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Sunflower's Productivity in the Context of Climatic Changes on Republic of Moldova's Territory

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Abstract: Current climate change represents a serious threats to sustainable development by its accelerated its pace of manifestations and inability to adequately adapt to these changes. Increasing intensity and frequency of climate change' related risk have conditioned the need to conduct a parallel study on the specifics of regional climate change and weather-climate risks' manifestation. The results indicate that the financial damage caused by some climatic related risks in recent years can substantially destabilize the country's economy.

Keywords: climate change, environmental risks, spatio-temporal estimation

Introduction

Since agricultural practices are climate-dependent and yields vary from year to year depending on climate variability, the agricultural sector is particularly exposed to changes in climate. Simulations executed on global level on the effect of climatic changes' influence on some cereals' productivity (wheat, maize) demonstrate that a significant decrease in their yield is forecasted for South-Western Europe for nearest future years (Parry *et al.*, 2004). As the above-mentioned area is the prevailing zone for cultivation of sunflower culture in Europe (Debaeke *et al.*, 2017), the knowledge of climatic changes consequences on the regional level is crucial. We should mention that according to the simulations made for Eastern Europe (Hungary, Bulgaria, and Romania) a significant decrease in sunflower's yield (12–14 %) is expected in 2030 (Donatelli *et al.*, 2012).

At the same time although sunflower is generally known as a drought-tolerant crop and consequently as a cropping opportunity for regions where

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water resources (used for irrigation) are decreasing and in situations where soil water deficit is expected to increase dramatically (García-Vila *et al.*, 2012), nevertheless the impact of dry periods (in certain years) on sunflower yield on the local level can be substantially negative (Duca *et al.*, 2016b). It was however demonstrated (Ahmad *et al.*, 2014) that water stress inhibits plant growth, decreases developmental activities of the cells and tissues and causes a variety of morphological, physiological and biochemical modifications.

Increase of dry periods in recent years conditioned mainly by the hydric deficit and also by the high temperatures that prevail during a lengthy time period, contributes to the necessity of investigations that would demonstrate the unfavourable influence of prolonged thermal stress. For example, according to De la Haba *et al.* (2014) its impact (a day/night regime of 33/19 °C for 16–42 days) on sunflower plants leads to decreased leaf mass. It was also demonstrated that temperatures higher than 31 °C are detrimental for sunflower yield because they affect pollen production and floret fertility (Chimenti and Hall, 2001).

Extreme climatic events registered in many European countries and simulations executed for nearest future years demonstrate the increasing trend for these events which would have a major impact on agriculture and food safety. Some of the obtained results had revealed that an earlier development phases and reduction of active vegetation period are already taking place. These changes could protect some of the agricultural crops from the influence of stressful droughty summers (in the case of perennial crops), while some agricultural crops can be significantly affected by the frequent and intensive manifestation of extreme climatic events (for example, early or late frosts, or heat waves) during their sensitive phenologic phases, which in its turn would result in damage done to the final crop's quantity and quality. At the same time, the knowledge of both frequency and intensity of extreme climatic events' manifestation and development phases' manifestation and crop level, and also selection of new stress-free areas favourable for cultivation would be a basis for various adaptation strategies to new climatic conditions in the region.

Materials and methods

At present stage it is a well-known concept of climatic evolution acceptable within the limits of a so-called "corridor" *(Tolerable Windows Approach, TWA)*. For mean global temperature it ranges between $T = 2.0°C$ *and* $T = 0.015°C/year$.

The given method is quite important for argumentation of effective measures preventing unfavourable climatic changes. While the trend of mean annual temperature warming is 0.01 23*°C/year* for Republic of Moldova's territory during the last 129 years (1887–2016), i. e. climatic changes are within the acceptable "corridor", the estimations of the last decades demonstrate a more pronounced rate of "warming".

Comprehensive regional climatic study included in the last Report (Ar5) of Intergovernmental Panel on Climate Change (IPCC) reveals that these increasing tendencies will continue (IPPC, 2013). Taking into account the increase in intensity and frequency of climatic risks during last decades we can conclude that this trend would continue to be observed in future (Figure 1).

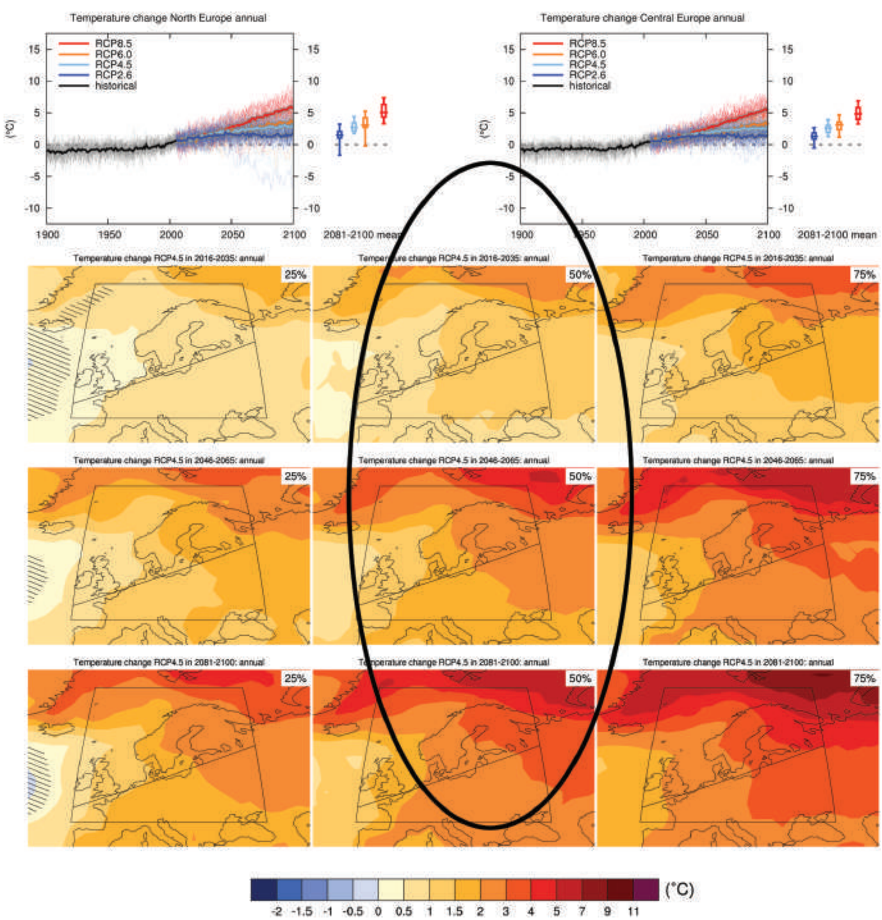

Figure 1: Atlas of global and regional climate projections.

In the given work we took into account ratio of physico-geographic factors that contribute to redistribution of climatic elements when elaborating cartographical models on regional, basinal and local level.

The optimal selection for significant predictors was executed (Figure 2) when revealing the ratio of independent variables influence (geographic factors: geographic latitude and longitude, absolute and relative altitude, orientation and slope, old erosional fragmentation's degree) over the variability of dependent values (temperature, atmospheric precipitations and other parameters) using multiple regression analysis with various alternative procedures:

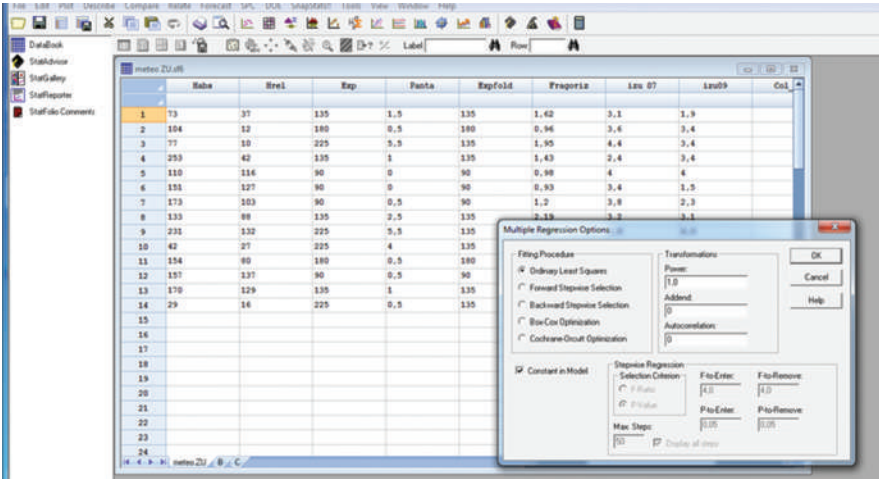

Figure 2: Estimation of physico-geographic factors' ratio in climatic parameters redistribution using multiple regression analysis.

– step procedure with successive adding of variables;
– step procedure with successive excluding of variables;
– selection according to Melous's criterion, expressed as follows:

$$C = \left(SSEp - S^2\right) - (N - 2p) \qquad (1)$$

where S^2 – mean square error of the model and includes in itself a multitude of variables, $SSEp$ – sum of square errors of the model with p parameters, and N is the volume of selection.

– selection according to the version of determination coefficient R^2, corrected at the level of parameters' multitude in the model which is determined according to the following formula:

$$R^2 = 1 - [(n-1)*(1-R^2)]/(N-P) \tag{2}$$

As the influence of different physico-geographic factors in climatic fields' distribution is not equivalent, we select a set of factors "responsible" for their "prediction". It is crucial that in the obtained regressional model one should always monitor R^2 value (determination coefficient) and of significance level for each factor, that is introduced in the model, apart. Those are the basic indicators that reveal the obtained model's quality in statistical software Statgraphics Centurion XVI.

In continuation, the obtained regression equations together with informational layers that characterize physico-geographic factors allow calculating of digital maps with spatial distribution of climatic parameters in study, that being executed on ArcGis 10.2 software. Thus, Regional Geographical Informational Systems as an instrument for investigation ensures storage and operative testing of necessary data for complex interpretations of a climatic character.

As the dry days' duration in May-August period directly influences the development of main phenologic phases of agricultural crops, we recommend using the Index of Dry periods (*Izu*), as it represents the ratio of their sum registered in certain years to their mean multiyear value for the above-mentioned period as shown in the following expression:

$$Izu = \frac{\sum zu_{(V-VIII)}}{\bar{X}zu_{(V-VIII)}}, \tag{3}$$

where $\Sigma zu_{(V\text{-}VIII)}$– the sum of dry days registered in May-August period, when growth and intensive development of agricultural crops takes place, $\bar{X}zu_{(V\text{-}VIII)}$ – mean multiyear of dry days (for May-August).

The grading of *Izu* allows identifying aridity degree during sunflower's growth and development in the most sensitive phases of development.

Crop forming is a very complicated process determined by the crop's biological particularities and territories' agrometeorological conditions. Agricultural crops achieve only 35–45 % of their possible biological potential in natural conditions of arid and semi-arid zones. Producing the new cultivars and technical scientific progress in agriculture in the following decade would mostly depend not only on the breakthroughs in biology and technology, but also on the optimal usage of climatologic data. That' why we consider that improvement of usage and correct estimation of actualized climatic data would play a deciding role in estimation of agricultural crops' loss after unfavourable meteorological factors manifestations at present stage.

In specialist literature these problems were described by many scientists. After the conducted investigations we had determined and estimated quantitatively the influence of main meteorological factors that condition crops productivity and lays a basis for a new scientific direction in the domain of elaborating a new method of long-term prognosis for productivity.

Each extreme factor is negatively influencing agricultural crop's productivity. Still the level of the negative influence of climatic factors on the plants' productivity depends also both from phenomenon's intensity and durations, and also from the time of its manifestation according to the phonological phase. Many agricultural plants are more sensitive in the period of reproductive organs' formation, which influence their productivity

In some cases the plants are under the influence of unfavourable factors during the whole period of active vegetation. In the years with the well expressed unfavourable conditions we observe a significant deficit of precipitations, high temperatures etc., when essential losses in crops cannot be explained according to the mediated agrometeorological factors, and thus the manifestation of short-term (a day or several hours) extreme factors (cold snaps, heavy frosts, canicular days etc.) could influence these losses directly.

In this context, we are able to state that climatic indexes expressed by generalized characteristics such as mean values or sums for the entire vegetation period, mainly do not reflect the real conditions of temperature and humidification in plants' productive process. For example one and the same sum of atmospheric precipitations or of active temperatures can be obtained as a result of these values accumulation in the short interval of time or may be accumulated in a bigger time interval on the background of mean smoothed values.

That is why in order to resolve this task effectively we need to use climatic information for short time periods, say, for ten-days periods or short time periods with the dominance of one meteorological situation (especially in the case of manifestations of extremes). At this scale we can select the presence of a more vulnerable period in agricultural crops development, from the point of view of their favourability or un-favourability for productivity. It is crucial for elaboration of strategies for agriculture's optimization. So, the information based on plants' growth and development estimation per ten-days basis would allow us estimating the probable loss from crops on the studied territory in anomalous years from the point of view of meteorological conditions, to propose placement strategies that would diminish crop loss for certain climatic conditions in the case when the level of cultivation and other economic conditions are respected.

This idea seems to have perspective and needs a detailed research, so we thus consider that then we estimate an area from agroclimatic point of view we should take plants' certain biological particularities into account in order to be able to offer normal or optimal conditions for their growth and development.

It is evident that in order to exactly estimate the conditions of productivity formation we could use the measure of productivities' modification, which is a particular index in climatic system's variability.

That's why we consider that agricultural crops' productivity (Y_i) from the agroclimatic point of view should be viewed as a sum of two components and is necessary in estimating the role of meteorological factors in productive process forming, a fact that was demonstrated also by the previous research (Nedealcov, 2012).

It is presented by the following formula:

$$Y_i = Y_i^{(T)} + DY_i^{(T)} \tag{4}$$

where $Y_i^{(T)}$ is dynamic average, determined by the intensity rate of agricultural development and climatic conditions close to the mean multiyear value, and deviation from it is $\Delta Y_i^{(T)}$ and it is explained on the basis of climatic conditions anomalies from the latter.

In all the above-mentioned investigations it was taken into account that in the years with positive anomalies of productivity none of the agrometeorological factors had an essential influence on the crop (favourable years) and vice versa, the years with negative anomalies of productivity are determined by excessive manifestation or lack in some of the agrometeorological factors (unfavourable years). For Republic of Moldova's territory, which is mainly ensured by heat resources and fertile soils, the main cause losses in sunflower crops is the humidification regime, that's why it serves as a determinative factor (Duca *et al.*, 2016a, 2016b; Nedealcov, 2012).

At the same time, the case of insignificant deviations of productivity from the dynamic average are hard to state, as they can be determined not just by the humidification or thermal conditions, but also by disrespecting cultivation levels, the influence of depredators etc. If we exclude them (conventionally) by trend component and estimate positive and negative anomalies in agricultural plants' crops together with optimal or extreme years from meteorological point of view we would be able to identify a correlative connection between the environmental factors and productive process of sunflower.

Results and discussions

Thus, in conditions of Republic of Moldova in 1960-prezent period we observe decrease in this crop's productivity by 0.0659 q/ha/year (Figure 3).

Analysis of favourable/unfavourable years from agroclimatic point of view Table 1 (Table 2), demonstrates the fact in the last years climate warming had

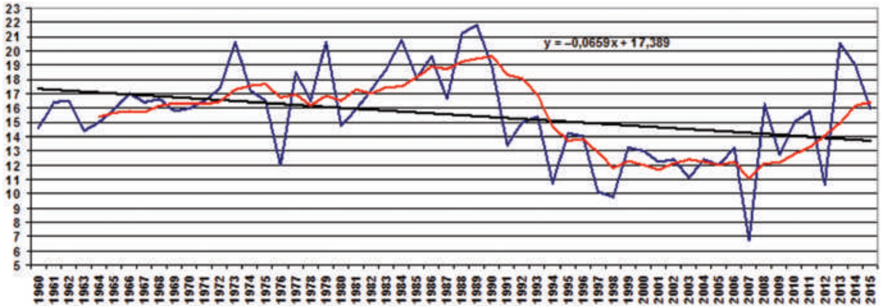

Figure 3: Sunflower crop evolution on Republic of Moldova's territory.

Table 1: Index of dry periods' grading system (*Izu*) by M. Nedealcov. Dangerously dry periods are marked in yellow.

Izu Values	*Izu grades*
0.1–1.0e	Normal period
1.1–2.0	Moderately dry period
2.1–3.0	Significantly dry period
3.1–4.0	Dangerously dry period
> 4.1	Extremely dry period

Table 2: Analysis of years with high and low sunflower crops of Republic of Moldova's territory. Negative crop anomalies conditioned only by unfavorable meteorological conditions are marked in yellow, positive crop anomalies in blue.

Unfavourable years			Favourable years
2007	6.9	1989	21.8
1998	9.8	1988	21.2
1997	10.1	1984	20.7
2012	10.6	1973	20.6
1994	10.7	1979	20.6
2003	11.1	2013	20.5
1976	12	1986	19.6
2005	12.1	2014	19
2001	12.2	1990	18.8
2002	12.4	1983	18.7

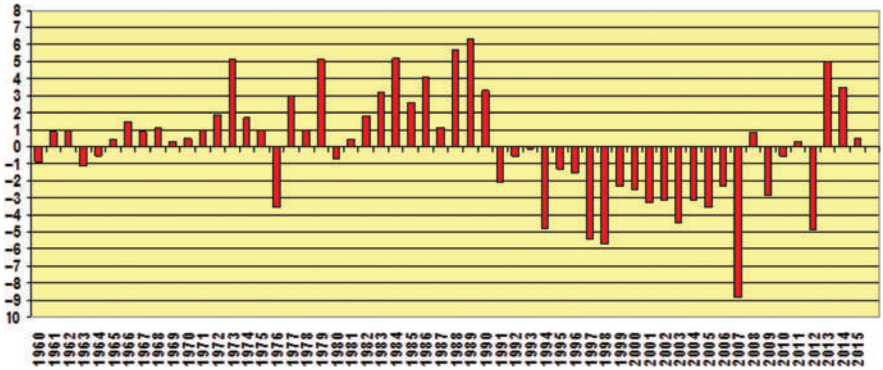

Figure 4: Anomalies in sunflower crops on Republic of Moldova’s territory.

determined low sunflower crops, and the biggest negative anomalies (−8.8 q/ha) of this plant’s crop (Figure 4) was conditioned in total by the lasting heat waves in spring-summer of 2007. At the same time we state that in the case of fulfilling sunflower’s necessities in water that were observed in 2013, 2014, the crops were contrariwise high.

Thus, in June and July 2007 monthly precipitations sum was equal to 27 mm and 4 mm correspondingly, while monthly climatic norm is 68.2 and 66.7 mm accordingly. At the same time the pluviometric values in 2013 were optimal for these months, namely 69 and 102 mm correspondingly. Thus the thermal stress of the last years had influenced this plant’s crops considerably.

In this context, it is necessary to have knowledge of regional climate change particularities for nearest future years and specifics of heat waves manifestation in regional aspect (Nedealcov, 2016)

Thus, mean annual air temperature (Figure 5(a)) on Republic of Moldova’s territory demonstrates a growing trend of 0.0123 °C/year, during 1887–2016 periods.

Year 2007 is still the warmest year within the range of instrumental observations (1887–2016), “closely followed” by years 2015 and 2016 with significant thermal values. Year 2009 is on the third place, but years 2012, 2013 are placed (according to their thermal values) after year 2000 „throw away” from the top of the warmest years such years as 1966, 1989, 2002 which were included in recent studies. Year 2013 represents a temporal limit of extremely warm years, when mean annual temperature equalled 11.1 °C compared with mean multiyear value of 9.6 °C (Table 3).

If, according to (Duca *et al.*, 2016a), a manifestation of extreme warm years had a once in two years return period during the last two decades, when including last 5 years into analysis we state that 8 years from the top of warmest

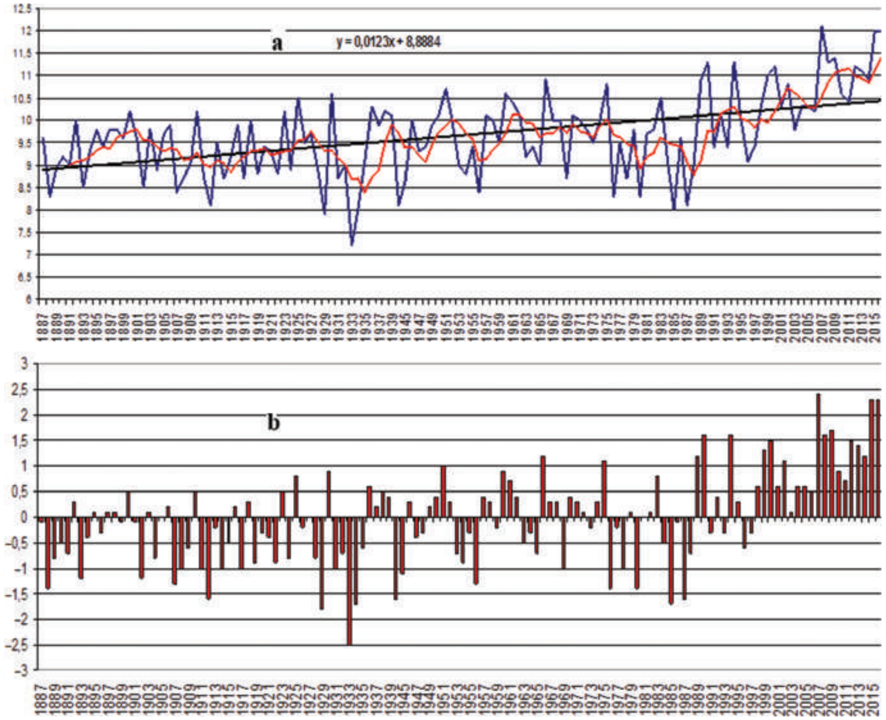

Figure 5: Mean (a) annual temperature's modification tendency (1887–2016) and temperature anomalies (b).

Table 3: Top of coldest and warmest years registered in 1887–2016 period.

1887–2010 (Duca *et al.*, 2016a)				**1887–2016**			
Coldest years		**Warmest years**		**Coldest years**		**Warmest years**	
1933	7.2	**2007**	12.1	1933	7.2	**2007**	12.1
1929	7.9	**2009**	11.4	1929	7.9	**2015**	12
1934	8.0	1990	11.3	1934	8.0	**2016**	12.0
1985	8.0	1994	11.3	1985	8.0	**2009**	11.4
1912	8.1	**2008**	11.3	1912	8.1	1990	11.3
1940	8.1	**2000**	11.2	1940	8.1	1994	11.3
1987	8.1	1999	11.0	1987	8.1	**2008**	11.3
1888	8.3	1966	10.9	1888	8.3	**2000**	11.2
1976	8.3	1989	10.9	1976	8.3	**2012**	11.2
1980	8.3	**2002**	10.8	1980	8.3	**2013**	11.1

years (from 1887–2016 time series) belong to 2000–2016 period (2007, 2015, 2009, 2008, 2000, 2012, 2013).

Regional climatic study simulates an increase of mean annual temperature in South-Eastern Europe (Duca *et al.*, 2016b) and this increase varies depending on scenario.

For example, according to climatic scenario RCP 4.5, within republic’s limits an increase with approximate 1.5 ... 2.0 °C is projected within republic’s limits. The digital map (Figure 6(b)) of mean annual temperature’s spatial distribution during 2016–2035 demonstrates that in Southern and South-Eastern extremities it can reach a value of more than 12.5 °C, and in the Northern parts of the country mean annual temperature can reach the values of 10.5–11.0 °C. We should note that according to the cartographic model (Figure 6(a)) elaborated for 1986–2005 period (the reference period in the case of proposed climatic simulations), mean annual temperature had a value of 10.5–11.0 °C in Southern and South-Eastern parts, and in Northern parts on the altitudes it varied within the limits of 9.5–10.0 °C, being close to climatic norm (9.6 °C).
We consider that these studies that demonstrate such accelerated rate of expected warming but still varied in space could contribute in careful selection of measures for climatic changes’ consequences mitigation.

In the same time, quantile plot (Figure 7) of Dry Periods Index (Izu) demonstrates that during the last years were also registered extremely dry periods in

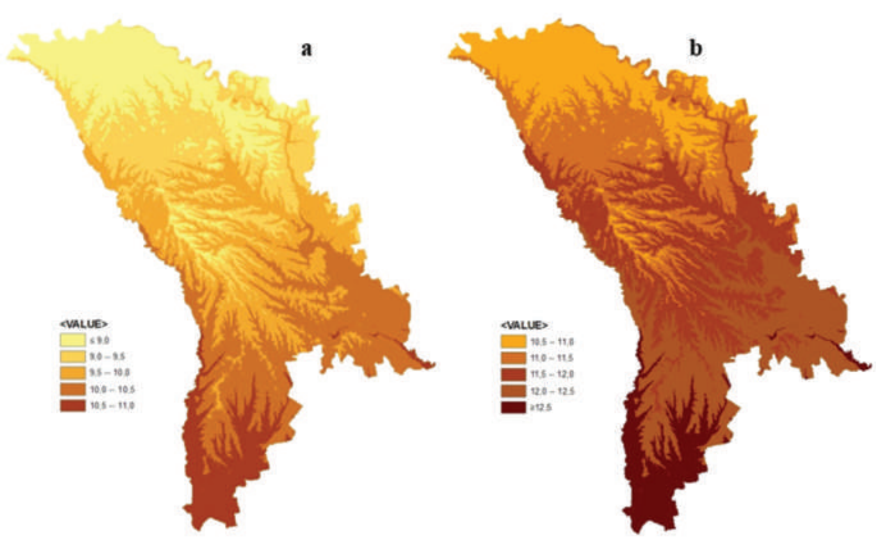

Figure 6: Cartographic modeling (according to RCP 4.5) on mean annual temperature’s distribution in actual (a- 1986–2005) and in the 2016–2035 period (b).

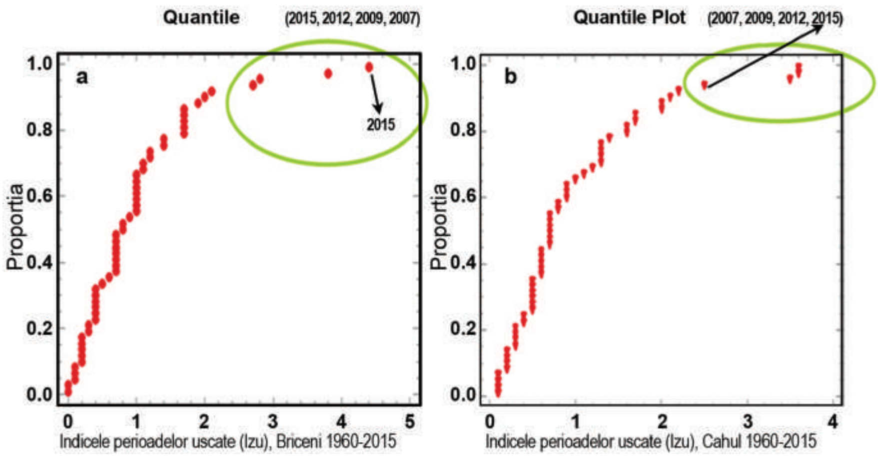

Figure 7: Quantile plot of Dry periods index (Izu) with extreme years identified in Northern (a) and Southern (b) part of Republic of Moldova.

May-August. Thus, in Northern part the most dangerous dry periods were registered in 2015, 2012, 2009, 2007, while Southern part has inverse order of years: 2007, 2009, 2012, and 2015. Thus, while the same extreme years chronology identified on the whole republic's territory is preserved in intensity degree, these years still differ in space. The drought of 2007 had caused material losses to state of nearly 1002090.8 lei, according to Department of Exceptional Situations from Republic of Moldova (Nedealcov, 2012).

Evolution of high temperatures (32 °C) over biological threshold in June on Republic of Moldova's territory shows us that with exclusion of two years when maximum temperatures' values were below 32 °C, sunflower crops were developing in the conditions of thermal stress in the rest of the period, e. g. the last 7 years (2000–2016) in southern parts of republic. In comparison with the southern parts of the republic where there were 14 cases of biological threshold exceeding, the northern parts of republic had only 4 such cases (2007, 2009, 2010, 2012), when conditions of thermal stress were established for this plant's growth and development (Figure 8).

Multiyear development of high temperatures (32 °C) in July on Republic of Moldova's territory demonstrate that in republic's South 15 out of past 16 years (2000–2015) had stressfully high temperatures for sunflower development, while the North had only 13 out 16 such years within the studied period (Figure 9).

Cartographic modelling of maximum temperatures in June-July demonstrate (Figure 10) the fact that if we consider the regional aspect during 1960–2016, we

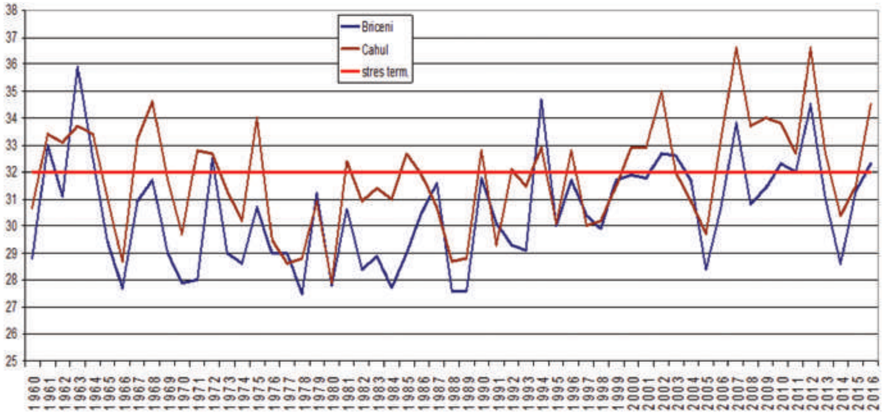

Figure 8: Evolution of high temperatures (32 °C) over biological threshold in June on Republic of Moldova's territory.

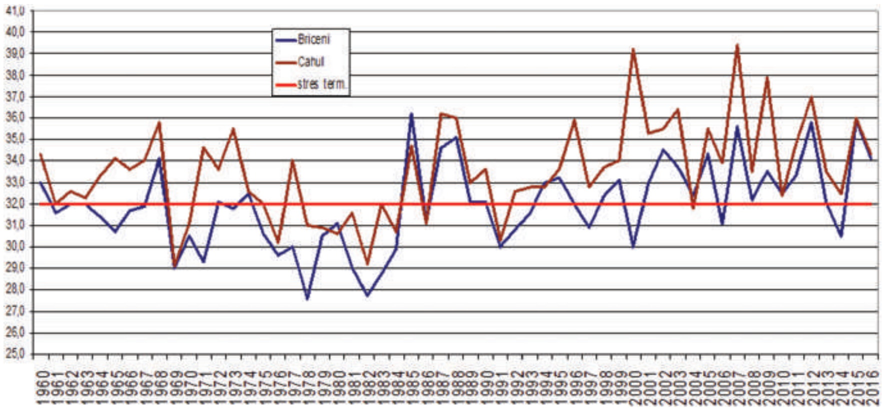

Figure 9: Evolution of high temperatures (32 °C) over biological threshold in July on Republic of Moldova's territory.

see that only in the North and on the high altitudes in republic's central parts do the thermal maximum values remain under 32 °C, ranging between 29.5 and 31.8 °C. Thermal values constitute 32.1 … 33.5 °C in valleys of small rivers in republic's South, in lower parts of Dniester and Prut flows, significantly exceeding the biological threshold for sunflower's growth and development (Figure 10(a)).

The same distribution is also present in July. The thermal values constitute 33.7 … 35.4 °C for the vulnerable areas, e. g. small rivers' valleys and lower courses of Dniester and Prut Rivers (Figure 10(b)).

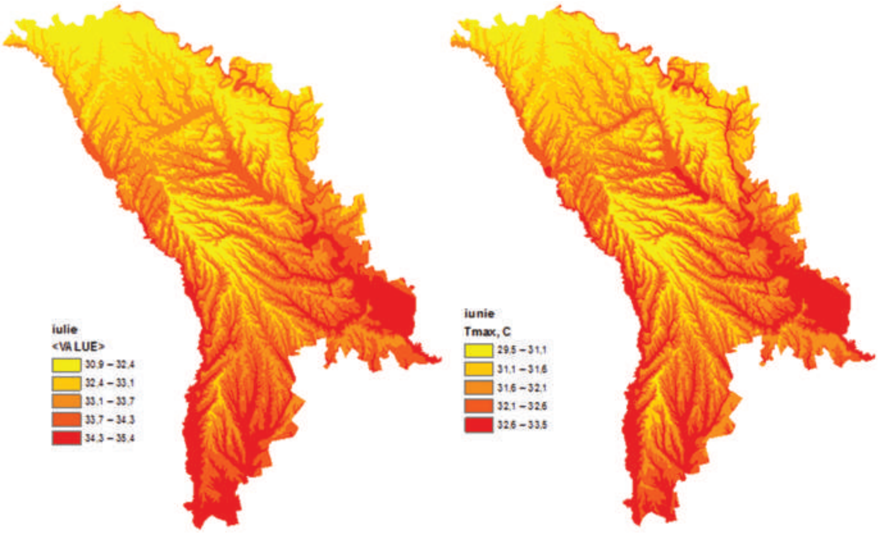

Figure 10: Cartographic modeling of maximum temperatures (a – June; b – July) on Republic of Moldova's territory (1960–2016).

Digital maps elaboration for atmospheric precipitations distribution in June (Figure 11(a)) and July (Figure 11(b)) reveal the fact that the above mentioned vulnerable territories are characterized by the lowest quantities of atmospheric precipitations, namely 59 mm–69 mm and 41.8 mm–57.8 mm correspondingly in comparison with 86.9 mm–108.2 mm and 83.3 mm–98.7 mm in republic's North, the territory that is characterized by a more stable humidification regime in comparison with the South and South-East.

Estimation of surface plots showing the dependency of sunflower crops from thermal regime and atmospheric precipitations in June (Figure 12(a)) and July (Figure 12(b)) shows that both excess in heat and humidity and lack of them contribute in decrease in productivity of the said plant. In the case of June (Figure 12(a)), we see that trend furthering from the thermal optimum to the insufficiency, or to the excess is equally negative. For July (Figure 12(b)), high thermal fund contributes significantly to decrease in sunflower's productivity. As for the whole vegetation period (Figure 12(c)) we mention that in case of high thermal fund and insignificant precipitations we observe the lowest sunflower crops.

Analysis of sunflower crops' climatic variabilities' spatial distribution expressed by variation coefficient and sun-flower productivity in 2007, an unfavourable year characterized by the highest critical thermal values in June and July, demonstrates that South, South-East and Central West parts of the country had lowest and most unstable crops.

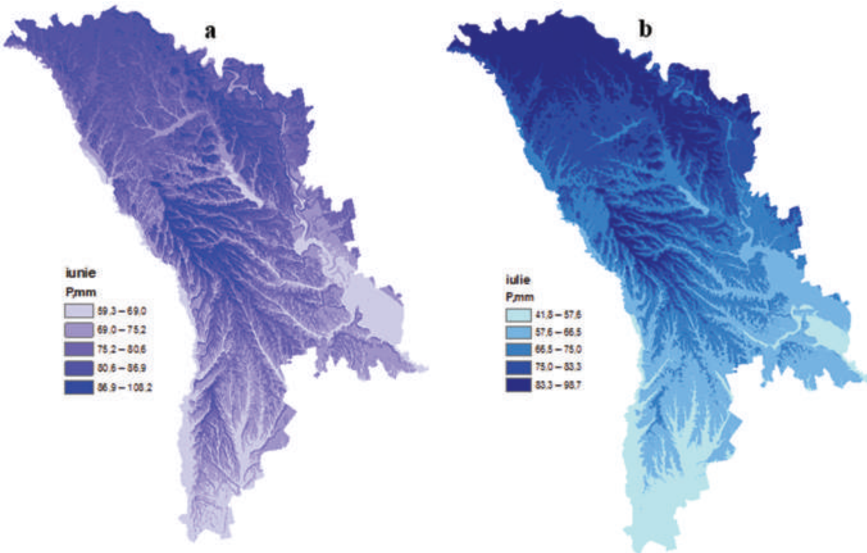

Figure 11: Cartographic modeling of monthly quantities of atmospheric precipitations (a – June; b – July) on Republic of Moldova's territory (1960–2016).

Thus, the elaborated digital map for Index of Dry Days (Izu) spatial distribution demonstrates, that dangerously dry and extremely dry periods were established in 2007 (May-August) in Southern and South-Eastern part of the country and in certain areas of the central part for sunflower growth and development. These areas that coincide with the territories placed in Cahul, Taraclia, Gagauzia, Basarabeasca, Cimislia, Stefan-Vodă, Causeni regions had the lowest crops registered on the regional level. We should also mention Falesti Region, situated in western parts of republic, where due to the dangerously dry periods the crops were twice as small as in adjacent regions where significantly dry periods were registered (Figure 13(a) and (b)).

Conclusions

The knowledge of the real impact of climatic changes in climatic conditions similar to Republic of Moldova, where sunflower is widely cultivated, could contribute to mitigation of the accelerated pace of the observed climatic changes and the consequential possibility of its future cultivation in the South-Eastern Europe, mainly in Romania's and Ukraine's South and in Republic of Moldova,

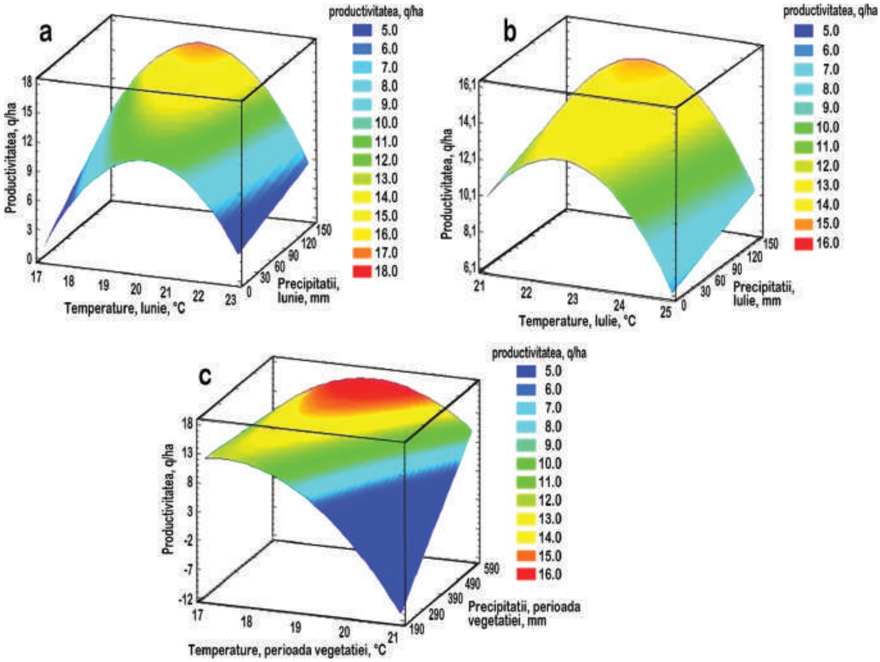

Figure 12: Surface plot for sunflower productivity dependence on meteorological conditions on Republic of Moldova's territory (a – June, b – July, c – vegetation period).

an area where at present we observe a trend of increase of dry periods during the May-August (months crucial for its growth and development). The future of sunflower's cultivation on Europe's South-East is probably connected with its potential adaptation to climatic changes (the knowledge and mitigation of thermal and hydric stress, identification of the possibly favourable regions that are further North and those limitrophe southern ones, etc.), but also with sunflower's competitiveness and consumer appeal, all of which needing improvement either of both by research and public policy. We state that producing new cultivars and scientific technologic process development in agriculture in the next decade would mainly depend on our knowledge of regional particularities of climate's manifestation and on maximum usage of climatic information. In this context we consider that improvement in the ways of usage and correct estimation of actualized climatic information on sunflower growth and development could contribute to adequate measures for adaptation of this plant to new climatic conditions that are characteristic to Republic of Moldova's territory.

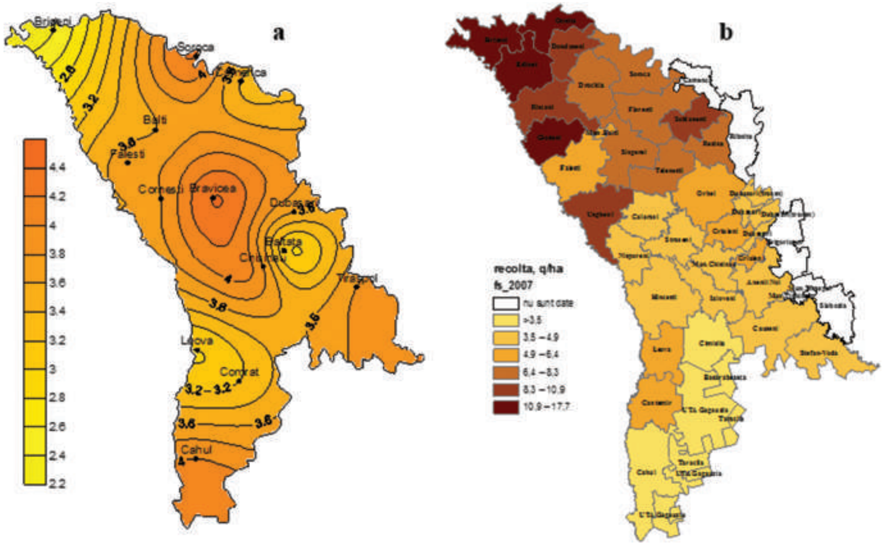

Figure 13: Digital map for Index of Dry Days (Izu) (a) and cartographic modeling (b) of sunflower productivity in certain years (2007).

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