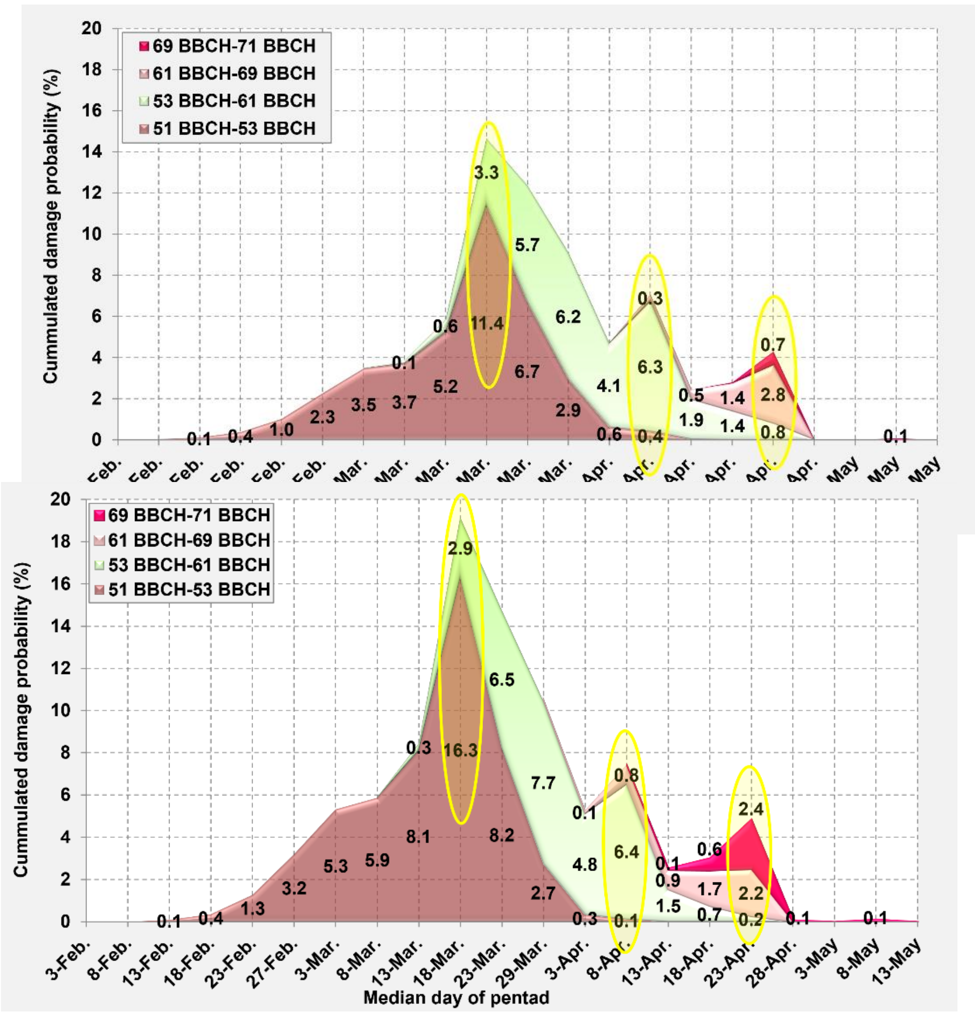

Fig. 9. The dynamics of the late frost damage probability for 'Crisana' sour cherry cultivar in 2000-2009 (top) and 2013-2022 (bottom) decades (%, Maracineni Arges County)

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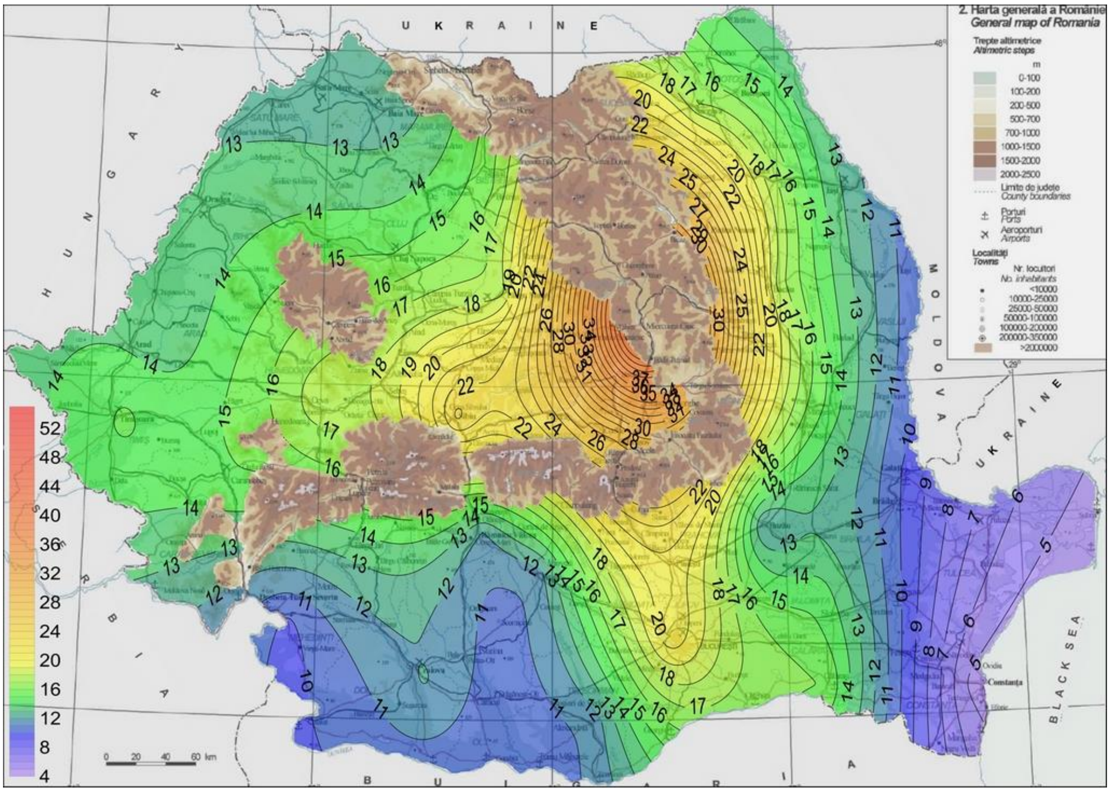

Fig. 10. Probability of floral organs damage caused by late frosts in the sour cherry 'Crisana' cultivar during 2000-2009 (%)

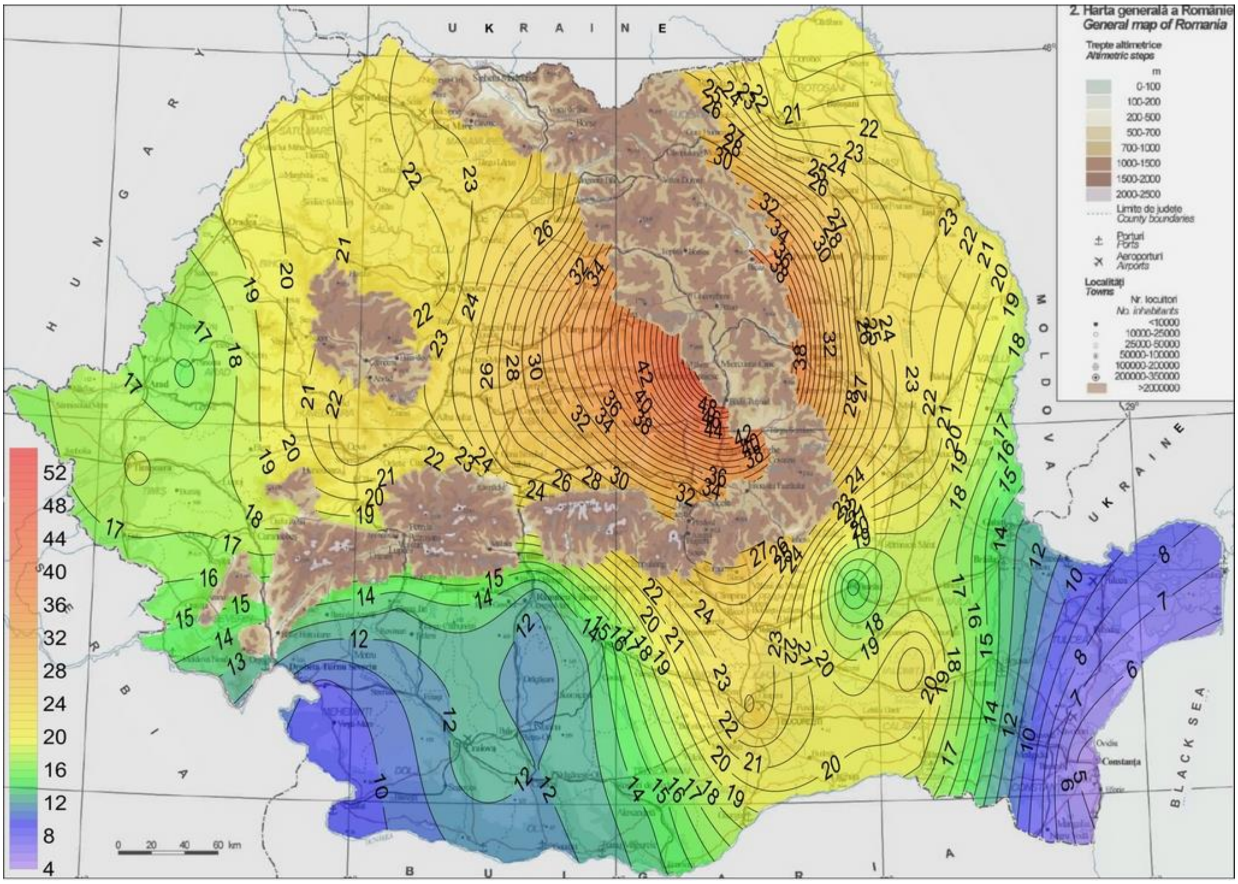

Fig. 11. Probability of floral organs damage caused by late frosts in the sour cherry 'Crisana' cultivar during 2013-2022 (%)

 DOI 10.33045/fgr.v41.2025.04

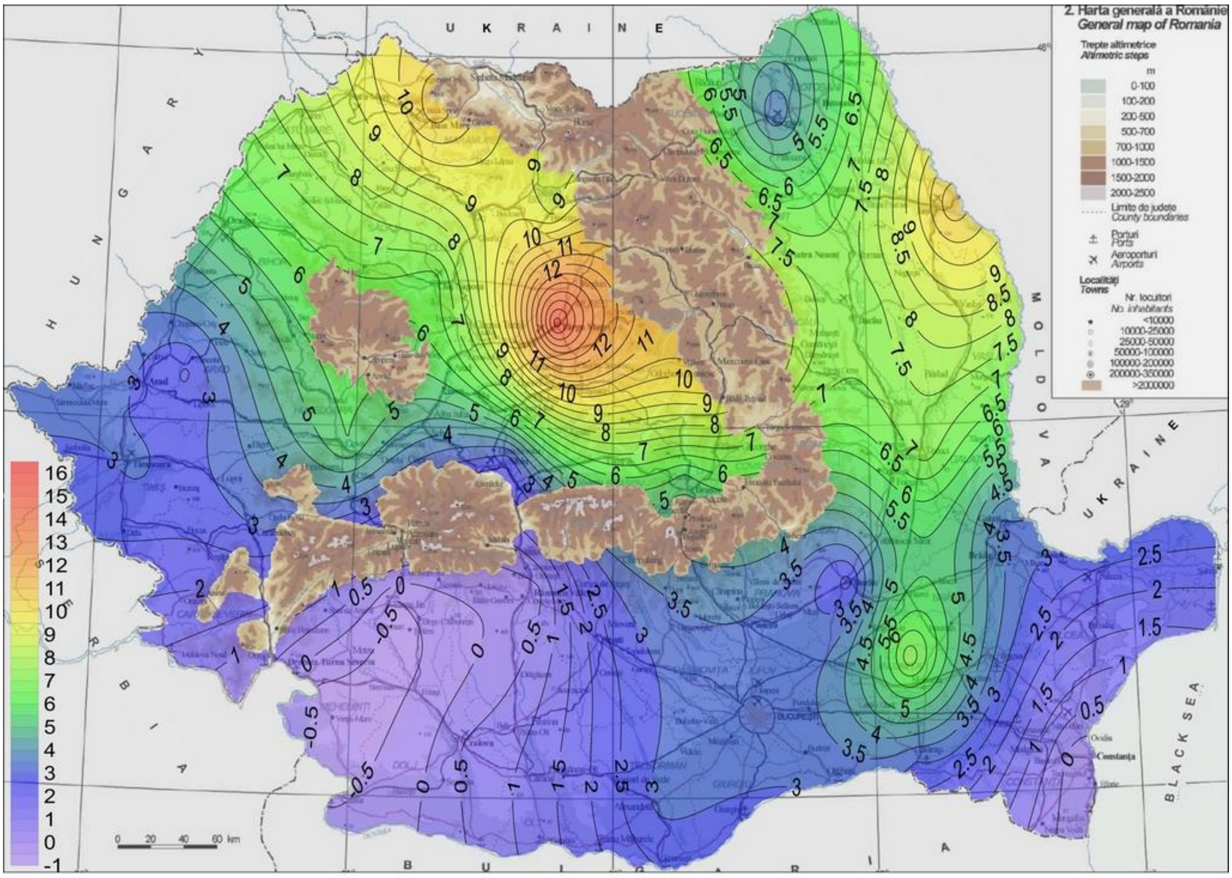

Fig. 12. Difference between the late frost damage probabilities in cherry in 2013–2022 and 2000–2009 (%)