

CLIMATE CHANGE IMPACTS ON MAIN AGRICULTURE CROPS IN THE REPUBLIC OF MOLDOVA

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Abstract: In this paper, statistic-empirical relationships between observed mean temperature and precipitation during the growing season and crop yield based on statistical data at the Republic of Moldova's (RM) agricultural enterprises are explored and used to estimate potential impacts of climate change on anticipated average yields for 2020s, 2050s, and 2080s time periods. Based on range of available temperature and precipitation climatic conditions projected by an ensemble of 10 GCMs for SRES A2 (high), A1B (medium) and B1(low) emissions scenarios average yields in the RM could decrease by about 49 (SRES B1) to 74% (SRES A1B) for grain maize; 38 (SRES B1) to 71% (SRES A2) for winter wheat; 11(SRES B1) to 33% (SRES A2) for sunflower, 10 (SRES B1) to 20% (SRES A2) for sugar beet; and 9 (SRES B1) to 19% (SRES A2) for tobacco by 2080s, not including the direct effect of increased atmospheric CO₂ concentration, advances in plant breeding and crop production practices or changes in the impacts of weeds, insects and diseases on yield. The sharp decline in the productivity of cereal crops can be explained by a shift of critical phenological phases in the more unfavorable humidity and temperature conditions due to climate change.

Key words: *Crop yield, climate change, impact assessment, statistical models.*

1. INTRODUCTION

It is now universally accepted that increased atmospheric concentrations of 'greenhouse gases' are the main cause of the ongoing climate change [1] and that these changes are expected to have important effects on different economic sectors as agriculture, forestry, energy consumptions, tourism, etc. [2]. 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. In Europe, the present climatic trend indicates that in the northern areas, climate change may primarily have positive effects through increases in productivity and in the range of species grown [3], while in southern areas the disadvantages will predominate with lower harvestable yields, higher yield variability and a reduction in suitable areas for traditional crops [4-6].

For climate change impact assessment, crop growth models have been widely used to evaluate crop responses (development, growth and yield) by combining future climate conditions, obtained from General or Regional Circulation Models (GCMs and RCMs, respectively), with the simulation of CO₂ physiological effects, derived from crop experiments [7]. Many of these impact studies were aimed at assessing crop development shifts and yield variations under changes in mean climate conditions. These analyses showed that increasing temperatures generally shortened the growing period of commercial crops [8], resulting in a shorter time for biomass accumulation. On the other hand, changes in yields were not homogeneous and dependent on crop phenology (e.g. summer and winter crops), crop type (e.g. C3 and C4 plants) or environmental conditions (water and nutrient availability) [7; 9; 10; 8; 6].

Other studies stressed that changes in climate variability, as can be expected in a warmer climate, may have a more profound effect on yield than changes in mean climate [11]. Furthermore, the changes in the frequency of extreme climatic events during the more sensitive growth stages have been recognized as a major yield-determining factor for some regions in the future [12;13]. Temperatures outside the range of those typically expected during the growing season may have severe consequences on crops, and when occurring during key development stages they may have a dramatic impact on final production, even in case of generally favorable weather conditions for the rest of the growing season. Many studies highlighted the potential of heat stresses during the anthesis stage as a yield reducing factor [14; 15; 16], while others pointed out that the joint probability of heat stress-anthesis is likely to increase in future scenarios [17; 18; 13; 3].

Statistical models of crop responses to climate change are the second method for climate change impact assessment in agriculture, based on historical datasets of crop and climate variables have recently been used [19-23; 5; 24] to address climatic change impacts on agriculture. This method has the advantage of being applicable on large spatial scales, thus facilitating the quantification of impacts in human terms such as levels of risk of hunger [25; 26]. One disadvantage of this method is the potential to introduce significant errors through the linearization of the equations for crop yield [27]

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and/or the use of monthly data [28], which may not be able to account sufficiently for sub seasonal variability in weather. The validity of empirical methods may be compromised when used with data outside the range for which they were fitted (e.g., climate change). This approach can be used for all crops and all regions, but has several deficiencies (as acknowledged by the authors): (i) errors in statistical data of production and in gridded climate data, and (ii) in some instances, low weight of climatic factors for the between year variation in crop yields. Moreover, statistical models cannot be extrapolated without further assumptions to predict production impacts for future conditions (e.g. higher temperature than any historical year, elevated CO₂ concentration [29]).

Lobell et al., 2010 [30] emphasized three important points that users of crop models should consider in future work. First, statistical models represent a very useful if imperfect tool for projecting climate responses, with all three statistical approaches able to reproduce some of the key aspects of the simulated responses to temperature and precipitation changes. Second, the relative performance of statistical models will depend on the response in question. Time-series models appear particularly good at estimating precipitation responses, while panel or cross-section methods appear more reliable for temperature responses. Finally, the accuracy of statistical approaches depends on the spatial scale of the training data and the scale at which output projections are required. In general, statistical models appear to become more appropriate as the scale of interest becomes broader. It is also at these broader scales that climate projections are most available and reliable, and therefore statistical models are likely to continue to play an important role in anticipating future impacts of climate change [30].

Projecting the qualitative consequences for the Republic of Moldovan agriculture as a result of global climate change is very difficult, because of the uncertainty of variety natural changes and the lack of reliable modeling tools as crop growth models, which need many input data and calibration. First assessment of the impact of climate change on crop production in Moldova was conducted by the authors as part of the First National Communication [31]. Continuation of the research in this area has been allowed to project the effect of direct exposure to elevated CO₂ concentrations in the atmosphere on a yield of winter wheat and maize for different time slices and models [32].

The purpose of our study was to (i) examine the statistic-empirical relationships between observed mean temperature and precipitation during growing season and average crop yield, based on yield data at the Republic of Moldova's agricultural enterprises of various categories, and (ii) use these relationships to postulate possible projections of future changes in yield of these crops by 2020s, 2050s and 2080s, based on the projected changes from an ensemble of 10 GCM for three SRES A2 (high), A1B (medium) and B1 (low) emission scenarios of greenhouse gases and aerosols. The typical winter (*Triticum aestivum* L.) and summer (*Zea Mays*, *Helianthus annuus* L., *Beta vulgaris* L. and *Nicotiana* L.) crops were considered in this study in order to analyze the specific interactions between the changing climate and crops having different seasonal growth cycles. The interactions phenology-environment in a changing climate were highlighted in order to explain the possible impact on final yield the most vulnerable cereal crops (winter wheat and maize).

2. DATA AND METHODS

2.1. Climate change scenarios.

The model simulations for precipitation and temperature used in this study stem from 10 of the global coupled atmosphere ocean general circulation models (AOGCMs) made available by the World Climate Research Program (WCRP) Coupled Models Intercomparison Program Phase 3 (CMIP3) [33]: **CSIROMk3** (Australia's Commonwealth Scientific and Industrial Research Organisation, Australia), **ECHAM5-OM** (Max-Planck-Institute for Meteorology, Germany), **HadCM3** (UK Met. Office, UK), **BCCR_BCM2.0** (Bjerknes Centre for Climate Research, Norway), **CCCma_CGCM3_T63** (Canadian Center for Climate Modeling and Analysis, Canada), **NIES_MIROC3.2_medres**, **NIES_MIROC3.2_hires** (National Institute for Environmental Studies; Japan), **MRI_CGCM2.3.2** (Meteorological Research Institute, Japan), **NCAR_CCSM3** (National Centre for Atmospheric Research, USA), **GFDL_CM2.1** (Geophysical Fluid Dynamics Laboratory, USA) model experiments for SRES A2, A1B and B1 were downloaded from: (http://www.ipcc-data.org/gcm/monthly/SRES_AR4/index.html).

Totally, 37 simulations for 10 global coupled atmosphere ocean general circulation models (GCMs) were downloaded and assessed. The GCM simulations were grouped into three multi-model ensembles depending on the different IPCC emission scenarios SRES A2, A1B and B1[34] and the climatic changes over the RM AEZs were computed for tree different future periods (2020s, 2050s and 2080s) with respect to the baseline 1961-1990. The first feature to highlight is that, both for temperature and precipitation, the ensemble average changes consistently have the same sign across scenarios and their magnitude increase from the low GHG emission scenario B1 to the high GHG ones A1B and A2, as we move into the later decades of the 21st century. Annual changes for temperatures are very homogeneous over the

RM's AEZs. The rate of warming is higher under A2 scenario reach +4.3 °C; medium +3.8 °C under A1B; and smaller +2.7 °C under the B1 scenario by 2080s. The ensemble, driven by the A2 emission scenario, estimate that the Northern AEZ will experience the most significant warming during winter up to +4.9°C by 2080s. For the rest of the RM territory the temperature increase will be from 0.5 to 1.0 °C lower. The pattern of change derived from the ensemble B1 models is quite similar, but the magnitude of change is lower from +2.6°C to +3.2°C with the maximum warming in Northern and Central AEZs. The warming would be higher during summer up to +5.1 - 5.2°C over the Central and Southern AEZs, but the Northern AEZ's temperature rise will be lower up to +4.5°C according to the A2 scenario. The B1 scenario reveals less intense and more uniform warming over the RM's AEZs from +2.9 to +3.1°C. The ensemble projections from the A2 forcing scenario show that the RM's AEZs would exhibit a general annual decrease in precipitation varying from 5.7% to 13.5% in the Northern to Southern AEZs. Controversially, according to B1 scenario slight decrease in precipitation by 1.8% is projected only for Southern AEZ, while moderate increase by +0.6-1.7% is expected in the Central and Northern AEZs by 2080s. Winters are estimated to be wetter in the RM by the end of the 21st century. The ensemble projections show the largest increase in precipitation from 5.3 % (B1) to 7.5% (A2) in winter over the Northern and the lowest one from 0.2% (B1) to 1.5% (A2) over the Southern parts of the country by 2080s. The precipitation reduction will be more extended in the RM's AEZs during summer; the greatest rainfall reduction from 8.4% (B1) to 26.4% (A2) is projected in the Southern and the lowest one from 4.6% (B1) to 16.1% (A2) in the Northern areas, see more in Taranu et al., 2012 [35].

2.2. Crops and approach used

To assess the vulnerability of main agricultural crops to climate change was used empirical-statistical approach linking fluctuations of crops production yields to climate conditions during the growing season. Statistical analysis of the possible impact of climate change on yield of cereal (*winter wheat and grain maize*), oil (*sunflower*) and technical (*sugar beet and tobacco*) crops was carried out in several steps:

Firstly, according to the statistical data on productivity at agricultural enterprises of various categories were constructed linear and polynomial trends for crop yields in the Republic of Moldova over the two distinct time periods: 1961-1990 (baseline periods) and 1981-2010 (recent periods).

Secondly, multiple regression equations linking yield variability with average monthly temperature and precipitation during the agricultural crops growing season, with the highest level of statistical significance were calculated (using the statistical application package STATGRAPHICS Centurion and Microsoft Office Excel). The temperature and precipitation predictor variables were selected in conformity with the step by step regression analysis taking into account their contribution to the crops productivity and consecutive analysis of all possible combinations to find the most reliable model. The regression coefficients of the remaining months show, in what direction and how much may be modified the crops productivity in response to changes in the temperature and precipitation of the respective month.

Finally, the analysis of the impact of future climate changes, determined by temperature and precipitation conditions on the yield of major cereal, oil and technical crops without undertaken any adaptation measures was carried out according to methodological approach [5]. Using the regression equations relationship in the yield variability of major agricultural crops with the temperature and precipitation of the growing season, there were calculated projections of future yield changes in the Republic of Moldova, (% / 30 years) according to an ensemble from 10 Global Climate Models (GCMs) for the three SRES A2, A1B and B1 emission scenarios relative to 1981-2010 current periods.

3. RESULTS AND DISCUSSIONS

3.1. Observed linear trends of variability in production of main agricultural crops

The yield of most crops has been increased over the past several decades. However, in the most recent decade, yields have stagnated for many crops in several regions, whereas temperatures have generally increased. The reasons for this stagnation are debated, and could include agricultural policy [36], fundamental genetic limits [37], climate [38; 39], agronomic practice and crop management [39] etcetera.

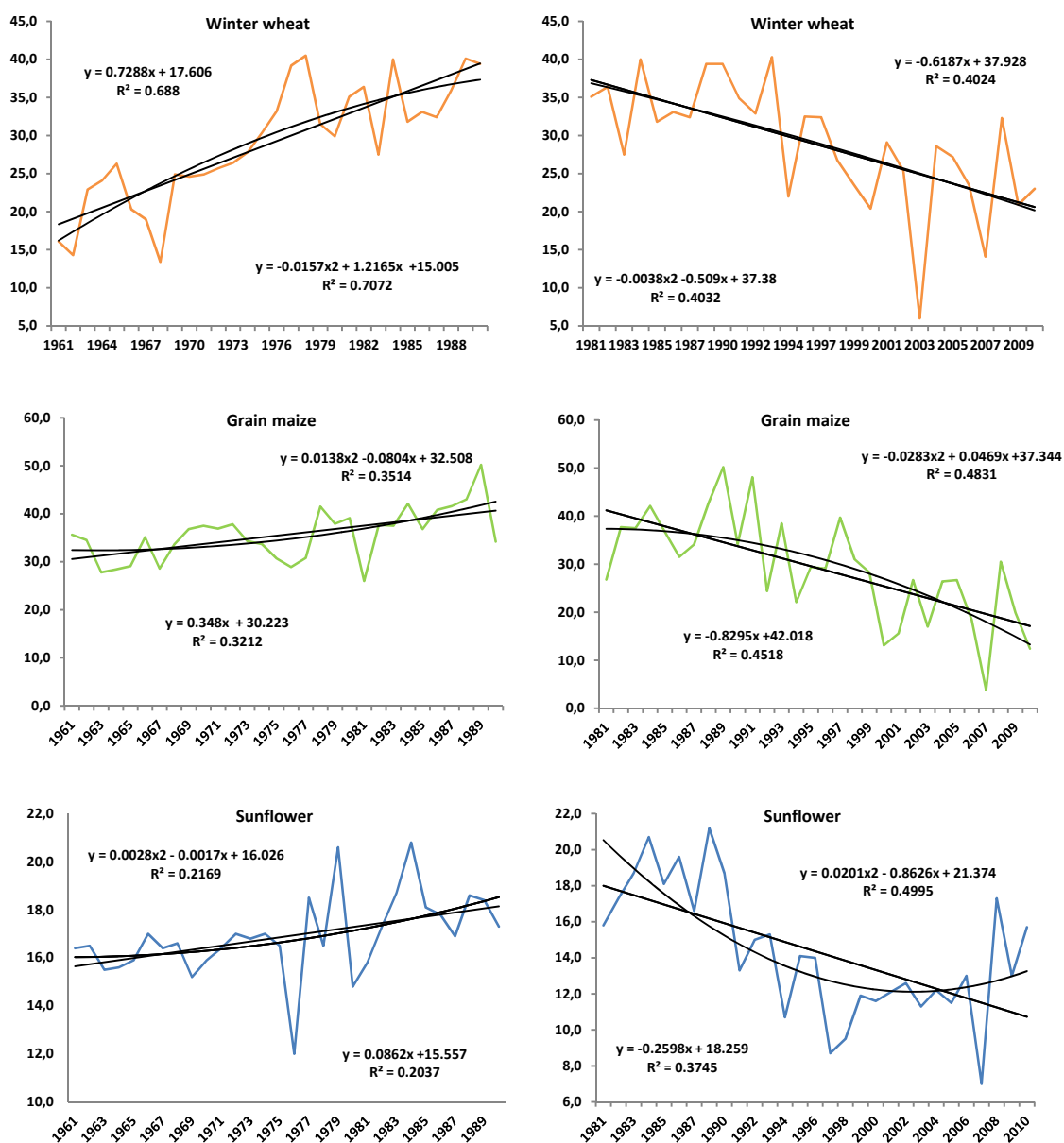
According to [40], agricultural crop productivity is determined by the level of farming culture, by soil, climatic and weather conditions. Following the generally accepted methodology, we have viewed crop productivity (Y_i) as a sum of two elements:

$$Y_i = Y_i^{(T)} + \Delta Y_i^{(T)} \quad (1)$$

Where $Y_i^{(T)}$ is presented via dynamic average value, determined by the rate of farming intensification and climatic conditions close to average for many years, and the deviation from it $\Delta Y_i^{(T)}$ is explained by the anomaly of weather conditions of the latter. In other words, the tendencies of crop productivity depend on the implementation of scientific

and technical achievements into practice, increased investment into technical means, compliance with the agro technical measures and crop rotation, improved labor organization, better use of fertilizers, modification of varieties used, irrigation, etc. These tendencies are a consequence of gradual improvement in the culture of farming in average soil and climatic conditions.

The linear trends of major agricultural crops productivity variability on the territory of the Republic of Moldova (RM) for years 1961-1990 have been characterized by a sustainable increase of crop yield, by 7.3 q/ha per decade for winter wheat, 3.5 q/ha per decade for grain maize, 0.9 q/ha per decade for sunflower and 25.6 q/ha per decade for sugar beet (Table 1; Figure 1). Crop productivity increased significantly due to the implementation of intensive technologies and use of irrigation in the 1981-1990 and has reached the maximum level for winter wheat – 35.0 q/ha; maize for grain – 39.0 q/ha; sunflower – 18.0 q/ha; and sugar beet – 272.5 q/ha.



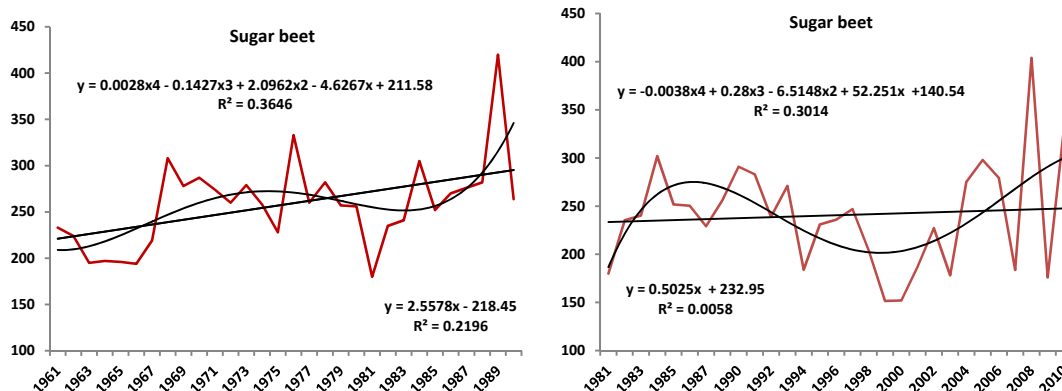


Figure 1: Yield Variability Trends for the Main Crops and Their Coefficients of Determination (R^2) for Two Observation Periods (left - 1961-1990, right - 1981-2010) in the Republic of Moldova

Then, in the forthcoming three decades (1981-2010) there was a tendency for sharp decrease in crop productivity by 6.2 q/ha per decade for winter wheat, 8.3 q/ha per decade for grain maize, 2.5 q/ha per decade for sunflower. The greatest decrease in crop productivity was observed in the 1991 – 2010 years, for winter wheat reaching the level of 23.0 q/ha; for grain maize – 19.8 q/ha, while for sunflower – 12.6 q/ha.

Table 1: Yield linear trends (quintal/year) of major crops and their statistical significance (*p-value*) for the three observation periods in the Republic of Moldova

Crop	Yield					
	1961-1990		1981-2010		1991-2010	
	Trend	<i>p-value</i>	Trend	<i>p-value</i>	Trend	<i>p-value</i>
Winter wheat	0.7288	0.0000	-0.6187	0.0003	-0.6958	0.0297
Grain maize	0.3480	0.0011	-0.8295	0.0000	-1.0674	0.0042
Sunflower	0.0862	0.0123	-0.2598	0.0004	-0.0038	0.9697
Sugar beet	2.5578	0.0090	0.5025	0.6956	0.5025	0.3392
Tobacco	-	-	-0.0687	0.2486	0.0030	0.9774

Note: Bold is used to mark statistically significant values.

3.2. The relationship of major agricultural crops yield variability with temperature and precipitation during the vegetation period (1981 - 2010)

Crops are known to be sensitive to various aspects of climate. Persistently elevated temperatures have long been known to accelerate progress towards maturity, and more recently have been shown to have a significant impact on leaf ageing [41; 42]. Crop responses to shorter periods of high temperature, particularly when coincident with flowering, show yield falling dramatically beyond a threshold temperature [43]. Maize is particularly sensitive to hot daytime temperatures, with rapid losses when temperature exceeds 30°C [22; 44]. Crop yields are also sensitive to precipitation. Quantifying the relative effect of temperature and precipitation variability is important for understanding impacts and developing adaptation options for future climatic changes.

The analysis of the data presented in the Table 2 shows that the influence of climatic conditions during growing season on winter wheat yield in the 1981-2010 years was statistically significant at 99.9% highest level of significance ($p \leq 0.001$).

Table 2: The Relationship of Major Agricultural Crops Yield Variability with Temperature and Precipitation during the Vegetation Period (1981 - 2010)

Crop	Regression equation	p – value	R2,%
Winter wheat	$Y = 130.47 - 2.27 \cdot T_V - 2.60 \cdot T_{VII} - 0.82 \cdot T_X + 0.03 \cdot P_{VI} + 0.03 \cdot P_{IX}$	0.0003	65.26
Grain maize	$Y = 177.36 - 2.20 \cdot T_{VI} - 1.62 \cdot T_{VII} - 3.21 \cdot T_{VIII} + 0.02 \cdot P_{IV} + 0.01 \cdot P_{VII}$	0.0002	61.79
Sunflower	$Y = 41.68 - 0.82 \cdot T_{VIII} - 0.67 \cdot T_X + 0.02 \cdot P_{VI} - 0.04 \cdot P_{VIII} - 0.057 \cdot P_X$	0.0011	66.36
Sugar beet	$Y = 431.53 - 16.96 \cdot T_{VI} + 1.09 \cdot P_{IV} + 0.34 \cdot P_V + 0.24 \cdot P_{VII} + 0.31 \cdot P_{VIII}$	0.0048	49.92
Tobacco	$Y = 26.66 - 1.05 \cdot T_X + 0.05 \cdot P_V - 0.02 \cdot P_{VIII} - 0.02 \cdot P_{IX} - 0.03 \cdot P_X$	0.0024	53.20

Note: Y - yield, quintal/ha; T - average monthly air temperature, °C; P - average monthly precipitations, mm; with Roman numerals are noted the corresponding months of vegetation period: since April (IV) to October (X).

Coefficient of determination R^2 shows that the combined effect of precipitation and temperature defined about 65.3% of the variability of average annual productivity of winter wheat during this period. The regression equation characterizing the interrelation of agricultural crops (corn, sunflower, sugar beet and tobacco) yield variability with the temperature and precipitations during the vegetation period, revealed as well a high level of significance at 99% ($p \leq 0.01$). The combined effect of temperature and precipitation during the vegetation period determined the yield variability at the level of 66.4 per cent for sunflower, 61.8 per cent for corn, 53.2 per cent for tobacco and 49.9 per cent for sugar beet.

3.3. Projections of future changes in productivity of major agricultural crops

As temperatures are projected to significantly increase over the next few decades due to continuing anthropogenic emissions of greenhouse gases, whereas precipitation changes are far less certain [45], this suggests predictability in future crop yields. In addition, it is likely that temperature will have the largest impact as the projected changes are far further outside the range of natural variability than for precipitation changes [46], and because of the seasonal timing of changes in climate [47].

To effectively guide adaptation to future changes, perhaps with different crop growing strategies [48] or selective crop breeding [49], there should several key questions to consider [50]. Firstly, can the relative effects of improved technology, precipitation variability and increasing temperatures be quantified? If so, what is the relative size of the effects of rainfall and hot temperatures on yields? And, what level of technology development may be required to overcome any impact of future climatic changes on yield?

As one of the most essential resources to world food supply, wheat yield is very sensitive to temperature change [51; 52]. Lobell & Field, 2007 [21] reported about 5.4 % decrease in global mean wheat yield per 1°C increase in temperature, but Asseng et al., 2011[41] suggested from model simulations that an average growing-season temperature increase by 2°C could cause 50 % grain yield reduction in Australia because temperatures more than 34°C stimulate leaf senescence. The possible changes in the yield of major agricultural crops (winter wheat, grain maize, sunflower, sugar beet and tobacco), due to future climate changes in the Republic of Moldova, without undertaken any adaptation measures, is presented in Figure 2. The analysis of the obtained results revealed that due to the impact of the main climate indicators (temperature and precipitation) in the RM, productivity of the winter wheat by 2020s could decrease from 9% (SRES A2) to 12% (SRES B1). In comparison with the 1981-2010 time periods, by 2050s the crop productivity may decrease in dependence of the assessed emission scenario from 27% (SRES B1) to 34% (SRES A2). The maximum values of productivity decrease may be reached by 2080s. So, due to changes in values of main climate indicators – precipitation and temperature – the productivity of winter wheat may decrease from 38% (SRES B1) to 71% (SRES A2).

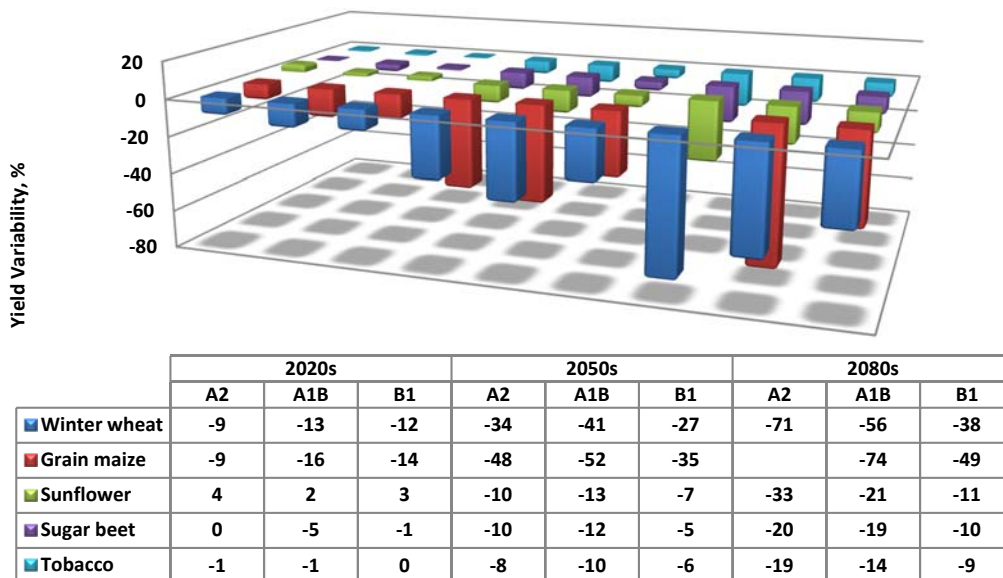


Figure 2: Projections of Future Changes in Productivity of Major Agricultural Crops in the Republic of Moldova, (%/30 years) Relative to 1981-2010 Current Period, According to an Ensemble from 10 GCMs for SRES A2, A1B and B1 Emission scenarios in the XXI century

Lobell & Asner, 2003 [53] evaluated maize and soybean production relative to climatic variation in the United States, reporting a 17 percent reduction in yield for every 1°C rise in temperature, but this response is unlikely because the confounding effect of rainfall was not considered. In a recent evaluation of global maize production response to both temperature and rainfall over the period 1961-2002 [21] reported an 8.3 percent yield reduction per 1°C rise in temperature. The analysis of obtained results revealed, that due to changes in heat and water regime during the growing season, yield of grain maize in RM by 2020s may decrease from 9-14% (SRES A2 and B1) to 16% (SRES A1B). In comparison with the 1981-2010 years, by 2050s the crop productivity may decrease in dependence of the assessed emission scenario from 35% (SRES B1) to 48-52% (SRES A2 and A1B). The maximum values of productivity decrease may be reached by 2080s. So, due to changes in values of main climate predictor variables – precipitation and temperature – the productivity of grain maize may decrease from 49% (SRES B1) to 74% (SRES A1B).

For oil crop such as sunflower, which is relatively drought-resistant, there are projected more favorable climate conditions during the growing season than for cereal crops: winter wheat and grain maize. Slight increase in productivity by 2-4% it is possible for sunflower in the 2020s, which will be replaced in the future with consecutive decline in yield. By 2050s, the most severe decrease in productivity by 10-13% is projected under the SRES A2 high and SRES A1B medium emission scenario. While under the SRES B1 low emission scenario the projection is more favorable, it is expected a decrease of productivity only by 7%. In 2080s, the most severe yield reduction for sunflower in the RM will be observed according to SRES A2 high emission scenario - by 33%, while for SRES B1 low emission scenario the forecast is more favorable – a decrease by 11% (Figure 2).

For sugar beet by 2020s, when assessing the combined effect of temperature and precipitation during the growing season, it is expected a decrease in productivity by 1-5% under two assessed emission scenarios SRES B1 and A1B. By 2050s, there will persisting the decreasing trend in productivity due to climate changes. The most severe decrease in productivity, by 10-12% is predicted under the SRES A1B medium and A2 high emission scenario. While under the SRES B1 low emission scenario the projection is more favorable, it is predicted a decrease of productivity only by 5%. In 2080s, the most severe yield reduction for sugar beet in the RM will be observed according to SRES A2 high emission scenario – by 20%, while for SRES B1 low emission scenario the forecast is more favorable – a decrease by 10% (Figure 2).

For other high value technical crop – tobacco, similar changes are expected: a slight decrease in the yield by 1%, according to the SRES A2 and A1B scenarios in the 2020s. By 2050s, there will persisting the decreasing trend in productivity due to climate changes. The most severe decrease in productivity, by 8-10% is predicted under the SRES A1B medium and SRES A2 high emission scenarios. While under the SRES B1 low emission scenario the projection is more favorable, it is predicted a decrease of productivity only by 6%. In 2080s, the most severe yield reduction for sugar beet in the RM will be observed according to SRES A2 high emission scenario – by 19%, while for SRES B1 low emission scenario the forecast is more favorable – a decrease by 9% (Figure 2).

3.4. Projections of future changes in phenology of main cereal crops

The sharp decline in the productivity of winter wheat and grain corn in the RM can be explained by a shift of critical phenological phases in a more unfavorable period due to temperature increase. The vegetation period of winter wheat (starting with temperatures higher than 5°C in spring), according to an ensemble of 10 GCMs will start in the RM by 2020' earlier by 1 - 4 days (under the SRES A2) and/or by 2 - 6 days (under the SRES B1). By the 2080s, the vegetation period of winter wheat will start earlier by 7-9 days (under the SRES B1) and/or by 10-13 days (under the SRES A2), in dependence of the assessed emission scenario, with a maximum expected shift in the Central Agro-Ecological Zone (AEZ). Change of phenology duration is an essential factor for wheat yield. Previous studies had found that warming will shorten wheat phenology duration and decrease wheat yield, mainly due to a shorter growing period, which decreases the duration of photosynthesis and wheat mass accumulation [14; 54]. The reduction would be 4–7% for each 1°C raised [54] and more see example above. Farooq et al., 2011 [55] have been found that wheat yield would decrease with maximum temperatures higher than the optimum temperature in anthesis and grain-filling stages.

By use of the index 'sum of effective temperatures above 5°C' there were calculated for winter wheat, according to an ensemble from 10 GCMs for three SRES A2, A1B and B1 emission scenarios, the average initiating date of main development phases in the spring-summer period. Analysis of the data for the most vulnerable Central AEZ presented in the table below, revealed that by 2020s output in the tiller initiating phase at winter wheat may have shifted in average from 4 days (SRES A2) up to 6 days (SRES B1) (Table 3). By 2050s the shift in the respective phenological phases will account from 9 days (SRES A2) up to 11 days (SRES A1B), while by 2080s according to the SRES A2 и

A1B emission scenarios the tiller initiating phase will start by 14 days early the onset of respective phase in the reference period (1961-1990).

Table 3: Projections on Shifting the Period of Initiation of Phenological Phases in Winter Wheat Depending on the Sum of Effective Temperatures According to an Ensemble from 10 GCMs for SRES A2, A1B and B1 Emission Scenarios in the Central Part of the Republic of Moldova

Scenario and reference period	Winter wheat			
	Sum of effective temperatures above 5°C necessary to initiate the phenological phase			
	Tiller initiating (125°C)	Jointing (455°C)	Kernel in milk (685°C)	Kernel in dough (945°C)
1961-1990	24/04	27/05	13/06	30/06
<i>2020s</i>				
A2	20/04	22/05	07/06	24/06
A1B	18/04	20/05	06/06	23/06
B1	18/04	20/05	06/06	23/06
<i>2050s</i>				
A2	15/04	17/05	02/06	18/06
A1B	13/04	16/05	31/05	17/6
B1	15/04	17/05	03/06	19/06
<i>2080s</i>				
A2	10/04	12/05	28/05	12/06
A1B	09/04	10/05	26/04	11/04
B1	14/04	15/05	31/04	18/06

According to the projections, by 2020s the phenological phase of jointing may come for winter wheat earlier from 4 days (SRES A2), up to 7 days (SRES B1). According to the performed assessment, the humidity conditions in this period will be close to optimal (HTC = 1.0) according to Taranu, unpublished data. However, by 2080s this shift can already draw from 12 days (SRES B1) up to 15-17 days (SRES A2 and A1B). Humidity conditions for this period would be sufficient only in accordance with the SRES B1 low emission scenario (HTC = 1.0), while according the other two emission scenarios (SRES A2 and A1B) there will be recorded insufficient humidity conditions (HTC = 0.8-0.9), thus the critical period for jointing at winter wheat will take place in dryer conditions, which will impact a sharp decrease in the productivity.

By use of the index ‘sum of effective temperatures above 10°C’ there were calculated for maize of different maturity groups, according to an ensemble from 10 GCMs for three SRES A2, A1B and B1 emission scenarios, the possible average initiating date of main development phases in the spring-summer period. Analysis of the data for the most vulnerable Central AEZ presented in Table 4, revealed that by 2020s onset in the germination - tasseling phase at maize varieties may have shifted, in dependence from emission scenario and maturity group from 7 days (SRES A2) up to 9 days (SRES B1) for the early and intermediate; and from 8 days (SRES A2) up to 11 days (SRES B1) for late maturity groups. While by 2080s, according to SRES B1 и A2 emission scenarios, the germination - tasseling phase will start by 17-22 days (for the early and intermediate); and by 20-26 days (for late maturity groups) early the onset of respective phase in the reference period (1961-1990) (Table 4). In this regard, it is interesting to note that the actual observed changes in the occurrence of phenological germination - tasseling phase of maize due to the temperature increase over the last two decades (1991-2010) were by 5 days, for early and intermediate, and by 6 days, for late maturing hybrids.

According to the projections, by 2020s onset in the sowing – milky grain phase at maize hybrids may have shifted, in dependence from emission scenario and maturity group from 9 days (SRES A2) up to 12 days (SRES B1) for the early-; and from 11 days (SRES A2) up to 14 days (SRES B1) for intermediate and late maturity groups. While by 2080s, according to the SRES B1 и A2 emission scenarios, the sowing – milky grain phase will start early the onset of respective phase in the 1961-1990 period by 21-30 days for the early-; and by 23-32 days for late maturity groups (Table 4). The actual observed changes in the occurrence of phenological sowing – milky grain phase at maize due to the temperature increase over past two decades (1991-2010) were by 7 days for early- and by 9 days for intermediate and late maturing hybrids. According to the projections, in the 2020s the humidity conditions will be close to optimal (HTC = 1.2) during the sowing – tasseling phenological phase across all three scenarios for early- and intermediate hybrids, while for late maturity corn hybrids moisture conditions will be sufficient only under two scenarios SRES A2 and B1 (HTC = 1.0). The next phenological stage the flowering - milky ripening at maize will be ongoing in low humidity conditions (HTC = 0.9-1.0). By the 2080s the humidity conditions would be close to optimal (HTC = 1.0) during the tasseling phenological stage under SRES A1B and B1 emission scenarios; and insufficient (HTC = 0.8) for the SRES A2 high emission scenario. The subsequent critical phenological phases as flowering and milk grain ripening at maize regardless of maturity group will take place in dryer conditions according to high emission SRES A2 (HTC =

0.6) and medium emission SRES A1B (HTC = 0.8) scenarios; or in insufficient humidity conditions (HTC = 0.9) under the low emission scenario SRES B1, which along with an increase of temperatures will reduce dramatically the crop yield.

Table 4: Projections on Shifting the Period of Initiation of Phenological Phases in Maize Varieties of Different Maturity Groups Depending on the Sum of Effective Temperatures According to an Ensemble from 10 GCMs for SRES A2, A1B and B1 Emission Scenarios in the Central Part of the Republic of Moldova

Scenario and reference period	Maize varieties of different maturity groups (early, intermediate and late)		
	Sum of effective temperatures above 10°C necessary to initiate the phenological phase		
	Germination - tasseling		
	(320-410°C)	(400-510°C)	(520-660°C)
1961-1990	23/06	02/07	16/07
<i>2020s</i>			
A2	16/06	25/06	08/07
A1B	14/06	23/06	05/07
B1	14/06	23/06	05/07
<i>2050s</i>			
A2	09/06	18/06	29/06
A1B	06/06	15/06	27/06
B1	09/06	18/06	03/07
<i>2080s</i>			
A2	01/06	09/06	20/06
A1B	31/05	08/06	20/06
B1	06/06	15/06	27/06
Scenario and reference period	Sowing – milky grain		
	(720-770°C)		
	(720-770°C)	(820-870°C)	(880-930°C)
	1961-1990	26/07	04/08
<i>2020s</i>			
A2	17/07	24/07	29/07
A1B	14/07	21/07	26/07
B1	14/07	22/07	27/07
<i>2050s</i>			
A2	08/07	15/7	19/07
A1B	05/07	12/07	16/07
B1	09/07	16/07	21/07
<i>2080s</i>			
A2	28/06	04/07	08/07
A1B	28/06	05/07	11/07
B1	05/07	12/07	17/07
Scenario and reference period	Sowing – milky dough grain		
	(770-820°C)		
	(770-820°C)	(870-920°C)	(970-1020°C)
	1961-1990	31/07	08/08
<i>2020s</i>			
A2	20/07	28/07	05/08
A1B	18/07	26/07	02/08
B1	18/07	26/07	03/08
<i>2050s</i>			
A2	11/07	18/07	25/07
A1B	09/07	15/07	22/07
B1	13/07	20/07	27/07
<i>2080s</i>			
A2	01/07	08/07	14/07
A1B	01/07	08/07	15/07
B1	09/07	16/07	23/07

By the end of the XXI century, the cultivation of major cereal crops such as the winter wheat and maize will be either impossible according to the SRES A2 high emission scenario or economically not cost effective according to the SRES A1B medium and SRES B1 low emission scenarios (see Figure 2), due to changes in climatic conditions without adaptation measures (*if maintaining the current cultivation technologies and used varieties*) in the Republic of Moldova.

4. CONCLUSIONS

In this paper, statistic-empirical relationships between observed mean temperature and precipitation during the growing season and average crop yield based on statistical data at the Republic of Moldova's (RM) agricultural enterprises of

various categories are explored and then used to estimate potential impacts of climate change scenarios on anticipated average yields for the 2020s, 2050s, and 2080s time periods. The typical winter (*Triticum aestivum* L.) and warm season (*Zea Mays*, *Helianthus annuus* L., *Beta vulgaris* L. and *Nicotiana* L.) crops were considered in this study in order to analyze the specific interactions between the changing climate and crops having different seasonal growth cycles.

The linear trends of major agricultural crops productivity variability on the territory of the RM for years 1961-1990 have been characterized by a sustainable increase of crop yield, by 7.3 q/ha per decade for winter wheat, 3.5 q/ha per decade for grain maize, 0.9 q/ha per decade for sunflower and 25.6 q/ha per decade for sugar beet. Crop productivity increased significantly due to the implementation of intensive technologies and use of irrigation in the 1981-1990. Then, in the forthcoming three decades (1981-2010) there was a tendency for sharp decrease in crop productivity by 6.2 q/ha per decade for winter wheat, 8.3 q/ha per decade for grain maize, 2.5 q/ha per decade for sunflower.

Average yields of winter wheat, grain maize, sunflower, sugar beet and tobacco in the 1981-2010 were highly correlated with precipitation and temperature during the growing period. The influence of climatic conditions during growing season on winter wheat yield in the 1981-2010 years was statistically significant at 99.9%. Coefficient of determination R^2 shows that the combined effect of precipitation and temperature defined about 65.3% of the variability of average annual productivity of winter wheat during this period. The regression equation characterizing the interrelation of corn, sunflower, sugar beet and tobacco yield variability with the temperature and precipitations during the vegetation period, revealed as well a high level of significance at 99%. The combined effect of temperature and precipitation during the vegetation period determined the yield variability at the level of 66.4 per cent for sunflower, 61.8 per cent for corn, 53.2 per cent for tobacco and 49.9 per cent for sugar beet.

Based on range of available temperature and precipitation climatic conditions during vegetation period projected by an ensemble GCMs experiments for SRES A2 (high), A1B (medium) and B1(low) emissions scenarios average yields in the RM could decrease by about 49 (SRES B1) to 74% (SRES A1B) for grain maize; 38 (SRES B1) to 71% (SRES A2) for winter wheat; 11(SRES B1) to 33% (SRES A2) for sunflower, 10 (SRES B1) to 20% (SRES A2) for sugar beet; and 9 (SRES B1) to 19% (SRES A2) for tobacco by 2080s, not including the direct effect of increased atmospheric CO_2 concentration, advances in plant breeding and crop production practices or changes in the impacts of weeds, insects and diseases on yield.

By the end of the XXI century, the cultivation of major cereal crops such as the winter wheat and maize will be either impossible according to the SRES A2 high emission scenario or economically not cost effective according to the SRES A1B medium and SRES B1 low emission scenarios, due to changes in climatic conditions without adaptation measures (*if maintaining the current cultivation technologies and used varieties*) in the RM. The sharp decline in the productivity of main cereal crops can be explained by a shift of critical phenological phases in the more unfavorable humidity and temperature conditions due to climate change.

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