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ZONAREA CULTURII SPECIILOR GOJI, DUD, KIWI ȘI BANANA NORDULUI ÎN ROMÂNIA, ÎN CONDIȚIILE SCHIMBĂRILOR CLIMATICE
ZONING GOJI BERRY, MULBERRY, KIWI AND PAWPAW SPECIES IN ROMANIA, IN THE CONDITIONS OF CLIMATE CHANGES

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Abstract

The warming trends of Romania's climate create increasingly favorable conditions for the cultivation of some new and subtropical species. However, the absolute minimum temperatures in the winter period do not follow a statistically assured increasing trend in all months, and this is not similar throughout the country. The objective of this work was to identify the areas in Romania where the climatic conditions are suitable for growing goji berry (*Lycium barbarum* L. and *L. chinense* Mill.), mulberry (*Morus rubra* L. and *M. alba* L.), kiwi (*Actinidia deliciousa* A. Chev., *A. arguta* Siebold & Zucc and *A. kolomikta* Rupr. et Maxim.) and pawpaw species (*Asimina triloba* (L.) Dunal), by using mathematical models. The areas where the minimum and cardinal temperatures of the growing season, its duration and annual rainfall are the most suitable for the growth and development of new species have been identified. The winter absolute minimum temperatures were recorded with a probability of 25%, which falls below the frost resistance limit of the species *Actinidia deliciousa* A. Chev. (-17°C), *Lycium chinense* Mill. (-23°C) and *Lycium barbarum* L. (-25°C), represented the limiting climatic factor of the spatial distribution of these species. Most of Romania's territory, except for mountainous areas, is suitable for growing mulberry, pawpaw (*Asimina triloba* (L.) Dunal), *Actinidia kolomikta* Rupr. et Maxim. and *Actinidia arguta* Siebold & Zucc species, which have frost hardiness limits of -28°C, -30°C, -39°C and -31°C respectively. Irrigation of all studied crops increased the whole country's average suitability score from 1.56 to 2.35 in the 0-4 range (0 unsuitable and 4 highly suitable) and expanded the areas of species' suitability. The heterogeneity and dynamics of climatic factors on the territory of Romania emphasize the importance of models for computing climate suitability as a decision tool in the establishment of goji berry, mulberry, kiwi, and pawpaw orchards.

Cuvinte cheie: temperaturi cardinale, rezistența la geruri, precipitații, durata sezonului de vegetație, specii exotice, tendință de încălzire.
Keywords: cardinal temperatures, frost resistance, rainfall, growing season duration, exotic species, warming trend.

1. Introduction

Agriculture is, exceptionally, limited only to the cultivation of autochthonous species. The worldwide extension of cultivated species was the consequence of man's introduction of new, exotic species in areas where these species had not been cultivated before. This extension was associated, in most cases, with an increased degree of risk due to the unforeseen impact of new pedoclimatic conditions on new species. The testing of perennials, fruit trees, and shrubs, under field conditions extends over a long period (often over 10 years), large areas, and involves large financial resources. Therefore, faster and cheaper ways were searched to establish the cultivation areas that are closest to the pedoclimatic requirements of these species.

The growers' requests regarding the introduction into the culture of new species originated from the warmer areas of the world and naturally followed the increasing trends of air temperature in Romania, especially in the spring and summer months. To highlight these trends, extensive studies regarding climate change have recently been undertaken at the European level, but also in our country.

On March 13 – 19, 2023, the IPCC finalized the Synthesis Report for the Sixth Assessment Report during the Panel's 58th Session held in Interlaken, Switzerland. The IPCC finds that there is a more than 50% chance that global temperature increase will reach or surpass 1.5°C between 2021 and 2040 across many scenarios, and under a high CO_2 emissions pathway, the world may hit this threshold even between 2018 and 2037. According to this AR6 Synthesis Report: Climate Change 2023, at 1.5°C global warming, heavy precipitation, and flooding events are projected to intensify and become more frequent in most regions in Europe. At 2°C or above, these changes expand to more regions and/or become more significant, and more frequent and severe agricultural and ecological droughts are projected in Europe, Africa, Australia, Asia, and North, Central, and South America. Compound heatwaves and droughts become likely more frequent, including concurrently at multiple locations. By 3°C, soft limits are projected for some water management measures for many regions, with hard limits projected for parts of Europe.

Romania has a temperate-continental climate of a transitional type, specific to Central Europe. The weather is warming up in Romania as well, along with global climate changes. 2022 was the third warmest year in the history of Romanian meteorological measurements, the average temperature being 11.77°C, and the thermal deviation of 1.55°C compared to the average of the period 1981 - 2010, according to the National Meteorological Administration analysis. Also, the five warmest years from 1900 to 2022 were: 2019, 2020, 2022, 2015, and 2007, and the period from 2012 to 2022 represents the warmest period of 11 consecutive years, a fact that confirms the marked trend of air temperature increase in Romania. The summer of 2022 was Europe's warmest summer on record with a unique drought in the last 500 years in Europe.

Knowing the degree of suitability of climatic factors for each fruit tree species is an important step in identifying the potential of a new species from a certain area. Most models used to determine the climatic suitability of an area for fruit crops compare their major climatic preferences with the geographical distribution of climate variables.

For species such as mulberry (*Morus rubra* L. and *M. alba* L.), kiwi (*Actinidia deliciosa* A. Chev., *A. arguta* Siebold & Zucc, and *A. kolomikta* Rupr. et Maxim.), and pawpaw (*Asimina triloba* (L.) Dunal), considered in this study (Table 1), preferences for climatic factors were adapted after (Bowen & Hollinger, 2004). For goji (*Solanaceae* family), two species were tested (*Lycium barbarum* L. and *Lycium chinense* Mill.) with very different preferences regarding climatic factors. Goji, native to Asia and SE Europe (Oðuz et al., 2022, 8. Mencinicopschi and Balan, 2013, Liu et al., 2004, Bean, 1981; Ohwi, 1965; Huxley, 1992) are perennial species with a maximum vegetation period of approximately 180 days. Currently, the main grower and producer of goji plants and derived products is China.

Climatic and pedological requirements of the goji species - *Lycium barbarum* L.

For good growth and fruiting of the most widely grown *Lycium* species, an accumulated temperature for the entire growing season of 3,450°C and sunshine solar of 1,640 hours is required. It rarely suffers from heat and high temperatures at the beginning of the growing season but is strongly influenced by dry winds. *Lycium barbarum* L. is slightly cold-hardy and can tolerate temperatures down to -15°C and even -25°C, but only for short periods (Mencinicopschi and Balan, 2013). The optimal hourly temperatures of the species are 13ºC minimum and 25°C maximum. The absolute minimum is 8°C and maximum 34°C (outside the range of absolute temperatures plant growth ceases, table 1). Plants are sun-loving and the amount and quality of fruit production largely depends on the amount of solar energy they receive.

In widespread cropping systems, water requirements are moderate, ranging between 700 and 1,200 mm of annual rainfall. *Lycium barbarum* L. is also capable of withstanding moderate drought episodes, although it is recommended not to go below 50% of available water holding capacity (water field capacity – permanent wilting point) during the vegetation period so that production does not be affected.

The favorable soil pH ranges from 6.6 to 8.2, but plants can also get used to an acid or alkaline pH (Elliott et al., 2023). Soil drainage must be very good. The shrub prefers sandy, loamy, or even clay soils as long as the soil is well-drained. Soils with high salinity are particularly well tolerated by this species. Although goji thrive in rich or moderately fertile soils, it can also tolerate poor soils.

Climatic and pedological requirements of the goji species - *Lycium chinense* Mill.

The species *Lycium chinense* Mill. is widespread in the wild flora of East Asia - China, Japan, Korea, and Thailand, where it occupies areas of temperate forests, riverbanks in lowlands (in Japan) or is present on slopes, brownfields, salt marshes, roadsides, and in residential neighborhoods (in China, Zhengyi and Raven, 2002). Although it is adapted to a wide variety of climates (cold, temperate, dry, Mediterranean, subtropical, and tropical), the species prefers temperate and subtropical regions. In tropical areas, it can only be grown at higher altitudes, up to 2000 m. Although it blooms profusely at low altitudes, it does not flower at very high altitudes.

It is relatively resistant to low temperatures and tolerates temperatures of up to -23°C during the winter (Elliott et al., 2023, Huxley, 1992). It generally grows best in areas with hourly temperatures between 13°C and 25°C during the vegetative season and can tolerate diurnal oscillations between 8 and 32°C (table 1, FAO Ecocrop, 2019).

Lycium chinense Mill. does not require rich soil and therefore, succeeds in poor ones. It can be found on various soils: light (sandy), medium (clay) and heavy (clay). However, it blooms and yields better in well-drained, but moist, medium-fertility soil. *Lycium chinense* Mill. has an optimal soil pH ranging from 5.5 to 7.5, but it also grows on more acidic or alkaline soils (pH 5 – 8). It even tolerates marine exposure (Huxley, 1992). The plants have an extensive root system and can be used for ground cover and to stabilize banks. It is also drought tolerant and therefore it is used as a soil protection plant at the edges of desert regions in China. It has a medium water requirement. It prefers average annual rainfall in the range of 700 - 1,200 mm, but also tolerates areas with poorer rainfall (up to 500 mm) or with temporary excess (up to 2,200 mm, FAO Ecocrop, 2019).

It prefers sun exposure although can also be grown in a slight shade, but not in shaded areas. It blooms from June (or May) to August. The species is hermaphrodite and is pollinated by bees. In the northern hemisphere, goji fruits ripen from July to October.

Climatic and pedological requirements of the mulberry species – *Morus rubra* L. and *Morus alba* L.

Among the mulberry species (part of the Moraceae family), black mulberry *Morus nigra* L., red mulberry *Morus rubra* L. and white mulberry (*Morus alba* L.) will be discussed. Mulberry is a unisexual dioecious species and probably comes from Asia Minor or China, where large trees and ages of up to 300 years are found. Although it is a species of southern origin, it has spread in culture far to the north, due to its fairly good resistance to frost, withstanding temperatures of up to -28°C. The white mulberry prefers areas with a lot of sun but grows equally well in semi-shaded areas. It is resistant to drought and frost, but also to polluting environments. However, it prefers areas with rainfall between 750 and 1500 mm (Bowen & Hollinger, 2004). It has a vegetation period between 120 and 140 days. It is not picky about the soil, with the optimum pH ranging between 5 and 7. It is attacked by diseases such as *Sclerotinia* and *Cercospora*.

Red mulberry (*Morus rubra* L.) is a subtropical climate species with dry to subtropical wet summers, native to North America. It has a vegetation period between 150 and 330 days. The cardinal temperatures of the species are 32°C for the absolute maximum, 25°C for the maximum optimum, 12°C for the minimum optimum, and 7°C for the absolute minimum, while its minimum resistance temperature threshold in winter is low, -28°C (Bowen & Hollinger, 2004). The rainfall requirement is quite high and ranges between 800 and 1,500 mm. The most suitable soils are those of medium or light texture, well-drained, with a pH between 5.5 and 7.5. It is attacked by diseases such as *Cercospora* and powdery mildew.

The black mulberry (*Morus nigra* L.) is an exotic fruit tree originating from Asia Minor (Iran) and is widespread in lowland and hilly areas. It is a species resistant to frost and drought. The black mulberry prefers fertile (humus-rich), well-drained, deep, moist, and loose soils. The mulberry has no particular demands on the soil and grows on compact-heavy (clay), light (sandy), loamy, or calcareous (with carbonates) soils. The black mulberry prefers sunny places (light temperament), but it also grows well in semi-shade.

The white mulberry (*Morus alba* L.) is a species native to Asia (China and Japan) and occasionally cultivated in Europe, North America, and Africa. It has a deep root system and only a small number of roots are distributed towards the soil surface. It prefers sun exposure, tolerates drought, and is frost-resistant. It adapts to a wide range of conditions from cold temperate steppes to hot humid or very dry tropical rainforests. It supports average temperatures of 5.9-27.5ºC, and, although it tolerates drought, it is also adapted to rainfall regimes ranging between 440-4,030 mm annually (Duke, 1978, 1979). Nevertheless, prefers annual rains between 750 and 1530 mm. White mulberry tolerates minimum temperatures between -23.3 to -28.9 degrees C. It prefers deep, well-drained soils, but thrives on a wide variety of soils (poor, saline, skeletal, or slopes), with a pH between 4.9 and 8.0. It grows at altitudes of 1,000-2,000 m (in India even 3,300 m), but can also be found at sea level.

Fertilization is essential for mulberry culture. The length of the growing season is about 130 days. It may bear fruit only once or even twice a year when the growing season is prolonged.

Climatic and pedological requirements of the kiwi species – *Actinidia deliciosa* A. Chev.

For kiwi (part of the *Actinidiaceae* family), three species will be treated: *Actinidia deliciosa* A. Chev., *Actinidia arguta* Siebold & Zucc, and *Actinidia kolomikta* Rupr. and Maxim. Originally from eastern China and Japan, today it is cultivated in New Zealand, USA, Italy, Japan, France, Greece, Spain, Australia, and Chile.

The first species of kiwi plant is very sensitive to frost and wind and prefers moist, shady soils and slightly calcareous places. Temperature is a limiting factor for kiwi plants, as they require long and warm autumns for the fruit to reach maturity. *Actinidia deliciosa* A. Chev. needs 225-240 frost-free days to complete its growing season, according to Bernadine Strik, Extension berry crops professor, Department of Horticulture, Oregon State University. The optimal temperature varies between 12-20°C, and during the vegetation period, the absolute minimum temperature is 10°C and the maximum one is 35°C (table 1).

The species *Actinidia deliciosa* A. Chev. is much more sensitive to frost than the other two species and can be affected below -17°C. Young shoots and fruits of all kiwi species are very sensitive to climatic accidents caused by early and late frosts. Temperatures of -1°C or lower, occurring for only 30 minutes, can severely damage shoots in spring and fruit in autumn. Thus, in areas with frequent frosts, kiwifruit species can only be successfully grown with frost protection by aerial irrigation systems or by using other methods of frost protection. It requires sunny places, but can also tolerate semi-shaded areas. It needs to be irrigated at short intervals, being a big consumer of water and insufficient water in the soil can cause dehydration and leaf fall (650-1500 mm rainfall).

For all species, the soil must be well-drained, with high fertility and a pH from slightly acidic to slightly alkaline (neutral being preferable, 5.5 to a maximum of 7.3), without a source of infection with *Phytophthora* spp. or with nematode attack risk.

Climatic and pedological requirements of the kiwi species – *Actinidia arguta* (Siebold & Zucc.) Planch. ex Miq.

The species *Actinidia arguta* (Siebold & Zucc.) Planch. ex Miq. it is more tolerant to frost, enduring temperatures from -23°C to -31°C during the winter (during dormancy, Bowen & Hollinger, 2004). However, even in this species, young plants are much more sensitive to frost, requiring protection of the trunk by covering it with different materials. The maximum levels of frost resistance presented above for this species are only valid during deep dormancy. This species has low chilling requirements (hours with temperatures between 0 and 7°C) and during ectodormancy, they can be affected at higher temperatures if cold waves are preceded by warm periods, especially late in winter. High temperatures in February or March can promote early budding and expose the very sensitive buds of *Actinidia arguta* to late frosts. Therefore, this species cannot be commercially grown in most areas without frost protection measures when temperatures drop below 0°C after bud break.

Generally, it grows optimal in areas where, during the vegetation season, hourly temperatures range between 22°C and 25°C, but can tolerate diurnal oscillations between 5 and 30°C (table 1). It prefers average annual rainfall between 900 – 1.600 mm (adapted after Bowen & Hollinger, 2004).

Climatic and pedological requirements of the kiwi species – *Actinidia kolomikta* Rupr. et. Maxim.

Actinidia kolomikta Rupr. Et Maxim. is spread spontaneously in temperate zones of China, East Asia, and the Soviet Far East. In its natural habitat, it inhabits well-drained rocky soils, mountain slopes up to 500-1000 m (it was observed at a maximum altitude of 1,345 m, in the south of Primorsky district, while in the north of the area, the maximum altitude populated was only 150 m, depending on the temperature in the two zones). *Actinidia kolomikta* grows in semi-shade in mixed conifer-deciduous and conifer forests. Occurs in deciduous forests on northern slopes, but not in oak forests. In Sakhalin, it grows at the edge of the mountain coniferous forest up to 200-300 m.

The vegetation period of *A. kolomikta* Rupr. et Maxim. it is 150-270 days (table 1). It has an optimum minimum temperature of 22°C and an optimum maximum of 25°C, while the absolute minimums and maximums are 5°C and 30°C, respectively (table 1).

It is the most frost-resistant kiwi species, withstanding up to - 39°C, but its shoots are sensitive to frost (young shoots and fruits of all kiwi species are very sensitive to frost). Temperatures of -1°C or lower, for only 30 minutes, can severely damage shoots in spring and cause fruit drop. Thus, in areas with frequent frost episodes, it is recommended to install anti-freeze protection systems.

In this species' natural habitat, the level of precipitation varies between 600 and 2000, and about half of the precipitation falls in the summer period. *A. kolomikta* Rupr. Et Maxim. seems more sensitive than other species to wet soils or *Phyophthora* spp. attack.

It grows well in direct sunlight (six hours or more of direct sunlight), but also tolerates shade or, according to some studies, requires partial shade for optimal growth. Too much shade or excessive fertilization can cause slight discoloration of the leaves. Winds can cause injury to the fruit, so the use of shelters is recommended. It flowers between mid-June and early July, and the fruit ripens from mid-August to the end of September.

This species grows on heavy (clay) and medium (loamy) soils but generally prefers light textured (sandy) soils with a pH between 6 and 8, rich in humus, moist but well drained.

It is a dioecious species. Thus, for fruit production, it is necessary to plant one male plant for every three to four females. Flowers are pollinated entomophily. If the purpose of cultivation is ornamental, it is recommended to plant only the male plants.

Climatic and pedological requirements of the northern banana species – *Asimina triloba* (L.) Dunal

The northern banana (Pawpaw) is part of the *Annonaceae* family and in this study the species *Asimina triloba* (L.) Dunal was discussed. It can be successfully grown in temperate regions, originating in the eastern part of the United States, where plantations extend from Florida (with annual absolute minimum temperatures between -7°C and -12°C, USDA 8) to the Great Lakes (with annual absolute minimum temperatures between -23°C and -29°C, USDA 5). According to the studies undertaken at the University of Agronomic Sciences and Veterinary Medicine of Bucharest [15], the northern banana has already been growing in Romania for more than 100 years. It is a slow-growing shrub, up to 4.0 – 4.5 m tall. The plants have hermaphrodites and rarely self-fertile flowers, so in commercial plantations, the interplanting of some pollinators and even the practice of artificial pollination is preferred.

In Europe, it stands out for its high resistance to frost, surviving winters with frosts from -25°C to -30°C, occurring during the dormancy period. It needs around 160 frost-free days for the growing season. It grows well in areas with only 700 – 800 mm rainfall, if are distributed proportional to the potential evapotranspiration. The rainfall deficit during the vegetation period causes the fall of the fruits and should be minimized by irrigation. Seedlings obtained from seeds, are very sensitive to exposure to direct solar radiation in the first years of life and therefore must be partially shaded. Later, it prefers the direct sun.

Plants are sensitive to dry winds, low humidity, and cool summers. The leaves can be damaged by strong winds. Transplanting seedlings or cuttings is difficult because the plants have long taproots with few lateral roots. Plants should be pulled from the soil as much as possible with both the roots and surrounding soil intact, the optimal time for transplanting being in the spring after bud break. Container plants are easier to handle.

It prefers deep, fertile, medium-textured, well-drained soils with a neutral to slightly acidic pH (5.2 – 7.2), and well-exposed to the sun. It is a moderately tolerant species to calcium carbonate in the soil.

The objective of this work was to apply some models that would identify in Romania areas where the climate conditions are likely to be suitable to grow species like goji berry (*Lycium barbarum* L. and *L. chinense* Mill.), mulberry (*Morus rubra* L. and *M. alba* L.), kiwi (*Actinidia deliciousa* A. Chev., *A. arguta* Siebold & Zucc and *A. kolomikta* Rupr. et Maxim.), and pawpaw (*Asimina triloba* (L.) Dunal).

2. Material and methods

The research was carried out at RIFG Pitesti, southern Romania, during the 2009-2012 period.

In this study, the areas with temperature (winter frosts, vegetation season duration, and the weight of cardinal hourly values in the growing season) and rainfall conditions suitable for growing species of goji berry, mulberry, kiwi, and pawpaw in Romania were identified based on mathematical models.

The Bowen & Hollinger, 2004 methodology adapted to the climatic conditions of Romania was applied. A climatological database registered in the period of 1989-2018 (30 years) by the National Meteorological Administration Bucharest for 121 localities was set to obtain the following parameters:

-to establish the thermal suitability and the duration of the vegetation period, multiannual average daily values of mean, minimum, and maximum air temperatures, plus the standard deviation of minimum and maximum temperatures (5 columns of weather data x 366 days/year x 121 weather stations) were used;

- to establish frost suitability, the lowest minimum temperature of each year from 1989 to 2018 was used (30 annual minimum thermal values x 121 stations);

- for rainfall suitability, the data-base consisted of the annual rainfall, from the interval 1989 – 2018 was used (30 annual precipitation x 121 localities).

The zones of climatic suitability for studied fruit tree species were mapped based on the four climatic parameters presented in Table 1 (growing period duration, thermal suitability during the growing season, frost and rainfall suitability). Scores from 0 (meaning completely unfavorable location – species growing is excluded) to 4 (area very suitable for fruit trees growing) were calculated for each representative weather station (121).

Establishing the *subroutine for thermal suitability score (TSS) calculation:* the 366 daily multiannual values of air temperatures: averages, minimum with a probability of 25% and maximum with a probability of 75% (after accepting normality by the Shapiro – Wilk test, the law of normality was used to calculate the probabilities of the distribution of the values), were transformed into hourly temperatures using sinusoidal functions. This calculation was carried out based on the observation that trees are in continuous interaction with the momentary temperature and not with the daily average.

By applying this subroutine, the vegetation season daily sum of hours with temperatures between the cardinal thermal values presented in Table 1 was calculated as follows:

- sum no. 1 - the number of hours between the absolute maximum and the optimum maximum,
- sum no. 2 - between the maximum optimum and minimum optimum, and
- sum no. 3 - between the optimum minimum and absolute minimum.

For each of the three intervals of the species' vegetation period, the daily sums were converted into daily suitability scores (from 0 to 4) by multiplying the sum no. 1 and sum no. 3 by 3 and the sum no. 2 by 5 and in the next step, by dividing the sum in 24 values corresponding to the 24 hours of a day.

The day when the average maximum temperature exceeded the absolute minimum of the species was taken as the first day of the growing season and the first day in the second half of the year when the average minimum temperature fell below 0 °C was considered the last day of the growing season. Calculation was performed for each weather station (121) and species (7) using Microsoft Office EXCEL spreadsheets.

The vegetation period duration (VPD) suitability score (VPDSS) was established by reference levels calculation according to the following protocol:

- score 0 was assigned if the growing season duration of the species in the respective locality, determined as above, was lower than the minimum limit (Lmin) of the species VPD from Table 1;
- score 1, if VPD was between Lmin and Lmin + (0.125*species range VPD amplitude (Ampl));
- score 2 was assigned if the VPD was between Lmin + (0.125*Ampl) and Lmin + (0.25*Ampl)
- score 3 was assigned if the VPD was between Lmin + (0.25*Ampl) and Lmin + (0.375*Ampl);
- score 4, if the VPD was above Lmin + (0.375*Ampl).

The degree of suitability to winter frosts (frost suitability score, FSS) was established based on the minimum temperature values recorded in each year of the 1989-2018 interval, in each locality:
- the every station value of the minimum temperature with the probability of occurrence of 25% (the value that appears once every 4 years) was established as a benchmark corresponding to the score 0 of suitability. If this temperature was less than or equal to the species' frost tolerance limit (Table 1), a score of 0 was given and the area (station) was considered unfavourable for that species;
- the next, suitability scores 1, 2, 3, and 4 were assigned by adding one degree Celsius to the species' winter frosts tolerance limit.

The degree of suitability of precipitation (precipitation suitability score, PSS) was established using the average value for the interval 1989-2018 of the annual amount of rainfall. The multiannual averages of the 121 localities rainfall were compared with the minimum and maximum limits (Table 1) and the amplitude between the minimum and maximum rainfall limits of each species. The more the precipitation level was lower than the minimum limits or higher than the maximum limits of the species in Table 1, the greater the penalty was.

To calculate the synthetic, climatic suitability score (CSS) for each of the 121 localities, the following formula was applied in Microsoft Office EXCEL:

$$CSS = [TSS]*((([FSS]*[PSS]*[VPDSS]) / 64)^{0.3}), \text{ where:}$$

TSS= thermal suitability score
FSS= frost suitability score
PSS= precipitation suitability score
VPDSS= vegetation period duration suitability score

Finally, to calculate the score of climatic suitability with the optimization of the aero-hydric regime of the soils through irrigation and/or drainage, the maximum score of 4, for the suitability of rainfall was assigned, within the above formula.

In the zoning methodology, the range between scores of:
- 0 and 0.5 was considered unfavourable for the respective species (red and orange map colors, Fig. 1-7);
- the range between 0.5 and 1.5 scores was considered slightly favorable (light orange and yellow);
- the range between 1.5 and 2.5 is moderately favorable (green color);
- the range between 2.5 and 3.5 was favorable (blue color), and
- scores higher than 3.5 gave the respective location the qualification of very suitable (violet color), which, of course, does not exclude the application of the basic technological measures for the respective crop.

Climate suitability maps without and with irrigation (with optimization of soil water regime) of the seven species for 30 years (1989-2018) were created using Surfer® Version 9.11.947 Surface Mapping System (Golden Software, Inc.) software. A data grid was created using the default kriging routine.

3. Results and discussions

Climatic zoning of the goji species - *Lycium barbarum* L.

Without irrigation, *Lycium barbarum* L. found moderate climatic suitability in most of the Romanian territory, although reduced in the arid areas of southeastern Moldova, Baragan, Dobrogea, but also in the Boianului, Romanați, and Timiş Plains (with suitability scores under 2, Figure 1-left, green color). While in Oravita and Oasului depressions, and Getic Subcarpatians the climatic suitability reached a maximum grade of 2.9 (blue color), this species was excluded from the southeast of Hartibaciului Plateau, the Fagarasului Depression (scores below 0.8, yellow), and especially Brasov (scores below 0.2, orange color).

These last-mentioned areas kept their lower suitability scores even under irrigation (Figure 1-right) due to the very low and frequent minimum temperature during the winter (under the species frost resistance). Nevertheless, when irrigated the species met favorable conditions in almost all of Romania's territory (with scores above 3.0), while moderate and low suitability could be found in some limited areas in Tarnavelor Plateau, the Radauti and Lapus Depression, North of Suceava town, Iasi and Targu Jiu Depression.

Climatic zoning of the goji species - *Lycium chinense* Mill.

The lowest scores, below 1.2, corresponding to low climatic suitability (Figure 2-left) and also the unsuitable areas for *L. chinense* Mill. growing were found in the west of Targu Jiu Depression, in Tarnavelor plateau, north of the Somesean plateau, Sucevei Plateau, north of the Moldova Plain, and Barladului Plateau, due to frosts below the species' resistance threshold of -23°C. The other areas of the country showed suitability from moderate (most frequent) to favorable (in very limited areas).

The irrigation increased the suitability score for this species mostly in areas with severe drought (from 1.7 to 2.5, in the central sector of the Romanian Plain or even from 2.1 to 3.3, in the coastal area of the Black Sea), although no improvements were observed in the already mentioned restricted areas. The maximum favorability scores are in the eastern Dobrogea and especially in the southeast (scores over

3.3), in the south of the Moldova Plain (3.2), in Covurluiului Plain, Oravita Depression and the Gătaia Plain (3.1), in Cotmeana Platform (3 ,14), Strehaia and Blahnitei Plain (score 3,1).

Climatic zoning of mulberry species – *Morus rubra* L. and *Morus alba* L.

From a climatic point of view, the two species of fruiting mulberry had relatively low restrictions regarding the placement of the culture on the Romania territory (scores between 0 and 2.8 in the non-irrigated regime, presented in Figure 3-left and between 1.8 and 3.4 in the irrigated regime, presented in Figure 3-right).

The lowest scores, below 0.5 (unfavorable), and the lowest natural climatic suitability, were found in Dobrogea (except a very limited area in the south), the eastern part of Baragan Plain and in the south of the Barlad Plateau, due to the severe summer drought. Irrigation increased suitability throughout the country, including in these three regions. Moreover, only a small area, in the southeast of Transylvania remained moderately favorable (scores between 1.5 and 2.3).

Climatic zonation of the kiwi species – *Actinidia deliciosa* A. Chev.

Actinidia deliciosa A. Chev. culture registered the strongest restrictions on almost the entire territory of the country, as the average grade of climatic suitability was 0.16 (Figure 4-left) and 0.20 under the irrigated regime (Figure 4-right). Even when the aero-hydric regime of the soil was optimized by irrigation and/or drainage, the kiwi species - *Actinidia deliciosa* A. Chev. (Figure 4) found in most areas of the country very low suitability, with scores below 0.4, due to its poor resistance to frost (limit -17°C, see Table 1).

For this species, the climatic suitability was very little influenced by the irrigation (average country score 0.2 - unfavorable). Therefore, in the soil water optimized regime, only a slight increase in suitability scores was recorded, especially in the east and southeast of Dobrogea Region, where the Negru Voda Plateau and Mangalia were the most suitable areas in Romania for *Actinidia deliciosa* A. Chev. cultivation (scores of 2.1-2.6). However, there were also limited areas with moderate suitability in the northwest of Balacita Piedmont and the Blahnita Plain, as well as the Oravita Depression (scores of 1.5 - 2.0). With smaller suitability (slightly favorable) were found small areas around Pitesti, Mioveni, Dragasani, Arad, and Zalau towns (with scores of 1.0 - 1.3).

Climatic zoning of the kiwi species – *Actinidia arguta* (Siebold & Zucc.) Planch. ex Miq.

The species had relatively high limitations regarding the location of the culture both in a non-irrigated regime (country average suitability score of 0.9, slightly favorable, Figure 5-left) and in optimized aero-hydric soil conditions (whole country suitability score 2.47, moderately favorable, Figure 5-right). Without irrigation, the culture of the species was excluded from the eastern part of Transylvania (where the minimum temperatures which occurs with a probability ≤ 0.25 – once every 4 years drop below the resistance threshold of the species, of -31°C,), and from almost all of Moldova, as well as from the Plains of Baraganului, Mostistei, Gavanu-Burdea and Romanati, due to the low amounts of precipitation (the species needs between 900 and 1,600 mm).

The improvement of the water regime brought to this species of kiwi a spectacular increase in suitability throughout the territory of Romania (except for the mountainous area) and showed very low amplitudes of spatial oscillation. Therefore, in the irrigated regime (soil optimized from the point of view of the aero-hydric regime), the suitability scores on the scale of the entire country were much higher – generally over 2.4. More favorable in the irrigated regime were the southern hills (over 2.44), and the Somesean Platform. The areas with the greatest enhanced climatic suitability were located in the Moldavian Plain (scores over 2.7), the eastern and especially southeastern Dobrogea (score about 2.8).

Climatic zoning of the kiwi species – *Actinidia kolomikta* Rupr. et. Maxim.

The species registered large to moderate restrictions regarding the location of the culture on the almost entire territory of the country. Its climatic suitability was similar to the previously described case, for *Actinidia arguta* Siebolt & Zucc., with an country average natural score of 0.91, slightly favorable (Figure 6), due to its very high-water requirement of 900-1,500 mm/year. Under the irrigated regime *Actinidia kolomikta* Rupr. et. Maxim. reached a 2.49 score of whole country climatic suitability (Figure 9, scores between 2.3 and 2.8), characterized as moderately favorable. Areas with the lowest scores, below 0.1, and the lowest non-irrigated soil climatic suitability (Figure 6-left), due to the deficient hydrological regime, were located in Dobrogea, the entire Baragan Plain, the Gavanu-Burdea, Romanati and Bailesti Plains, the entire eastern part of Moldova, the Secase Plateau, the east and west of Tarnavelor Plateau, Arad Plain and Carei Plain. More favorable in the non-irrigated regime, were found the southern hills (over 1.9 scores) and a strip from north to south, from Baia Mare to Oravita (over 2.1 scores), as well as the Plain of Oravitei and Gataiei (over 1.9).

Under irrigation, the suitability scores of *Actinidia kolomikta* Rupr. et. Maxim. were higher than 2.4. The species met the greatest enhanced climatic suitability (Figure 6-right) in eastern Dobrogea (over 2.6) and especially in the southeast (over 2.8), the south of the Moldavian Plain (over 2.6), the Oravitei Depression, the Plain Gataiei but also the Platforms Cotmeana and Somesana (score 2.6).

Climatic zoning of the northern banana species – *Asimina triloba* (L.) Dunal

From the point of view of climatic suitability, the species registered the lowest restrictions regarding the location of the culture on almost the entire territory of the country, with scores between 1.5 and 3.2, in the non-irrigated regime (Figure 7-left) and between 2.8 and 3.4 under irrigation ones (Figure 7-right). The average score of climatic suitability for the entire country was 2.8 and 3.04 in the irrigated regime. *Asimina triloba* (L.) Dunal is therefore the species that found the most favorable conditions in Romania among the analysed species. Moreover, except for the mountainous areas, the suitability scores for this species did not fall below 2.55. It is thus justified, the fact that irrigation does not bring significant improvements to the culture suitability (2.5-3.5. scores).

The lowest scores, below 2.2, and the lowest climatic suitability, were in the south-eastern part of Transylvania (frosts below the species' resistance threshold of -30°C, which appeared with a frequency greater than once every 4 years between 1989 and 2018). East of the Baragan, Dobrogea, and the Barlad Plateau also had lower scores in the non-irrigated regime, below 2.6, due to the severe summer drought. The greatest climatic suitability enhanced with irrigation (Figure 7-right) was in the Oravitei Depression and the Gataiei Plain with scores over 3.2, the Strehaiei Plain, the Blahnitei Plain (over 3.1), the Cotmeanei Platform (3.14), and in the south of the Moldavian Plain (3.2). The most favorable area for irrigated culture in Romania was in eastern and especially southeastern Dobrogea (over 3.3).

4. Conclusions

The models identified the areas where climatic conditions are likely to be suitable for goji berry, mulberry, kiwi, and pawpaw species over Romania. The natural climatic suitability of the seven studied species varied widely, from no restrictions (*Asimina triloba* (L.) Dunal) to strong limitations on almost the entire territory of the country (*Actinidia deliciosa* A.Chev.) Ensuring the necessary water through irrigation, increased climatic suitability and expanded the cultivation area for species such as *Actinidia arguta* Siebold & Zucc, *Actinidia kolomikta* Rupr. At Maxim, and *Morus spp.*, but also for *Asimina triloba* (L.) Dunal. Although irrigation increases the climatic suitability for the *Lycium* species, some regions remained unfavorable due to their low winter temperatures, below the frost resistance limit of these species. Similarly, *Actinidia deliciosa* A.Chev. remained restricted on almost all Romanian territory, even under irrigation, due to the too-low winter minimum temperatures. This study showed that, according to the presented models, with exceptions in the case of *Lycium barbarum* L, *Morus spp.*, *Actinidia arguta* Siebold & Zucc, *Actinidia kolomikta* Rupr. Et Maxim, and *Asimina triloba* (L.) Dunal, the decision to establish *Lycium chinense* Mill. and *Actinidia deliciosa* A.Chev. orchards on Romania's territory, must be strongly sustained by prior climate suitability studies.

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Tables and Figures

Table 1. Indicators of climatic suitability for the seven studied species, used in the algorithms of the estimation models

Scientific name	Vegetation period duration (days)		Cardinal temperatures (°C)				Rainfall (mm)		Frost resistance (°C)
	Min.	Max.	Maximum		Minimum		Min.	Max.	
			absolute	optimum	optimum	absolute			
Lycium barbarum L.	150	180	34	25	13	8	700	1,200	-25
Lycium chinense Mill.	150	180	32	25	13	8	700	1,200	-23
Morus rubra L., *Morus alba* L.	130	330	32	25	12	7	800	1,500	-28
Actinidia deliciousa A.Chev.	235	365	35	20	12	10	650	1,500	-17
Actinidia arguta Siebold & Zucc	150	365	30	25	22	5	900	1,600	-31
Actinidia kolomikta Rupr. et Maxim	150	270	30	25	22	5	900	1,500	-39
Asimina triloba (L.) Dunal	130	365	32	24	14	5	500	1,200	-30

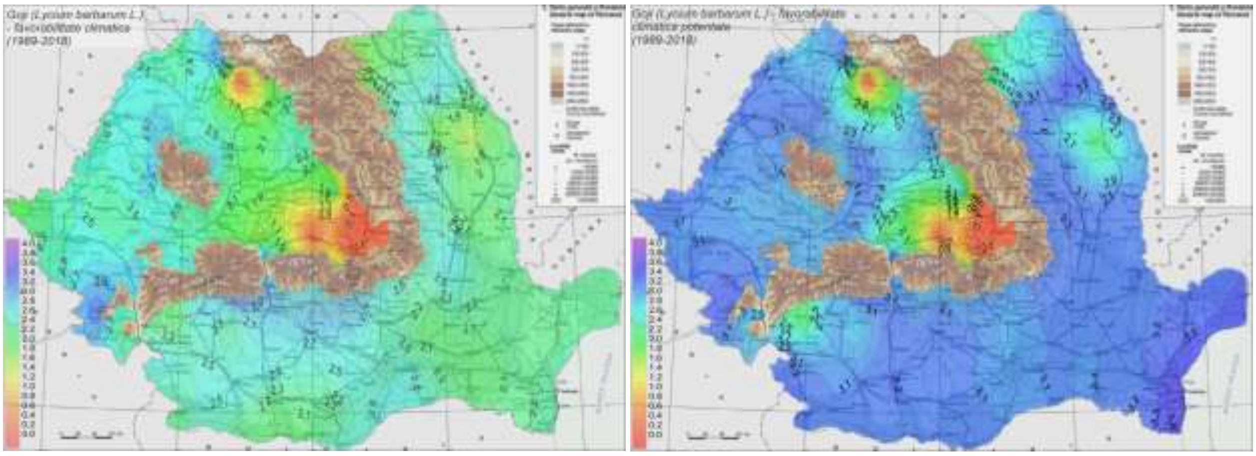

Fig. 1. The distribution of natural (left) and irrigation-enhanced (right) climatic suitability zones for goji species - *Lycium barbarum* L., in Romania (1989-2018)

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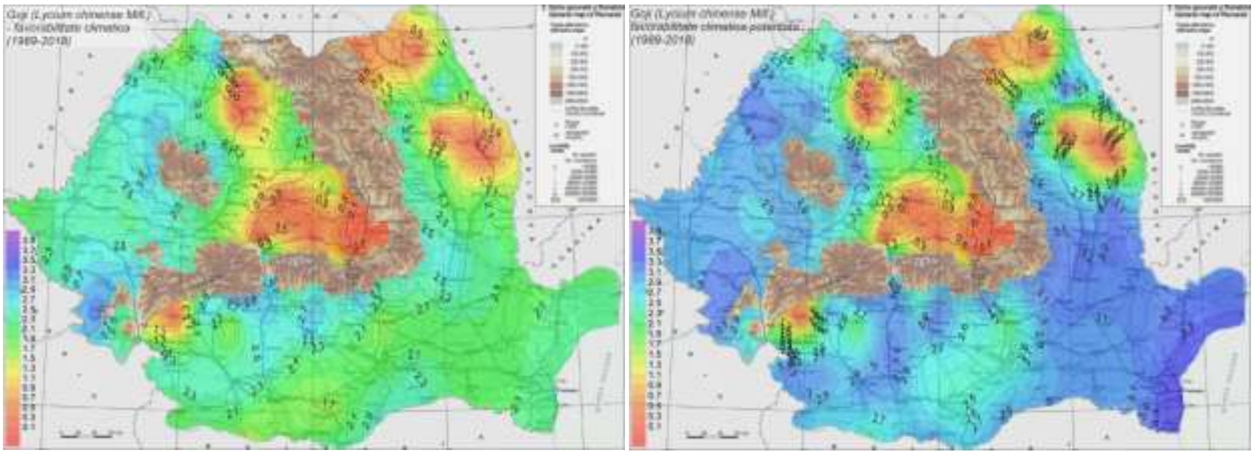

Fig. 2. The distribution of natural (left) and irrigation-enhanced (right) climatic suitability zones for the goji species - *Lycium chinense* Mill., in Romania (1989-2018)

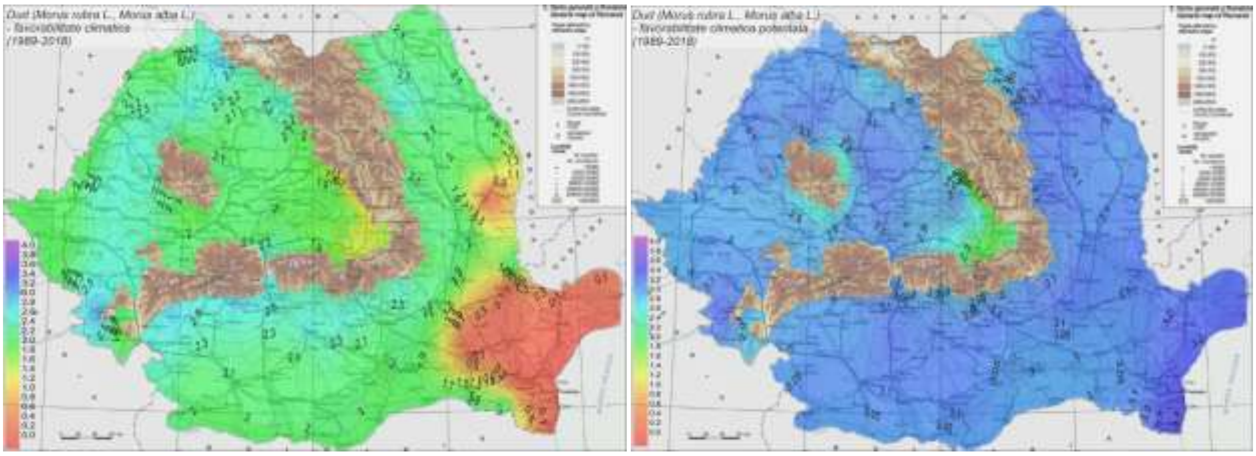

Fig. 3. The distribution of natural (left) and irrigation-enhanced (right) climatic suitability zones for the fruiting mulberry species *Morus rubra* L. and *Morus alba* L., in Romania (1989-2018).

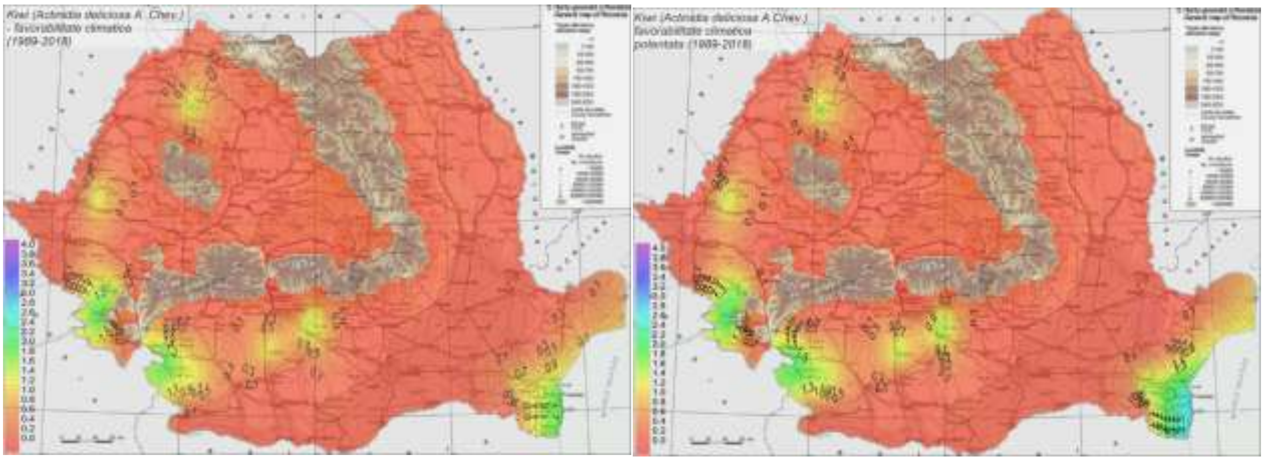

Fig. 4. The distribution of natural (left) and irrigation-enhanced (right) climatic suitability zones for the kiwi species - *Actinidia deliciosa* A.Chev., in Romania (1989-2018)

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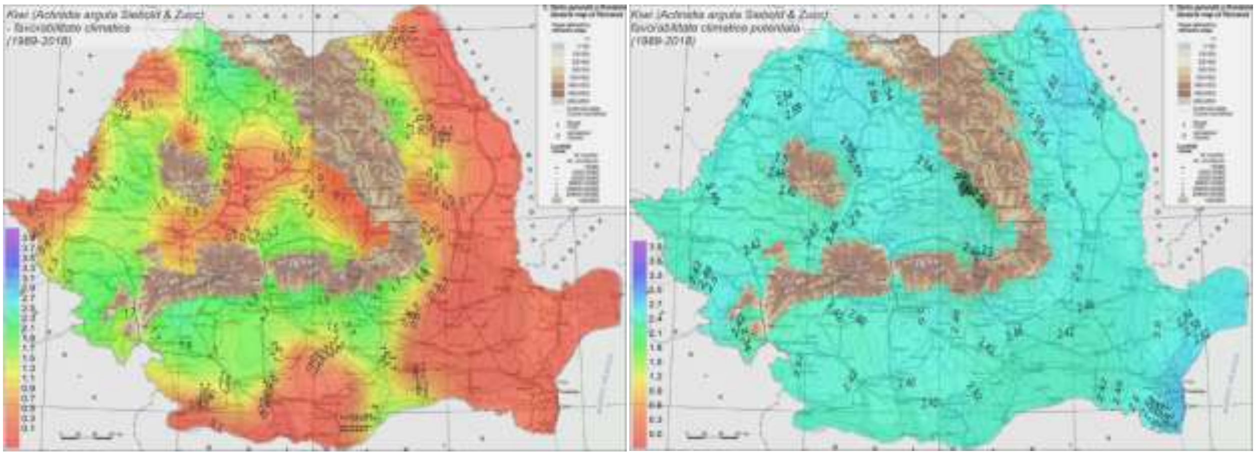

Fig. 5. The distribution of natural (left) and irrigation-enhanced (right) climatic suitability zones for the kiwi species - *Actinidia arguta* Siebold & Zucc., in Romania (1989-2018)

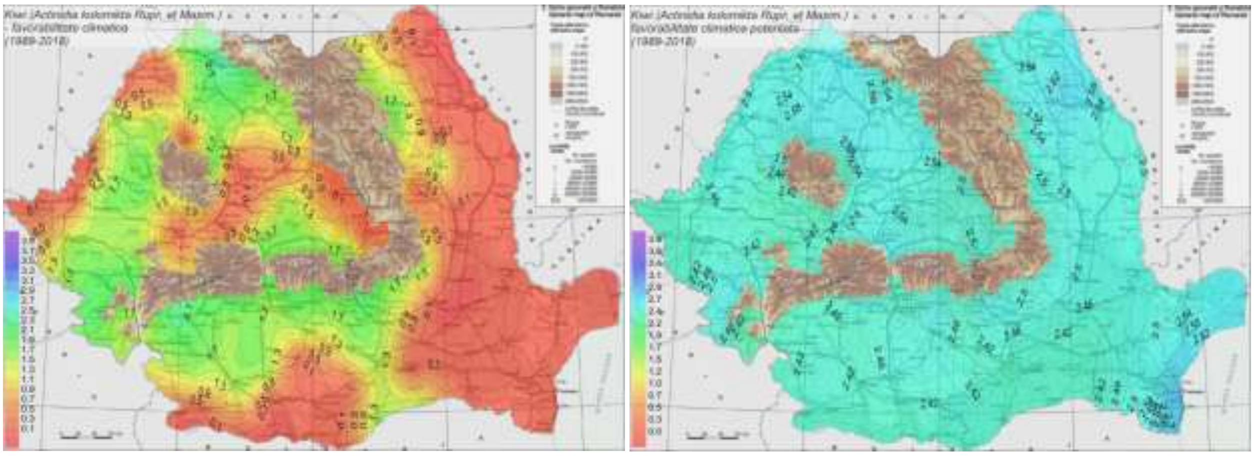

Fig. 6. The distribution of natural (left) and irrigation-enhanced (right) climatic suitability zones for the kiwi species - *Actinidia kolomikta* Rupr. et Maxim., in Romania (1989-2018)

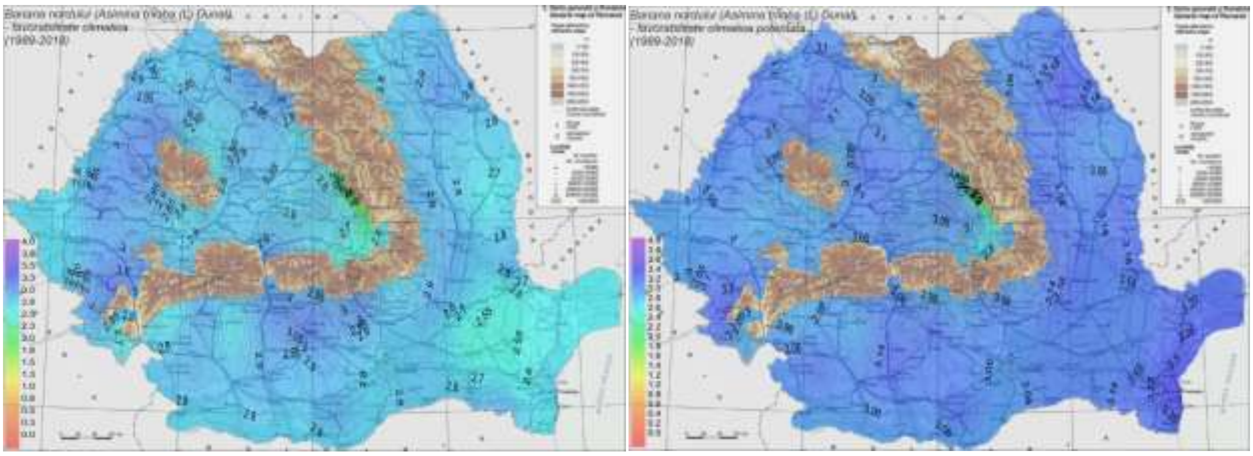

Fig**. 7. The distribution of natural (left) and irrigation-enhanced (right) climatic suitability zones for the northern banana species - *Asimina triloba* (L). Dunal, in Romania (1989-2018)**