ANALYSIS OF POSSIBLE SPREADING OF THE AREA UNDER CULTIVATION OF LATE MATURITY MAIZE HYBRIDS ON THE TERRITORY OF THE REPUBLIC OF MOLDOVA BY USE OF GIS TECHNOLOGIES

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Показано, что будущее увеличение продолжительности вегетационного периода и соответственно сумм активных и/или эффективных температур позволит перейти уже к 2010-2039 гг. к выращиванию практически на всей территории Республики Молдова среднепозднеспелых гибридов кукурузы ($\sum T_{ак}$ >10^{0}C - 2950^{0}C), обладающих более высокой потенциальной урожайностью, чем их скороспелые аналоги. К 2040-2069 гг. в результате возможных изменений в термическом режиме значительно увеличится и ареал возделывания позднеспелых гибридов кукурузы ($\sum T_{ак}$ >10^{0}C - 3200^{0}C), относительно базового периода 1961-1990гг. Что позволит повысить адаптационный потенциал и урожайность кукурузы как культуры в целом. Так как в среднем в системах выращивания зерновых такие меры адаптации как изменения сортового состава и времени посадки позволяют избежать 10-15% снижения урожайности, что соответствует местному повышению температуры на 1-2^{0}C.

Key words: *maize (Zea mays L.), late maturity hybrids, sum of biologically active and/or effective temperatures, area under cultivation*

Rezumat *S-a relatat, că prelungirea perioadei de vegetaţie şi în consecinţă, creşterea sumei temperaturilor active şi/sau efective, ar urma să contribuie către anii 2010-2039, la sporirea arealului de cultivare a hibrizilor de porumb semitardivi ($\sum T_{ac}$ >10^{0}C - 2950^{0}C), cu un potenţial de productivitate mai mare decât omologii lor timpurii, practic pe întreg teritoriul Republicii Moldova. Către anii 2040-2069, ca urmare a unor eventuale modificări în regimul termic, va creşte în mod semnificativ suprafaţa de cultivare a hibrizilor de porumb tardivi ($\sum T_{ac}$ >10^{0}C – 3200^{0}C), în comparaţie cu perioada de bază (1961-1990). Ceea ce va spori capacitatea de adaptare şi productivitatea a porumbului ca cultură agricolă. Urmează a se ţine cont şi de faptul, că măsuri de adaptare în cadrul sistemele de producţie a cerealelor, precum modificarea compoziţiei de soiuri şi termenilor de*

însămânţare, permit a evita scăderea productivităţii cu circa 10-15%, ceea ce ar corespunde unei creşteri a temperaturii la nivel local cu circa 1-2^0 C.
Cuvinte cheie: *porumb (Zea mays L.), hibrizi semitardivi şi tardivi, suma temperaturilor active și/sau efective, arealul de cultivare*

INTRODUCTION

The yield of cultivated crops is directly dependent on the length of the period during which they can carry the photosynthetic process and accumulate biomass. This dependence is typical for maize. In particular, the length of the growing season and the sum of biologically active and/or effective temperature defines a group of maturity of maize hybrids, which can be grown in specific climatic conditions, as well as their potential yields. Late maturity maize hybrids are usually more productive in comparison with the early-ripening hybrids growing in similar conditions. The most productive maize hybrids are mid and mid-late ripening ones for the climatic conditions of the Republic of Moldova [1].

With the lengthening periods of active vegetation and, correspondingly with increasing the sum of biologically active and/or effective temperatures is possible to cultivate hybrids of later maturing, thus enhancing their adaptive capacity and yield of maize as a crop in general. As generally, within the grain production systems, such adaptation measures like change of sort composition and time of planting allow to avoid a 10-15% reduction of yield, which corresponds to the local air temperature rise of 1-2^{0}C [2].

Therefore, the aim of presented work was to analyze the possible expansion of the area under cultivation the most productive mid-late and late maturity maize hybrids on the territory of the Republic of Moldova as a result of future changes in the length of the growing season and as a consequence increase the sum of biologically active and/or effective temperatures for three time periods according to CSIRO-Mk2, HadCM2, ECHAM4 models relative to the reference period 1961-1990.

MATERIALS AND METHODS

It is known that maize requires a longer growing season and in comparison with other crops is more sensitive to weather conditions. According to some studies, as the lower threshold of maize vegetation start there is accepted the temperature of 10^{0}C [3-7], while according to the others, the 13^{0}C [8-10]. We have chosen as agro-climatic indices the degree of adaptability of the thermal regime for maize cultivation: the date of transition of average daily air temperature over 10^{0}C in spring and autumn; the length of the growing season with air temperatures above 10^{0}C; the sum of the biologically active and/or effective air temperatures above

10^0C. For these agro-climatic indices were calculated the projections of future changes according to global circulation models of the atmosphere and ocean (GCM): CSIRO-Mk2, HadCM2 and ECHAM4, for three time periods (2010-2039, 2040-2069 and 2070-2099) relative to the reference period of 1961-1990. IS92a scenario served as the basis for the determination of the greenhouse gas emissions development patterns. GCM scenarios are available in the archives of Hadley Center for Climate Prediction and Research (http://ipcc-ddc.cru.uea.ac.uk/ is92/gcm_data.html) (DDC GCM Data Archive). A spatial assessment of the possible spreading of the area under cultivation of mid-late and late maturity maize hybrids on the territory of the Republic of Moldova as a result of the future changes in the thermal regime has been undertaken by use of the computer program EcoClass [11, 12]. The respective program is based on GIS technology and allows generating maps of spatial and temporal distribution of agro-climatic indices for the reference climate scenario and other different climate change scenarios. The main input data of the program are: the average daily air temperature and the average daily precipitations for the 1961-1990; climate change scenarios, which include models of global atmospheric and ocean circulation (GCM): CSIRO-Mk2, HadCM2 and ECHAM4.

RESULTS AND DISCUTION

With the temperature conditions of growth and development of maize are closely related the issues of agro-climatic zoning of this crop. For the normal passage of ontogeny (from germination to full maturity of grain) maize plants shall receive a certain amount of heat. This amount represents the sum the average daily air temperatures during the vegetative season, except for days with daily average air temperature below 10^0C. To be noted that the maize hybrids which are distinguished along the length of the vegetative season require different sum of cumulated air temperatures.

In a range of studies [13, 9, 10, 3, 4, 6, 7, 14 and others] there were revealed the sum of biologically active and/or effective temperatures needed for maize plants to achieve the certain phenological phases of development, inclusive the physiological maturity of the grain at hybrids of ifferent group of maturity.

As an example, could serve the classification of Shashko [cit. to 6] developed on the base of scientific literature analysis and personal researches (Table 1).

Table 1: Heat Demand of Different Maize Hybrids and Varieties by Phenological Phases of Vegetation, according to D.I. Shashko

Group of maturity	Phenological phases of vegetation	Sum of temperatures (^{0}C)	
		Biological	Bioclimatic
The earliest (Beloiarskoe psheno et al.)	sowing – silking	1100	1350
	sowing – milk ripe	1700	1950
	sowing – maturity	2100	2350
Early (Bezenchukskaia 41 et al.)	sowing – silking	1200	1450
	sowing – milk ripe	1800	2050
	sowing – maturity	2200	2450
Semi-early (Harcovskaia 23 et al.)	sowing – silking	1300	1550
	sowing – milk ripe	2000	2250
	sowing – maturity	2500	2650
Mid (VIR 25 et al.)	sowing – silking	1400	1650
	sowing – milk ripe	2100	2350
	sowing – maturity	2500	2750
Mid-late maturity (Krasnodarskii et al.)	sowing – silking	1500	1750
	sowing – milk ripe	2200	3450
	sowing – maturity	2700	2950
Late maturity (VIR 166 et al.)	sowing – silking	1600	1850
	sowing – milk ripe	2300	2550
	sowing – maturity	2900	3150

Using the data presented in Table 1 and the sum of biologically active air temperatures $\Sigma T_{ac} > 10^0$C, it is possible in the first approximation to identify potential areas of cultivation under maize hybrids and varieties with different maturity degree.

For accuracy of calculations it had better use the bio-climatic temperatures. The *sum of bioclimatic temperatures represents the sum of biological air temperatures, increased by a certain amount to guarantee the full yield ripening (or the occurrence of the desired phase of vegetation).* Thus for instance, the late maturity maize hybrid LG 25.33 (LZM 549/06) for grain can be cultivated just southward of $\Sigma T_{ac} > 10^0$C - 3200^{0}C; mid maturity maize hybrid PORUMBENI 375 AMRf, respectively southward of $\Sigma T_{ac} > 10^0$C - 2800^{0}C and the early maturity hybrids and varieties - southward of $\Sigma T_{ac} > 10^0$C - 2400^{0}C. Northward of this line growing of grain maize cannot be guaranteed, there can be cultivated only the maize for silage or for green feed.

For comparative assessment of heat requirements of different maize hybrids it is sometimes used the biological indicator 'number of leaves on the main stem' [13]. It was revealed, that the respective character of precocity of the maize hybrids and varieties it is closely related with the indices of ‘sum of active $\Sigma T_{ac}> 10^0C$ and/or effective $\Sigma T_{ef}>10^0C$ air temperatures.

Average daily air temperatures can be transformed into effective air temperatures by subtracting the biological minimum (i.e., temperature 10^0C) from each average daily index, then by summarizing the obtained temperatures during the whole growing season.

Although in the southern regions during the daytime the air temperature often exceeds 30^0C, when the growth and development of plants are significantly suppressed. Such temperatures are called ‘ballast temperatures’ and they must also be considered. It was obtained the equation which permits to switch from $\Sigma T_{ef}> 10^0C$ (x) to the sum of effective temperatures without ballast (y). This relationship is represented by the equation: $y = 0.74x + 140$. By using the respective equation it is possible easily to calculate the effective temperatures without ballast for each maize development phase in any area of its cultivation [15].

By using the sum of biologically active and/or effective temperatures can be also predicted the possibility of additional cultivation of crops on the same plot of land. The study [16] revealed that the sum of effective temperatures $\Sigma T_{ef}> 10^0C$ in the Central and Southern areas of the country, since the period of harvesting the winter crops (early July) until the stop of vegetation period at maize (the first decade of October), has constituted $800\text{-}860^0C$. During this period, the early-maturing maize hybrids can achieve the dough phase of grain ($820\text{-}840^0C$), while the semi-early and mid maturing maize hybrids can achieve the milk- dough phase of grain ($850\text{-}880^0C$).

Table 2: Development of the Growth Pattern in the Average Daily Air Temperature above 10^0C and the Length of the Period with Temperatures above 10^0C for the Three Time Periods According to the CSIRO-Mk2, HadCM2 and ECHAM4 Models in Comparison with the Reference Climate Period (1961-1990)

Region	CSIROMk2			HadCM2			ECHAM4		
	The date when the average daily air temperatures exceeds 10^0C		Deviation (+/-) as compared to 1961-1990	The date when the average daily air temperatures exceeds 10^0C		Deviation (+/-) as compared to 1961-1990	The date when the average daily air temperatures exceeds 10^0C		Deviation (+/-) as compared to 1961-1990
	Spring	Autumn		Spring	Autumn		Spring	Autumn	
2010-2039									
North	06.04	15.10	+20	21.04	19.10	+9	20.04	15.10	+6
Center	30.03	19.10	+24	08.04	23.10	+20	04.04	20.10	+21
South	29.03	22.10	+26	06.04	26.10	+22	29.03	22.10	+26
2040-2069									
North	04.04	21.10	+28	21.04	25.10	+15	04.04	19.10	+26
Center	29.03	26.10	+33	04.04	31.10	+32	27.03	26.10	+35
South	27.03	31.10	+37	01.04	01.11	+33	26.03	07.11	+45
2070-2099									
North	01.01	22.10	+32	07.04	25.10	+29	25.03	26.10	+43
Center	29.03	07.11	+45	04.04	13.11	+45	21.03	12.11	+58
South	28.03	12.11	+48	30.03	13.11	+47	18.03	13.11	+59

Note. The observed mean annual date of the transition air temperature over 10^0C and the length of the period with average daily air temperatures above 10^0C during the base period 1961-1990: North in the spring - 22.04, in the autumn 10.10 (173 days); Center: in the spring - 20.04, in the autumn -16.10 (179 days); South: in the spring - 21.04, in the autumn - 19.10 (182 days), respectively.

New conditions of heat supply for maize (see Table 2) is estimated as changes in the length of the period with the average daily air temperatures above 10^0C, as well as the degree-days sum of this temperature (see Table 3). In the future climate, due to earlier springs and longer autumns, it is expected that there will be a significant increase in the length of the vegetation period (Table 2).

Long-term average observed length of the vegetation period with the average daily air temperatures above 10^0C changed across the territory: from 173 days in the North to 182 days in the South of the country for the reference climate 1961-1990. By the end of 2099 year the length of the vegetation period will be significantly increased, varying within the range of 29-43 days in the North and 47-59 days in the Centre and South of the Republic of Moldova. An increase in the length of the vegetation period is accompanied by a corresponding increase in degree-days.

Table 3: Projections of Changes in the Amounts of Active and /or Air Temperatures above 10^0C for the Three Time Periods According to the CSIRO-Mk2, HadCM2 and ECHAM4 Models in Comparison with the Reference Climate Period 1961-1990

Region	CSIRO-Mk2				HadCM2				ECHAM4			
	$\sum T_{AC} > 10^0C$	(+/-) to 1961-1990	$\sum T_{EF} > 10^0C$	(+/-) to 1961-1990	$\sum T_{AC} > 10^0C$	(+/-) to 1961-1990	$\sum T_{EF} > 10^0C$	(+/-) to 1961-1990	$\sum T_{AC} > 10^0C$	(+/-) to 1961-1990	$\sum T_{EF} > 10^0C$	(+/-) to 1961-1990
2010-2039												
North	3224	+479	1294	+269	3174	+429	1354	+329	3126	+381	1336	+311
Center	3719	+554	1679	+304	3758	+593	1728	+353	3712	+547	1713	+338
South	3788	+566	1708	+306	3798	+376	1758	+356	3824	+602	1744	+342
2040-2069												
North	3504	+759	1494	+469	3507	+762	1627	+602	3513	+768	1523	+498
Center	4025	+860	1904	+529	4134	+969	2024	+649	4066	+901	1926	+551
South	4121	+899	1931	+529	4207	+985	2057	+655	4234	+1012	1964	+562
2070-2099												
North	3763	+1018	1714	+689	3837	+1092	1817	+792	4117	+1372	1967	+942
Center	4379	+1214	2139	+764	4523	+1358	2233	+858	4715	+1550	2406	+1031
South	4472	+1250	2172	+770	4564	+1342	2274	+872	4861	+1639	2451	+1049

Note. The observed mean annual sum of active and effective temperatures for the reference period 1961-1990: $\sum T_{AC} > 10^0C$: North (2745^0C), Center (3165^0C), South (3222^0C); $\sum T_{EF} > 10^0C$ - North (1025^0C), Center (1375^0C), South (1402^0C).

The obtained results show that a pronounced pattern of the significant sum of air temperatures growth will persist during the next 100 years for the days with the temperatures above 10^0C. Already by 2039 year the sum of biologically active temperatures $\Sigma T_{ac} > 10^0C$ will grow by 429 and 479^0C and make 3174 and 3224^0C in the North of the Republic of Moldova under HadCM2 and CSIRO-Mk2 models, the respective values would constitute 381^0C and 3126^0C respectively under the ECHAM4 model.

By 2099 year the sum of biologically active temperatures $\Sigma T_{ac} > 10^0C$ will be within the range of 3763-4175^0C in the North of the Republic of Moldova and as high as 4379-4715^0C and 4472-4861^0C respectively in the Central and Southern zone (Table 3).

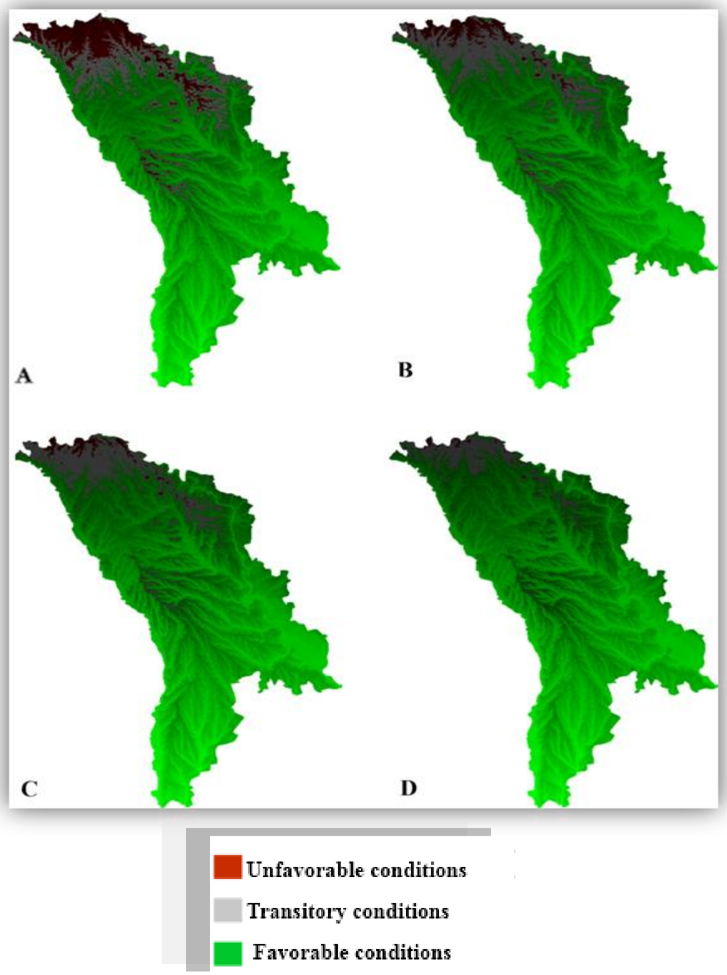

Figure 1: Distribution of the potential spreading area under the mid-late maturity maize hybrids as KISHINIOVSKYI 401 L, LG 34.09 (LZM 451/05), MOLDAVSKYI 411 MRf, MOLDAVSKYI PORUMBENI 459 MRf 425 MRf, MOLDAVSKYI 450 MRf, PORUMBENI 458 CRf on the Republic of Moldova's territory. $\sum T_{AC} > 10^0C$ **- 2950⁰C**

A. Reference Period, 1961-1990, B. CSIRO-Mk2, 2010-2039, C. CSIRO-Mk2, 2040-2069 , D. CSIRO-Mk2, 2070-2099

Note: Names of hybrids and maturity groups are given according to the National Register of Plant Varieties, 2009 [17].

Such changes in the thermal regime on the Republic of Moldova's territory, in particular the increase of the length of vegetation period with active temperatures above 10^0C and, correspondingly the increase of the sum of biologically active temperatures ΣT_{ac}> 10^0C and/or effective temperatures ΣT_{ef}> 10^0C would lead to a possible spreading to the North of the area under cultivation of mid-late and late maturity maize hybrids.

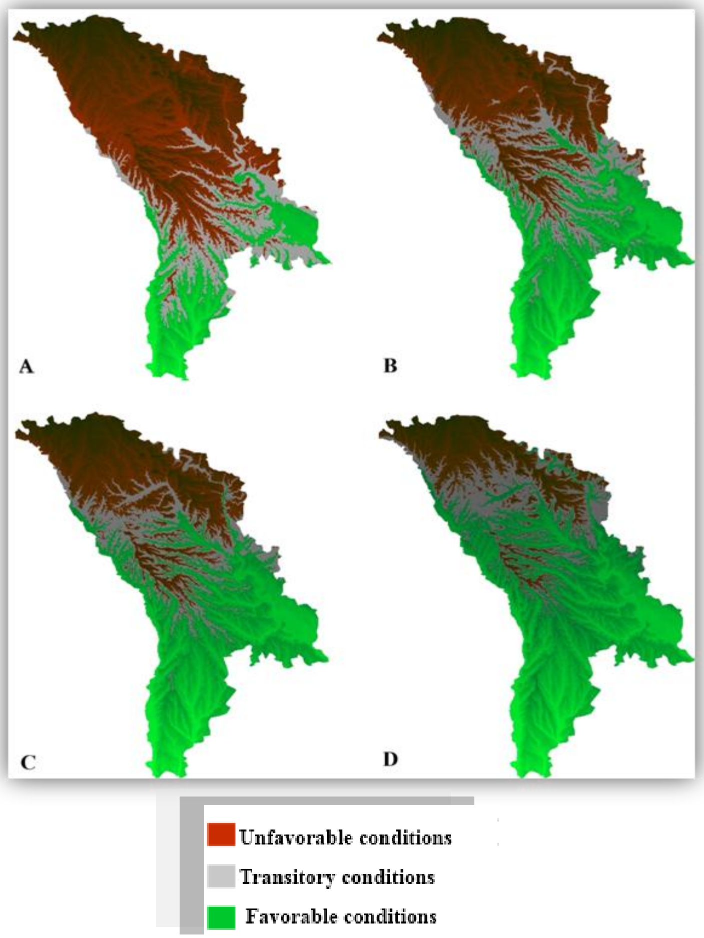

Figure 2: Distribution of the potential spreading area under late maturity maize hybrids as CANTABRIS (ESM 44X), ES DIADEME (RM 23), ES SENSOR (ESM 54X), LG 25.33 (LZM 549/06), FRUCTIS (RM 25), KWS 3381 (KXA 3381), KWS AMBER (KXA 6378) on the Republic of Moldova's territory. $\sum T_{AC}$ >10^0C - 3200^0C

A. Reference Period, 1961-1990, B. CSIRO-Mk2, 2010-2039, C. CSIRO-Mk2, 2040-2069

D. CSIRO-Mk2, 2070-2099

Note: Names of hybrids and maturity groups are given according to the National Register of Plant Varieties, 2009 [17].

The assessment of the potential spreading of the area under cultivation with mid-late and late maturity maize hybrids as impact of future climate change has been undertaken through the use of the computer program EcoClass. Figures 1 and 2 show the possible spreading of the area under cultivation with mid-late and late maturity maize hybrids according to the CSIRO-Mk2 model for the three time periods 2010-2039, 2040-2069 and 2070-2099, as compared to the climatic values registered during the reference period of 1961-1990. To determine the suitability of the thermal regime for cultivating mid-late and late maturity maize hybrids on the territory of the Republic of Moldova it was used the index 'cumulated biologically active temperatures' $\sum T_{ак} > 10^0C$, which amounted 2950^0C and 3200^0C, respectively.

During the 1961-1990 time series (Figure 2A) the favorable conditions for cultivating the late maturity maize hybrids has existed only in some Southern areas of the Republic of Moldova and in certain very limited areas in the Center and the Western part of the country. Within the 2070-2099 years the favorable conditions for cultivating the respective hybrids will exit almost on the whole territory of the Republic of Moldova (Figure 2D). The EcoClass program is able to generate maps – similar to those exposed below (Figures 1 and 2), revealing the optimum conditions which would determine the potential spreading area under any other varieties or hybrids cultivated or expected to be cultivated in the Republic of Moldova or for any wild flora species, any pest or pathogen causing plant damage or disease for any point in time during the period of 2010-2100.

CONCLUSION

It was revealed that a further increase of the length of vegetation period and respectively, of the sum of active and/or effective temperatures, would allow by the years of 2010-2039 the cultivation of mid-late maturity maize hybrids ($\sum T_{ac} > 10^0C$ - 2950^0C) with a greater productivity potential than their earlier counterparts, by almost the entire territory of the Republic of Moldova.

By the years of 2040-2069, as a result of expected changes in the thermal regime, there will increase significantly the area under cultivation with late maturity maize hybrids ($\sum T_{ac} > 10^0C$ - 3200 ^0C), comparative with the reference period (1961-1990). This will increase the adaptation potential and the productivity of maize as a crop. In general, in the respective agricultural systems, such adaptations measures as changes in the sort composition and planting periods, allow to avoid the yield decline in productivity by circa 10-15%, which corresponds to a local temperature rise by 1-2^0C.

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