PRACE GEOGRAFICZNE, zeszyt 110

Instytut Geografii i Gospodarki Przestrzennej UJ
Kraków 2002

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CLIMATIC POTENTIAL OF THE REPUBLIC OF MOLDOVA, ITS CHANGES AND INFLUENCE ON AGRICULTURAL PRODUCTION

Abstract: The regularities of formation of winter thermal fields have been studied, using modern methods of multidimensional statistical analysis. The factors, which are controlling their spatial differentiation in regional scale in complex relief of Moldova, have been revealed. The temporal variability of winter temperature has been studied and assessment of wintering conditions and its influence upon the cultivation of peach and apricot fruit have been revealed.

Key words: agroclimate, wintering, drupaceous, thaws and frosts, statistical analysis, climatic resources.

1. Introduction

During the last years, concerning the orientation of agriculture to the market economy, the recognition and registration of agrometeorological conditions is of great importance in order to reduce the unfavorable climatic influence on the productivity of agricultural crops. The efficiency of technological measures and economic solutions in many respects depends on that how often this branch is exposed to agrometeorological risk factors – frosts, early frosts, droughts etc., and also on the soil-climatic conditions.

Pomiculture, to large extent depending on properties of the environment, is one of the most important elements in the structure of the Republic of Moldova's agriculture, the main branch of national economy. The total area of gardens of Moldova is 151.4 thousand ha, from which orchards occupy 141.4 thousand ha, and drupaceous crops – 47.5 thousand ha. For drupaceous crops (apricot and peach), the wintering conditions are the limiting factor. The long-term analysis of data concerning productivity of given crops shows that the damage of blossoming buds by frosts depends both on intensity of frosts and frequency of alternately occurring thaws with frosts. In Moldova in 1985, due to very low temperature, the losses in productivity of drupaceous were 45.1 thousand tons. In 1983 as a result of frequent thaws and frosts, the losses were even higher, than in the first case and amounted 58.2 thousand tons.

Due to the insufficient recognition of soil-climatic potential in the past, in the Republic of Moldova there is no scientifically based ecological system of optimal allocation of agricultural crops, including drupaceous ones. It is well manifested in planting large gardens in unfavorable places from the ecological point of view (e.g. at the bottom of a valley, where cold air accumulates, creating cold-air pool and as a consequence freezing of crops).

2. Database and methods

For realization of our research, homogenous data series from 14 Moldavian meteorological stations for the period 1950-1999 were used. For the spatial analysis of climate variability, the data series from 13 stations were enlarged using the longer series of Kishinev to cover the whole period 1887-1999. It was possible due to relatively small area of the country and good data correlation between the stations.

As a criterion of selection of years with extreme temperatures in the long-term period, the value of their anomalies (Δt_i) concerning average long-term values of seasonal temperatures was used. Thus the years were considered as abnormal when the deviations exceeded some threshold level, the value of standard deviation (σ). The winters were considered as moderate-warm (cold) when the anomaly of temperature was $\pm 0.5\sigma$; warm (cold) winters – $\pm\sigma$; very warm (cold) winters – $\pm 1.5\sigma$; extremely warm (cold) winters – $\pm 2.0\sigma$.

Unfortunately, the operating meteorological network of Moldova does not provide all kinds of observations of underlying surface, therefore we have undertaken the attempt of reconstructing climatic fields, taking into account, first of all, character of relief of Moldova's territory.

In the present research, the authors concentrate on revealing and estimation of influence of the local geographical factors, influencing the differentiation of thermal regime of winter. The regression analysis has allowed to determine the contribution of separate geographical factors to the thermal fields.

3. Results

Latitude, absolute and relative height (Tab. 1) and also exposition and angle of inclination of slopes play the significant role in controlling the temperature. Obtained model of regression was used for reconstruction of the temperature fields and for agroclimatic estimation of potential with the goal of optimization of crops' allocation.

The equation of regression for 10 % of supply of absolute minimum is:

$$y = 179.1 - 0.001223\varphi + 0.00950H + 0.0274472A - 0.581353\alpha \qquad (1),$$

where:

the first figure is a constant of regression; φ– latitude; A – slope aspect; H – absolute height; and α – slope inclination.

Tab. 1. Contribution (%) of various geographical factors to the dispersion of temperature

Month	Temperature	Geographical factors								
		φ	λ	H	Δh	α	A	D	Model	Error
Dec.	T_{mean}	71.1***	15.3*	3.9	0.0	0.9	2.5	0.5	94.4**	5.6
Dec.	$T_{abs.max.}$	65.6**	9.5	9.3	0.2	3.9	0.4	4.1	93.1*	6.9
Dec.	$T_{mean\ max.}$	53.8*	0.6	12.0	3.1	4.5	1.5	2.9	78.4*	11.6
Dec.	$T_{abs.min.}$	72.4**	4.0	6.0	1.9	6.1	0.4	0.2	91.1	8.9
Dec.	$T_{mean.min.}$	59.2*	1.5	6.6	2.1	2.4	3.1	1.6	76.7*	23.3
Jan.	T_{mean}	73.6***	10.7*	7.0**	0.2	2.5	0.0	0.0	94.9**	5.6
Jan.	$T_{abs.max.}$	68.1***	10.1*	11.2*	0.0	6.1	0.0	1.0	96.7	3.3
Jan.	$T_{mean.max.}$	78.6**	1.3	4.2	0.3	6.0	0.0	0.3	90.8	9.2
Jan.	$T_{abs.min.}$	60.5***	0.7	6.9	5.9	6.1	13.7	2.1	95.1	4.9
Jan.	$T_{mean.min.}$	59.2*	1.5	6.6	2.1	2.4	3.1	1.6	76.7*	23.3
Feb.	T_{mean}	61.8*	9.6	2.9	1.7	0.4	1.0	0.8	78.1	21.9
Feb.	$T_{abs.max.}$	70.3***	3.2	13.3	0.0	5.2	0.0	0.8	92.9*	7.1
Feb.	$T_{mean.max.}$	67.1**	0.0	5.4	0.0	8.3	0.1	4.4	85.5*	14.5
Feb.	$T_{abs.min.}$	82.8**	0.4	1.3	0.8	0.1	0.5	0.0	86.0	14.0
Feb.	$T_{mean.min.}$	68.6**	3.6	1.1	5.8	2.6	0.8	3.8	86.2*	13.8

Note: * – $0.01 < p < 0.05$, ** – $0.001 < p < 0.01$, *** – $p < 0.001$.

Explanations: φ – geographical latitude, λ – geographical longitude, H – absolute height, Δh – relative height, α – slope inclination, A – slope aspect, D – coefficient of relief dissection.

The obtained equations of regression and digital model of relief, developed in the Institute of Geography, Moldavian Academy of Sciences, allowed revealing cold-air pools in the territory of the Republic of Moldova (Fig.1). The diversified local factors cause the mosaic of these conditions.

For the first time for Moldova, the thaws are analyzed according to orographical structure of the country. A day with thaw was the one with temperature increase above 0ºC in winter. The link between the number of days with thaws and the relief is reflected in the equation of regression:

$$y = 155.3 - 0.000566\varphi - 0.039507H \qquad (2),$$

where:

φ– geographical latitude, H – absolute height.

The coefficient of determination is 0.79, which means that the given factors of the environment influence essentially the investigated phenomenon. The vertical gradient of thaws for the territory of Moldova is equal to 4 days/100 m (Fig. 2). The thermal regime of winter is characterized in Moldova by significant instability and the tendency of warming is observed.

In the present research, the results of investigations of changes of climatic conditions of winter on the territory of the Republic of Moldova, located in the southeastern part of

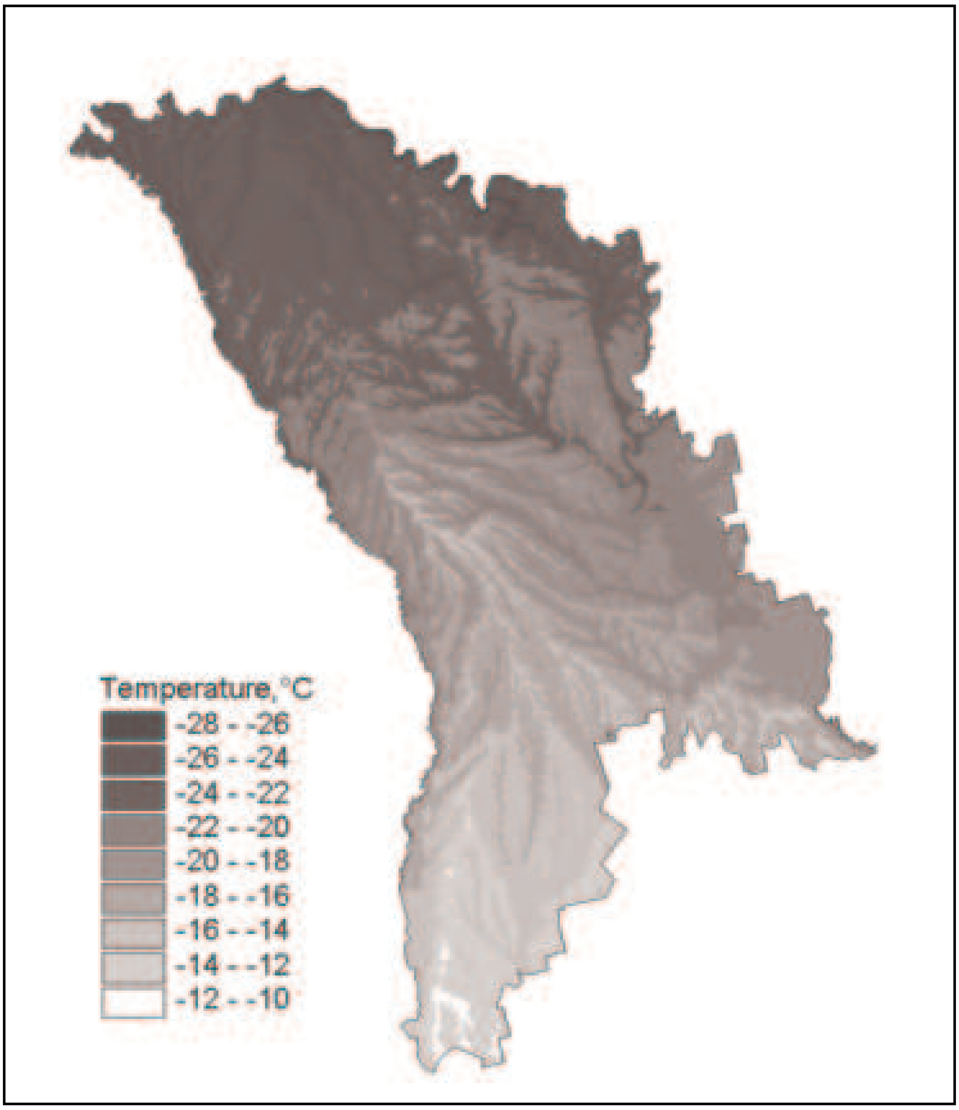


Fig. 1. Cases of an absolute minimum once per 10 years

the European continent, are represented in the context of existing global climate change models. Thus, the authors attempted to not only estimate the changes of average long-term temperature, but also the changes of extreme temperatures, mainly due to negative influence on economy (Daradur et al. 1996).

Having quantitative criteria of an estimation of "severity" of winters by the degree of anomaly, the numbers of average seasonal temperatures were subjected to

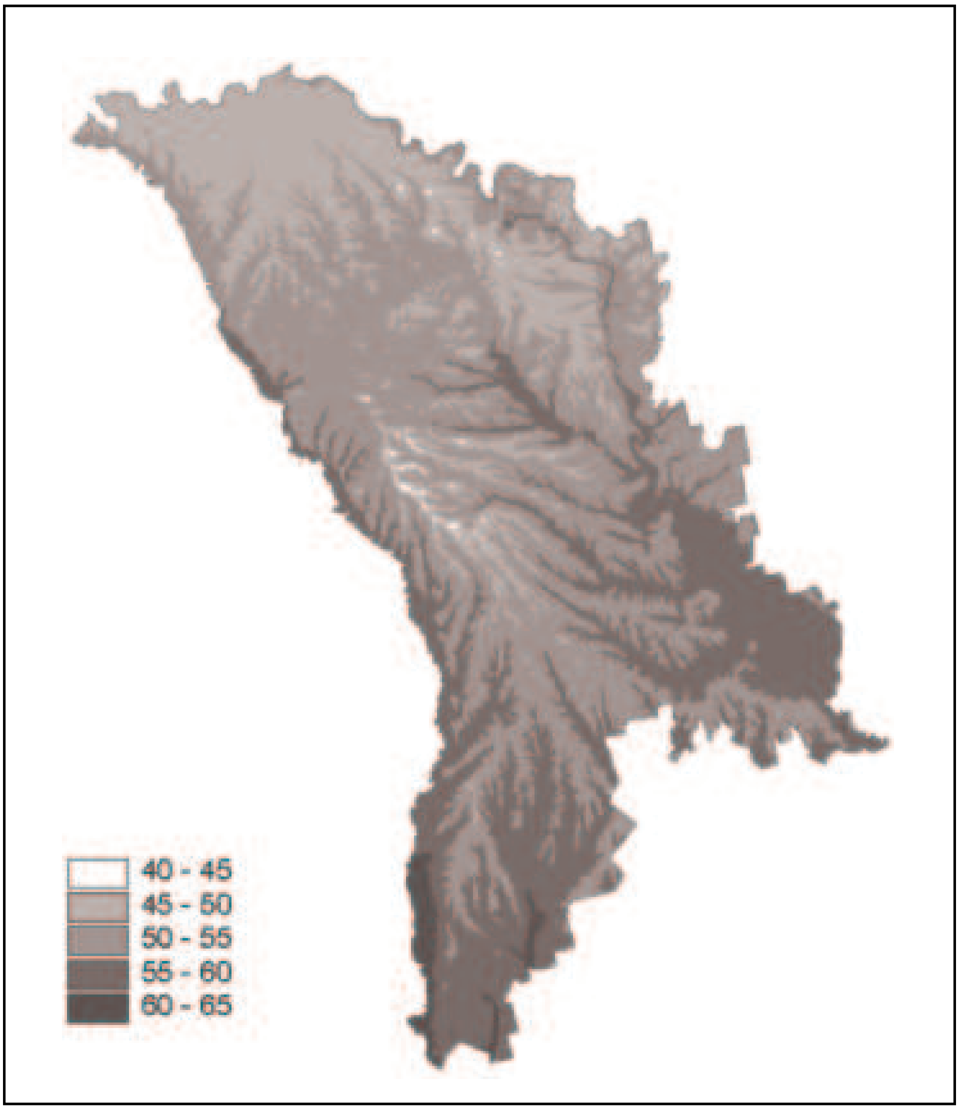


Fig. 2. Annual number of days with thaws in Moldova

the trihotomy analysis (presentation of temporary rows of meteorological parameters as impulse process, when the meteorological parameter independently of its value is accepted as one of three values): -1 – winters with negative anomaly; 0 – mean seasonal long-term value; +1 – winters with positive anomaly (Dorff Gurland 1961; Sazonov 1991). Trihotomy Z (Δt_i) accepts the constant discrete values according to a rule:

$$Z(\Delta t_i) = \begin{cases} -1 \text{ at } (\Delta t_i) \leq a^{/} \\ 0 \text{ at } a^{//} < (\Delta t_i) \leq a^{//} \\ +1 \text{ at } (\Delta t_i) > a^{//} \end{cases}$$

where:

$Z(\Delta t_i)$ – sequence of temperature anomalies,$a^{/}$ and $a^{//}$ – appropriate threshold values for identification of anomalies' intensity ($a^{/}$, $a^{//} = k\sigma$; k = ±0.5; ±1.0; ±1.5; ±2.0).

Thus, from a temporary number of thermal parameters some discrete sequence, considerably facilitating learning of temporary features of manifestation of abnormal winters in the region (Fig. 3) is selected.

All experimental observations, on the basis of which this analysis was carried out, were selected conditionally on two periods: 1887-1959 and 1960-1999.

The numerous opinions (Gedeonov 1971; Dzerdzievsky 1975; Imanaeva 1974; Perevedentsev et al. 1994; Pirs 1971; Pirs, Kodratiev 1978) concerning essential increase of greenhouse gas concentration in atmosphere after 1960s have served as the basis for such separate analysis. It was assumed, that those changes were reflected in the regional climate, and expressed in changes of temperatures of winter period. To estimate the variability of winter temperatures, the climatic characteristics for each of selected periods were calculated.

Total numbers of abnormal warm and abnormal cold winters for all studied period were 41 and 43, respectively. Herewith, for the period 1887-1959 the predominance of abnormal cold winters above warm (33 to 21) is noted. During the last decades from total

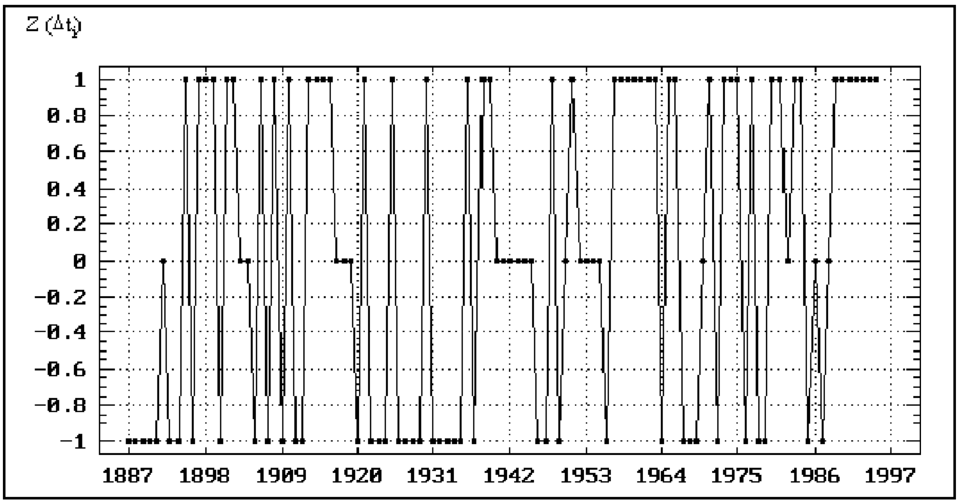


Fig. 3. Trihotomy $Z(\Delta t_i)$ of temporary number describing winters in the Republic of Moldova

number of abnormal winters (30) 10 were cold and 20 were warm. Thus, since 1960s the essential increase of frequency of warm winters is observed. So, for example, if in the first period the number of abnormal cold winters was 51%, than in second period it was only 25%.

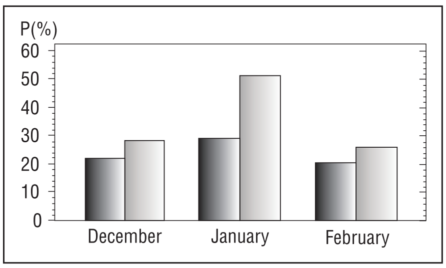
For the first period, frequent sequences of 4 and 5 cold winters are observed (the end of 1880s and the end of 1920s and 1930s), while in the second period (1960-1999), frequent sequences of warm winters are registered (the end of 1950s and 1960s, the end of 1980s and 1990s), even as long as 7 years (Fig. 3). The last decade of the 20th century was probably the warmest one for the whole last century.

Structural features of winter temperatures in terms of intensity of anomalies of average monthly temperatures are analyzed. According to obtained data (Tab. 2, Fig. 4, 5), positive deviation of winter temperatures is the phenomenon specific for Moldova's climate. The probability of positive anomalies of temperatures 0.5σ in winter months is 20-50%. Frequency of deviations amounted in σ – 8-20%. Besides, the anomalies of 1.5σ and even 2.0σ are characteristic for the area of study.

The comparative analysis of temperatures' structure of selected periods has shown significant increase of frequency of their positive anomalies in the second period. So, in January they were 51% in the second period against 28.7% in the first one; in February it was 14% and 5.7%, respectively. The same regularity is characteristic for anomalies of the greater intensity (σ).

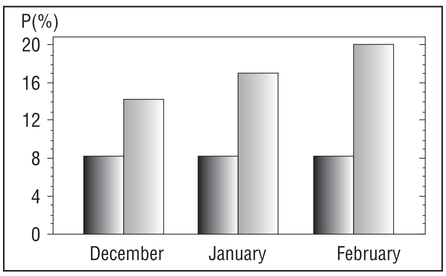
Tab. 2. Frequency (%) of monthly positive deviations in two periods of observations

Intensity of deviations	1887-1959			1960-1999		
	Dec.	Jan.	Feb.	Dec.	Jan.	Feb.
0.5σ	21.9	28.7	20.5	28.6	51.4	25.7
σ	8.2	8.2	8.2	14.2	17.1	20.0
1.5σ	0.0	4.1	1.3	5.7	5.7	14.2
2σ	0.0	0.0	1.3	2.8	2.8	2.8



Note: black columns – period 1887-1959, shaded columns – period 1960-1999

Fig. 4. Probability P(%) of positive deviations of temperatures (0.5σ)



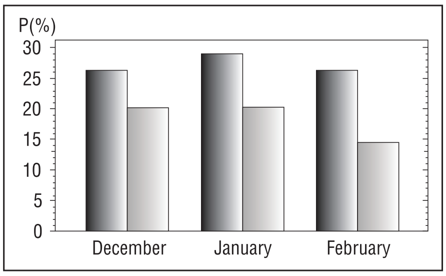
Note: black columns – period 1887-1959, shaded columns – period 1960-1999

Fig. 5. Probability P(%) of positive deviations of temperatures (σ)

As for negative anomalies (-0.5σ), it is necessary to note, that the frequency has decreased irrespective of their intensity (Tab. 3). In December it varies from 26% in the first period up to 20% in the second one, in January – from 28.8% up to 20% and in February – from 26% up to 14.3%, respectively (Fig. 6-7). Such regime of temperatures cannot have an effect on a state of wintering of agricultural crops, as according to Nedealkova (1998), in abnormal warm winters early vegetation and increase of risk of their damage (especially fruit and grapes) are observed, as a result of returns of colds and early frosts. At the same time, we can note that the decrease of frequency of abnormal cold can be regarded as the favorable tendency of dynamics of temperature in terms of wintering conditions of crops.

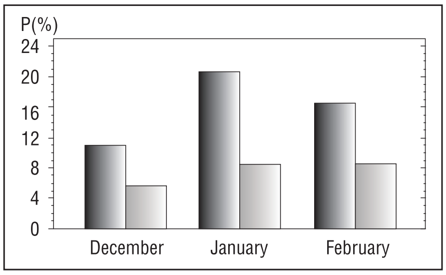
Tab. 3. Frequency (%) of monthly negative deviations in two periods of observations

Intensity of deviations	1887-1959			1960-1999		
	Dec.	Jan.	Feb.	Dec.	Jan.	Feb.
-0.5σ	26.0	28.8	26.0	20.0	20.0	14.3
-σ	10.9	20.5	16.4	5.7	8.5	8.5
-1.5σ	6.8	6.8	6.8	2.8	2.8	2.8
-2σ	4.1	1.3	4.1	2.8	0.0	2.8



Note: black columns – period 1887-1959, shaded columns – period 1960-1999

Fig. 6. Probability P(%) of negative deviations of temperatures (-0.5σ)



Note: black columns – period 1887-1959, shaded columns – period 1960-1999

Fig. 7. Probability P(%) of negative deviations of temperatures (-σ)

Spatial changes of critical temperatures (for drupaceous -23°Cand -25°C) in earlier selected periods can serve as confirmation to the above-told.

The estimation of advantageous of territory of Moldova is based on 10 % probability of plant damage (peach and apricot) by low temperatures. From this point of view it is necessary to note, that in the first period in Moldova there were not any territories with favorable wintering conditions for peach and apricot (Fig. 8a, 8c). Up to a beginning 1960s, the probability of damage by low temperatures of peach and apricot even in southern part of the country was once per 4 years, apricot – once per 7 years.

Fig. 8. Probability (%) of damage by low temperatures of peach (a, b) and apricot (c, d) crones for the period 1887-1959 (a, b) and 1960-1999 (c, d)

In the second studied period (1959-1999) the boundary of risk of allocation of these crops (isoline of 10% supply) reaches the latitude of Kishinev. At present the dangerous temperatures for the wintering of drupaceous are observed once per 10-20 years and once per 50 years, respectively. Therefore, there are possibilities of significant extension of areas of cultivation of the given crops.

The role of climatic supply of wintering conditions for analyzed crops is expressed in the geography of peach and apricot productivity shown in Fig. 9. The norm of apricot productivity is 2.2 tons/hectare and peach productivity 2.1 tons/hectare for the whole territory of the country. Recently in Moldova once per 2-3 years, the droughts are the reason of large losses in agriculture. They occur in all territory of the country, but have the greatest intensity in its southern part. The analysis of data has allowed to reveal that rather often (67% of cases) droughty summer periods' follow after warm winters.

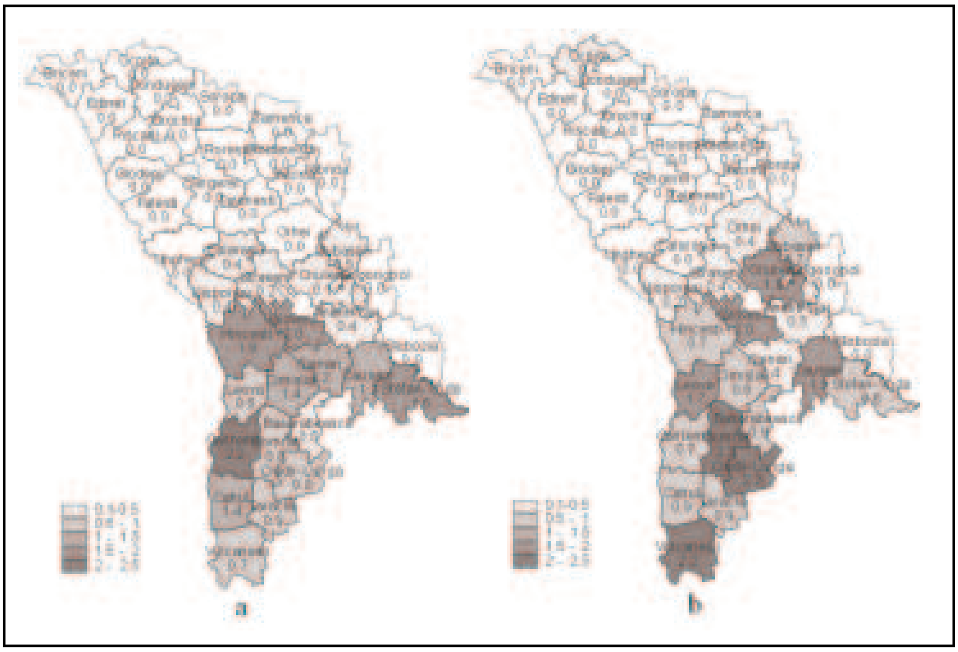


Fig. 9. Productivity (tones/ha) of peach (a) and apricot (b) in 1997, an unfavorable year in respect of wintering conditions

4. Conclusions

The present state of Moldova's climatic system may be summarized as follows:

1. The factors, which are controlling the spatial differentiation of winter thermal fields in the conditions of complex relief of Moldova, have been revealed, using modern methods of multidimensional statistical analysis;
2. A significant increase of abnormal warm winter frequency in Moldova is observed;
3. The geography of cultivation of peach and apricot has varied;
4. The created data base on climate and phenology is a scientific basis for solving numerous problems of optimization of the agricultural crops allocation.

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Potencjał klimatyczny Republiki Mołdawii, jego zmiany i wpływ na produkcję rolniczą

Streszczenie

Sadownictwo jest jedną z najważniejszych gałęzi gospodarki Mołdawii. Brak jednak badań nad potencjałem glebowo-klimatycznym kraju, co pozwoliłoby optymalnie zlokalizować obszary upraw. Niniejsze opracowanie, w którym wykorzystano dane klimatyczne z 14 stacji z lat 1950-1999, przedstawia wpływ czynników geograficznych na reżim termiczny zim (Tab. 1). Zastosowano wielowymiarową analizę statystyczną. Stacja Kiszyniów posiada dane obserwacyjne od 1887 r. i przy pomocy tej serii poszerzono dane dla pozostałych stacji, tak by obejmowały cały okres 1887-1999.

Od lat 60. XX w. obserwuje się znaczący wzrost częstości ciepłych zim. Stwarza to zagrożenie dla upraw owocowych wiosną, związane z możliwością nawrotów mrozów i występowaniem przymrozków, gdy wegetacja jest już dobrze rozwinięta. W okresie 1887-1959 znaczne zniszczenia moreli i brzoskwiń wskutek niskich temperatur zdarzały się raz na 4-7 lat, natomiast w latach 1960-1999 – raz na 10-20 lat (brzoskwinie) i raz na 50 lat (morele). Ostatnio znaczne szkody rolnicze są powodowane w Mołdawii co 2-3 lata przez susze, a 67% suchych okresów letnich następuje po ciepłych zimach.

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