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PROJECTIONS OF CHANGES IN PRODUCTIVITY OF MAJOR AGRICULTURAL CROPS IN THE REPUBLIC OF MOLDOVA ACCORDING TO CMIP5 ENSEMBLE OF 21 GCMs FOR RCP2.6, RCP4.5 AND RCP8.5 SCENARIOS

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Abstract

In present study, relationships between observed mean temperature and precipitation during growing season and average annual crop yield based on statistical data at the Republic of Moldova's agricultural enterprises of various categories were explored and then used to estimate potential impacts of climate change scenarios on anticipated average yields by 2035 (2016–2035), by 2065 (2046–2065), and by 2100 (2081-2100) on national and district level, based on the projected changes from the CMIP5 multi-model ensemble of the 21 GCMs used for AR5 of the IPCC, covering the end of 20th (reference period) and 21st (scenario) centuries introduced by three Representative Concentration Pathways (RCPs): RCP 8.5, RCP 4.5, and RCP 2.6. 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. In these circumstances, without undertaken any adaptation measures, it can be expected on national level by 2100: a significant drop in the productivity for grain corn, from 34% (RCP 2.6) to 67% (RCP 4.5); and winter wheat, from 22% (RCP 2.6) to 46% (RCP 4.5); a medium drop in the productivity for sunflower from 16% (RCP 2.6) to 57% (RCP 8.5), respectively for sugar beet, from 9% (RCP 2.6) to 37% (RCP 8.5); and for tobacco, from 10% (RCP 2.6) to 30% (RCP 8.5), in comparison with the average productivity of the Republic of Moldova's major agricultural crops in the most recent period of 1981-2010. Due to changes in climatic conditions in the Republic of Moldova, by the end of the XXI century, the cultivation of grain corn and winter wheat will be impossible according to the RCP 8.5 high emission scenario.

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

INTRODUCTION

The regional distribution of climate change impacts on agricultural production is likely to vary widely (Donatelli et al., 2012; Iglesias et al., 2012). Southern Europe would experience the largest yield losses -25% by 2080 under a 5.4°C warming (Ciscar et al., 2011), with increased risks of rainfed summer crop failure (Ferrara et al., 2010; Bindi and Olesen, 2011). Warmer and drier conditions by 2050 (Trnka et al., 2011) would cause moderate declines in crop yields in Central Europe regions (Ciscar et al., 2011). The Republic of Moldova, without undertaken any adaptation measures could expect by 2080s: the significant drop in yield for grain maize from 49% (SRES B1) to 74% (SRES A1B), and winter wheat from 38% (SRES B1) to 71% (SRES A2); medium drop in yield for sunflower from 11% (SRES B1) to 33% (SRES A2), respectively for sugar beet from 10% (SRES B1) to 20% (SRES A2); and for tobacco from 9% (SRES B1) to 19% (SRES A2), in comparison with the average productivity of the Republic of Moldova's major agricultural crops in the most recent period of 1981-2010 (Taranu, 2014). 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 CO_2 physiological effects, derived from crop experiments (Ainsworth et al., 2005). Crop models have been used to examine a large number of management and environmental conditions, such as interactions among various components of food production systems (Lenz-Wiedemann et al., 2010), determination of optimum crop management practices (Soltani and Hoogenboom, 2007), vulnerability and adaptability assessments (Sultana et al., 2009), evaluation of water consumption and water use efficiency (Kang et al., 2009). The robustness of crop model results depends on data quality, model skill prediction, and model complexity (Bellocchi et al., 2010). Modeling and experiments are each subject to their own uncertainties. For example, interactions among CO_2 fertilization, temperature, soil nutrients, O_3, pests, and weeds are not well understood (Soussana et al., 2010) and therefore most crop models do not include all of these effects, or broader issues of water availability, such as competition for water between industry and households (Piao et al., 2010). There are also uncertainties associated with generalizing the results of field experiments, as each one has been conducted relatively few times under a relatively small range of environmental and management conditions, and for a limited number of genotypes. This limits breadth of applicability both through limited sample size and limited representation of the diversity of genotypic responses to environment (Craufurd et al., 2013). The use of multiple crop models in impacts studies is relatively rare. Field-scale historical model intercomparisons have shown variations in the simulation of mean yield and above-ground biomass of more than 60% (Palosuo et al., 2011). Early results from impacts studies with multiple crop models suggest that the crop model uncertainty can be larger than that caused by GCMs, due in particular to high temperature and temperature-by-CO_2 interactions (Asseng et al., 2013).

Statistical models offer a complement to more process-based model approaches, some of which require many assumptions about soil and management practices. Process-based models, which extrapolate based on measured interactions and mechanisms, can be used to develop a causal understanding of the empirically determined relationships in statistical models (Schlenker and Roberts, 2009; Lobell et al., 2013a). Although statistical models forfeit some of the process knowledge embedded in other approaches, they can often reproduce the behavior of other models (Iglesias et al., 2000; Lobell and Burke, 2010) and can leverage within one study a growing availability of crop and weather data (Lobell et al., 2011b). Statistical models usually exclude the direct impact of elevated CO_2, making multi-decadal prediction problematic. In determining future trends, crop models of all types can extrapolate only based on historically determined relations.

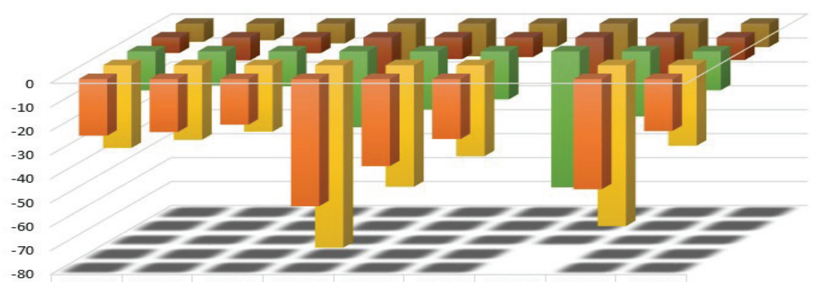
The purpose of this study was to (i) examine the statistic-empirical relationships between observed mean temperature and precipitation during growing season and average crop yield, based on yield data at the Republic of Moldova's agricultural enterprises of various categories, and (ii) use these relationships to postulate possible projections of future changes in yield of these crops by 2035 (2016–2035), by 2065 (2046–2065) and by 2100 (2081-2100) on national and district level, based on the projected changes from the CMIP5 multi-model ensemble of the 21 GCMs used for AR5 of the IPCC, covering the end of 20th (reference period) and 21st (scenario) centuries introduced by three Representative Concentration Pathways (RCPs): RCP 8.5, RCP 4.5, and RCP 2.6. 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.

MATERIALS AND METHODS

The assessment of the climate change impact on agricultural sector was made based on projections of changes in temperature and precipitation received by regionalization of global experiments the most reliable in the Republic of Moldova of CMIP5 21 GCMs experiments for RCP 8.5, RCP 4.5 and RCP 2.6 emission scenarios. 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. Additionally to the national level, we have assessed the impact of temperature and precipitation during the growing season on major crop productivity in the Republic of Moldova's territorial administrative units (district level) in order to distinguish the most and least vulnerable to climate change crop production districts see more in Taranu, 2014.

RESULTS AND DISCUSSIONS

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, according to the CMIP 5 Ensemble of 21 GCMs for RCP 8.5, RCP 4.5, and RCP 2.6 emission scenarios is shown in Figure 1.



	2016-2035			2046-2065			2081-2100		
	RCP8.5	RCP4.5	RCP2.6	RCP8.5	RCP4.5	RCP2.6	RCP8.5	RCP4.5	RCP2.6
Winter wheat	-24	-22	-19	-53	-36	-25		-46	-22
Grain maize	-35	-31	-28	-76	-51	-38		-67	-34
Sunflower	-16	-14	-15	-32	-24	-20	-57	-27	-16
Sugar beet	-6	-10	-7	-18	-9	-8	-37	-17	-9
Tobacco	-8	-7	-8	-18	-14	-10	-30	-15	-10

Figure 1. 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 the CMIP 5 Ensemble of 21 GCMs for RCP 8.5, RCP 4.5, and RCP 2.6 emission scenarios

The impact assessment performed on national level allow conclude that the negative effect of global warming, according to the CMIP 5 Ensemble of 21 GCMs for RCP 8.5, RCP 4.5, and RCP 2.6 emission scenarios in the XXI century will not be offset by increase of precipitations. In these circumstances, without undertaken any adaptation measures, it can be expected by 2100: a significant drop in the productivity for grain corn, from 34% (RCP 2.6) to 67% (RCP 4.5); and winter wheat, from 22% (RCP 2.6) to 46% (RCP 4.5); a medium drop in the productivity for sunflower from 16% (RCP 2.6) to 57% (RCP 8.5), respectively for sugar beet, from 9% (RCP 2.6) to 37% (RCP 8.5); and for tobacco, from 10% (RCP 2.6) to 30% (RCP 8.5), in comparison with the average productivity of the Republic of Moldova's major agricultural crops in the most recent period of 1981-2010. Due to changes in climatic conditions in the Republic of Moldova, by the end of the XXI century, the cultivation of grain corn and winter wheat will be impossible according to the RCP 8.5 high emission scenario.

Additionally to the national level we have assessed the impact of temperature and precipitation during the growing season on agricultural crops productivity in the Republic of Moldova's territorial administrative units (district level), in order to distinguish the most and least vulnerable districts to climate change. According to projections, the most vulnerable districts for cultivation of winter wheat will be Basarabeasca, Taraclia, Cimislia, Causeni, Cahul, and Stefan Voda in Southern, and Dubasari, Anenii Noi, Hincesti, Ialoveni, Nisporeni, Criuleni, Telenesti and Orhei, in Central AEZs, in which productivity of the winter wheat may decrease from 19-26% under RCP 2.6 to 52-63% under RCP 4.5 by 2100.

The least vulnerable districts for cultivation of winter wheat production will be Donduseni, Briceni, Riscani, Soroca, and Singerei in the Northern AEZ; and Ungheni, Calaras and Soldanesti in Central AEZs, in which productivity of the winter wheat by 2100 could decrease from 8 to 28% under RCP 2.6 and/or from 69 to 94% under RCP 8.5 (Table 1).

Table 1. Projected Winter Wheat Yield Changes Relative to the Current Situation (%/30 Year) under the CMIP 5 Ensemble of 21 GCMs for RCP 8.5, RCP 4.5, and RCP 2.6 emission scenarios

AEZs/district	1981-2010, q/ha	2016-2035			2046-2065			2081-2100		
		RCP8.5	RCP4.5	RCP2.6	RCP8.5	RCP4.5	RCP2.6	RCP8.5	RCP4.5	RCP2.6
Northern AEZ										
Briceni	33.5	-19	-20	-19	-41	-31	-22	-75	-39	-22
Donduseni	29.0	-23	-18	-20	-49	-35	-23	-90	-41	-19
Drochia	32.1	-14	-13	-16	-36	-25	-19	-81	-37	-19
Edinet	30.0	-17	-19	-15	-45	-26	-23	-86	-42	-24
Falesti	32.4	-27	-23	-22	-56	-38	-28		-52	-26
Floresti	29.3	-29	-26	-25	-64	-42	-30		-57	-29
Glodeni	33.6	-24	-20	-20	-52	-35	-25	-97	-48	-24
Ocnita	30.4	-21	-24	-19	-49	-30	-28	-91	-47	-28
Riscani	31.4	-15	-16	-13	-37	-22	-20	-69	-34	-21
Singerei	30.6	-18	-19	-14	-45	-29	-24	-83	-42	-28
Soroca	29.5	-16	-17	-13	-40	-25	-21	-76	-38	-24
Central AEZ										
Anenii Noi	28.1	-29	-27	-23	-73	-48	-32		-63	-26
Calaras	24.9	-17	-16	-14	-46	-30	-19	-89	-39	-16
Criuleni	30.4	-22	-20	-14	-60	-39	-25		-52	-19
Dubasari	29.6	-26	-25	-20	-71	-47	-30		-62	-24
Hincesti	27.1	-26	-24	-20	-67	-44	-28		-58	-23
Ialoveni	26.6	-26	-24	-20	-66	-44	-28		-57	-23
Nisporeni	27.3	-23	-22	-19	-66	-43	-27		-57	-21
Orhei	28.3	-27	-25	-21	-65	-44	-29		-56	-25
Rezina	25.0	-24	-22	-19	-56	-38	-25		-48	-21
Straseni	26.5	-22	-20	-17	-55	-36	-24		-47	-21
Soldanesti	25.5	-21	-19	-16	-48	-32	-21	-94	-41	-18
Telenesti	25.1	-29	-26	-21	-66	-44	-30		-57	-25
Ungheni	30.9	-11	-9	-6	-32	-20	-11	-69	-27	-8
Southern AEZ										
Basarabeasca	25.5	-25	-24	-17	-68	-46	-30		-63	-27
Cahul	26.4	-24	-24	-19	-64	-43	-29		-56	-24
Cantemir	26.4	-19	-18	-13	-45	-30	-20	-88	-40	-17
Causeni	26.6	-24	-23	-17	-62	-42	-28		-57	-23
Cimislia	26.1	-25	-24	-18	-61	-43	-29		-57	-26
Leova	26.1	-20	-19	-14	-47	-32	-22	-92	-42	-19
Stefan Voda	30.2	-24	-23	-18	-60	-41	-29		-56	-24
Taraclia	28.7	-24	-23	-16	-63	-42	-27		-58	-24

Due to climate change the most vulnerable for grain corn cultivation would be the Central and in less extent the Northern and Southern AEZs. The most vulnerable districts will be Orhei, Anenii Noi, Straseni, Ialoveni, Nisporeni, Telenesti, Ungheni, Calarasi, Criuleni and Dubasari; and UTA, Basarabeasca, Cahul, Taraclia, and Stefan Voda in Southern AEZ, in which yield of the grain corn may decrease by 2100 from 28 to 50% (RCP 2.6) and/or up to 58-91% (RCP 4.5). The significant drop in grain corn yield from 65 to 100% under RCP 8.5 emission scenario is projected in Northern AEZ by 2100 relative to 1981-2010 reference period. The least vulnerable districts to climate change will be Donduseni, Drochia, Falesti, and Ocnita in Northern; Rezina, and Soldanesti in Central, and Leova in Southern AEZs, in which productivity of the grain corn may decrease by 2100, in dependence of the assessed emission scenario from 7 to 23% (RCP 2.6) and/or from 25 to 49% (RCP 8.5).

Without adaptation, due to changes in climatic conditions in the most districts of the Republic of Moldova, by the end of the XXI century, the cultivation of grain corn and winter wheat will be impossible according to the RCP 8.5 high emission scenario or economically not cost effective under the RCP 4.5 medium emission scenario (Table 2).

The most vulnerable for sunflower cultivation without application of adaptation measures, would be Central AEZ and in less extent Northern and Southern AEZs. According to projections, the most vulnerable districts will be Ialoveni, Hincesti, Straseni, Telenesti, Anenii Noi, Dubasari, and Orhei in Central AEZ, in which productivity of sunflower by 2100 may decrease from 23 to 37% (RCP 2.6) and/or from 44 to 76% (RCP 4.5).

Table 2. Projected Grain Corn Yield Changes Relative to the Current Situation (%/30 Year) under the CMIP 5 Ensemble of 21 GCMs for RCP 8.5, RCP 4.5, and RCP 2.6 emission scenarios

AEZs/district	1981-2010, q/ha	2016-2035			2046-2065			2081-2100		
		RCP8.5	RCP4.5	RCP2.6	RCP8.5	RCP4.5	RCP2.6	RCP8.5	RCP4.5	RCP2.6
Northern AEZ										
Briceni	36.0	-52	-51	-46		-88	-60			-50
Donduseni	28.9	-16	-15	-17	-35	-30	-16	-65	-25	-7
Drochia	25.1	-22	-24	-19	-49	-34	-25	-88	-34	-17
Edinet	28.6	-40	-37	-33	-87	-59	-41		-66	-31
Falesti	24.2	-19	-23	-20	-48	-33	-25	-88	-45	-29
Floresti	28.6	-46	-48	-40		-76	-55			-48
Glodeni	29.1	-33	-32	-27	-77	-49	-33		-56	-23
Ocnita	36.7	-21	-19	-16	-52	-34	-20	-93	-38	-16
Riscani	31.1	-38	-38	-29	-98	-62	-43		-73	-33
Singerei	26.2	-46	-45	-38		-76	-52		-90	-42
Soroca	30.7	-37	-38	-33	-90	-60	-40		-71	-33
Central AEZ										
Anenii Noi	25.3	-44	-48	-41		-78	-54			-47
Calaras	24.8	-35	-36	-32	-89	-60	-41		-77	-37
Criuleni	28.5	-53	-48	-44		-76	-54		-91	-44
Dubasari	28.6	-45	-43	-38		-68	-49		-83	-41
Hincesti	24.9	-35	-37	-31	-85	-57	-40		-72	-35
Ialoveni	26.5	-42	-44	-38		-71	-49		-89	-43
Nisporeni	27.5	-43	-44	-38		-71	-49		-88	-43
Orhei	24.0	-49	-51	-44		-82	-57			-50
Rezina	24.3	-24	-24	-17	-57	-37	-26		-49	-23
Straseni	23.8	-45	-45	-39		-74	-51		-93	-44
Soldanesti	23.6	-23	-25	-18	-55	-35	-26		-46	-22
Telenesti	19.7	-38	-41	-34	-89	-59	-43		-73	-36
Ungheni	34.3	-29	-28	-23	-68	-46	-32		-58	-28
Southern AEZ										
Basarabeasca	24.8	-30	-33	-27	-76	-52	-33		-69	-34
Cahul	27.0	-42	-42	-35	-99	-67	-47		-85	-40
Cantemir	23.8	-27	-29	-25	-64	-43	-30		-52	-25
Causeni	25.1	-31	-32	-28	-73	-49	-35		-60	-28
Cimislia	20.6	-31	-33	-26	-84	-54	-33		-69	-33
Leova	24.7	-21	-24	-19	-54	-36	-24		-45	-21
Stefan Voda	26.5	-31	-30	-26	-69	-47	-34		-58	-28
Taraclia	27.6	-31	-33	-28	-77	-52	-35		-65	-30
UTA	26.0	-32	-35	-29	-82	-55	-37		-69	-32

The least vulnerable for sunflower cultivation districts will be Floresti, Falesti, Riscani, Briceni, Donduseni, Drochia, Edinet, Ocnita, Singerei, and Soroca in Northern AEZ in which productivity of sunflower may decrease by 2100, from 4 to 15% (RCP 2.6) and/or from 17 to 40% (RCP 4.5). Without adaptation measures due to changes in climatic conditions in the most districts of the Republic of Moldova, by the end of the XXI century, the cultivation of sunflower will be impossible or economically not cost effective according to the RCP 8.5 high emission scenario (Table 3). According to projections, without application of adaptation measures, the most vulnerable districts for sugar beet cultivation will be Glodeni, Drochia, Falesti, Floresti, and Singerei in Northern; Telenesti, Orhei, and Rezina in Central AEZs, in which productivity of sugar beet may decrease by 2100 from 14 to 27% (RCP 2.6) and/or from 65 to 87% (RCP 8.5). The least vulnerable districts for sugar beet cultivation will be Briceni and Donduseni in Northern; and Ungeni in Central AEZs, in which productivity of the sugar beet may increase by 2100 from 2 to 9% (RCP 2.6) and/or from 9 to 34% (RCP 8.5), in comparison with the reference period. Increase in the productivity of sugar beet is also projected for Edinet and Ocnita districts in Northern AEZ, however the yield trends in reference period (1981-2010) are statistically significant on the lowest significant level ($p \leq 0.1$), so it can be noted just a tendency to yield increase in these districts (Table 4).

The most vulnerable to climate change tobacco areas in the Republic of Moldova would be Northern, Central and in less extent Southern AEZs. The most vulnerable districts for tobacco cultivation will be Donduseni, Briceni, Ocnita, Edinet, Soroca, Floresti, Riscani, and Glodeni in the Northern; Nisporeni, and

Ungheni districts in Central; and Cimislia in Southern AEZs, in which tobacco productivity could decrease from 23 to 56% (RCP 2.6) and/or from 47 to 98% (RCP 4.5).

The least vulnerable districts for tobacco cultivation will be Cantemir, Leova,

Table 3. Projected Sunflower Yield Changes Relative to the Current Situation (%/30 Year) under the CMIP 5 Ensemble of 21 GCMs for RCP 8.5, RCP 4.5, and RCP 2.6 emission scenarios

AEZs/district	1981-2010, q/ha	2016-2035			2046-2065			2081-2100		
		RCP8.5	RCP4.5	RCP2.6	RCP8.5	RCP4.5	RCP2.6	RCP8.5	RCP4.5	RCP2.6
Northern AEZ										
Briceni	16.3	-21	-16	-16	-53	-35	-22	-97	-40	-15
Donduseni	15.4	-20	-17	-17	-51	-33	-20	-95	-39	-14
Drochia	18.3	-20	-16	-16	-49	-31	-20	-91	-37	-13
Edinet	17.0	-19	-17	-17	-49	-31	-20	-93	-37	-14
Falesti	16.2	-9	-8	-8	-25	-15	-11	-51	-22	-9
Floresti	15.7	-9	-7	-9	-24	-15	-8	-46	-17	-4
Glodeni	19.7	-16	-12	-14	-40	-25	-15	-76	-31	-10
Ocnita	16.5	-17	-15	-15	-43	-27	-18	-82	-33	-13
Riscani	16.4	-5	-4	-5	-17	-10	-5	-35	-12	-1
Singerei	17.2	-12	-11	-11	-33	-20	-14	-65	-27	-11
Soroca	15.4	-10	-7	-9	-26	-17	-8	-50	-19	-4
Central AEZ										
Anenii Noi	12.2	-36	-32	-32	-74	-55	-42		-63	-33
Calaras	11.7	-22	-19	-19	-49	-32	-27	-90	-46	-26
Criuleni	15.2	-29	-25	-25	-60	-44	-35		-51	-28
Dubasari	13.3	-29	-27	-26	-66	-46	-33		-57	-29
Hincesti	13.8	-30	-28	-26	-70	-49	-35		-60	-31
Ialoveni	13.5	-37	-35	-33	-88	-61	-43		-76	-37
Nisporeni	14.9	-17	-16	-18	-45	-35	-27	-90	-45	-21
Orhei	14.5	-29	-28	-27	-68	-47	-32		-58	-30
Rezina	12.7	-21	-19	-19	-44	-33	-26	-80	-38	-22
Straseni	12.7	-23	-21	-20	-51	-37	-27	-92	-44	-23
Soldanesti	14.0	-10	-9	-9	-25	-16	-15	-48	-26	-15
Telenesti	13.8	-28	-26	-25	-67	-45	-31		-59	-27
Ungheni	16.5	-12	-11	-12	-29	-20	-18	-53	-28	-16
Southern AEZ										
Basarabeasca	12.4	-36	-37	-31	-87	-60	-42		-76	-37
Cahul	11.3	-17	-16	-15	-31	-21	-15	-57	-23	-11
Cantemir	13.6	-9	-10	-9	-21	-15	-11	-43	-18	-8
Causeni	12.9	-25	-24	-22	-57	-40	-30		-49	-24
Cimislia	13.4	-36	-36	-31	-86	-59	-42		-75	-35
Leova	12.7	-17	-19	-15	-43	-30	-20	-80	-37	-16
Stefan Voda	13.5	-19	-20	-17	-47	-31	-23	-85	-40	-20
Taraclia	10.5	-16	-15	-14	-28	-17	-13	-49	-19	-8
UTA	10.4	-12	-14	-8	-30	-20	-14	-62	-28	-10

Table 4. Projected Sugar Beet Yield Changes Relative to the Current Situation (%/30 Year) under the CMIP 5 Ensemble of 21 GCMs for RCP 8.5, RCP 4.5, and RCP 2.6 emission scenarios

AEZs/district	1981-2010, q/ha	2016-2035			2046-2065			2081-2100		
		RCP8.5	RCP4.5	RCP2.6	RCP8.5	RCP4.5	RCP2.6	RCP8.5	RCP4.5	RCP2.6
Northern AEZ										
Briceni	250.3	3	2	1	6	6	5	9	3	3
Donduseni	228.7	10	5	5	21	17	11	34	17	9
Drochia	258.9	-18	-20	-16	-47	-31	-24	-87	-45	-25
Edinet	213.9	7	1	3	11	9	5	22	12	4
Falesti	284.1	-18	-22	-16	-45	-26	-21	-87	-40	-20
Floresti	225.7	-12	-16	-11	-31	-17	-14	-65	-30	-16
Glodeni	262.9	-14	-14	-12	-38	-23	-17	-68	-34	-17
Ocnita	227.6	12	8	7	28	20	13	48	23	9
Riscani	251.0	-3	-6	-4	-13	-6	-4	-23	-10	-4
Singerei	250.5	-25	-26	-24	-60	-40	-28		-52	-27
Soroca	207.1	-7	-13	-8	-20	-9	-8	-43	-19	-10
Central AEZ										
Orhei	213.1	-17	-19	-15	-36	-24	-18	-65	-30	-16
Rezina	150.1	-13	-16	-12	-34	-20	-15	-62	-29	-14
Soldanesti	176.0	1	0	0	5	4	3	10	6	2
Telenesti	183.4	-17	-18	-13	-41	-24	-19	-73	-36	-18
Ungheni	281.1	-5	-5	-5	-9	-7	-4	-18	-7	-3

Taraclia and UTA Gagauzia in Southern AEZ, in which productivity of tobacco may increase by 2100 from 9 to 11% (RCP 2.6) and/or from 7 to 34% (RCP 8.5), in comparison with the 1981-2010 reference period. Without adaptation measures, due to changes in climatic conditions, by the end of the XXI century the cultivation of tobacco in Donduseni, Briceni, Edinet, Soroca, Glodeni, Floresti, Ocnita, Riscani, Nisporeni, Ungheni and Cimislia districts will be either impossible according to the RCP 8.5 high emission scenario, or economically not cost effective according to RCP 4.5 medium emission scenarios (Table 5).

Table 5. Projected Tobacco Yield Changes Relative to the Current Situation (%/30 Year) under the CMIP 5 Ensemble of 21 GCMs for RCP 8.5, RCP 4.5, and RCP 2.6 emission scenarios

AEZs/district	1981-2010, q/ha	2016-2035			2046-2065			2081-2100		
		RCP8.5	RCP4.5	RCP2.6	RCP8.5	RCP4.5	RCP2.6	RCP8.5	RCP4.5	RCP2.6
Northern AEZ										
Briceni	13.0	-42	-43	-40		-72	-55		-98	-56
Donduseni	13.9	-48	-43	-41		-73	-55		-97	-56
Drochia	17.0	-15	-14	-14	-41	-28	-19	-72	-37	-18
Edinet	12.9	-21	-21	-19	-52	-36	-27	-94	-50	-27
Falesti	15.6	-15	-13	-12	-35	-24	-19	-62	-34	-20
Floresti	15.8	-31	-29	-26	-61	-45	-37		-60	-37
Glodeni	14.6	-33	-30	-30	-80	-55	-37		-72	-34
Ocnita	12.1	-41	-42	-42	-65	-53	-47	-96	-63	-48
Riscani	15.9	-28	-23	-24	-56	-41	-31	-94	-54	-30
Singerei	16.1	-10	-9	-10	-21	-15	-10	-40	-19	-9
Soroca	13.0	-33	-30	-27	-79	-57	-42		-77	-43
Central AEZ										
Criuleni	15.3	-4	-4	-7	-7	-10	-7	-11	-6	-6
Dubasari	14.6	-12	-8	-8	-27	-19	-12	-52	-24	-10
Hincesti	14.7	-11	-9	-8	-33	-19	-14	-62	-31	-15
Ialoveni	14.5	-3	-3	-5	-8	-7	-3	-14	-6	-1
Nisporeni	12.6	-28	-26	-24	-69	-46	-34		-64	-33
Orhei	14.1	-2	-2	-3	-6	-4	-3	-8	-4	-5
Rezina	12.7	-1	-2	-4	-9	-7	-2	-14	-7	-2
Soldanesti	11.6	-18	-16	-16	-39	-28	-22	-68	-33	-20
Telenesti	14.3	-11	-10	-10	-25	-18	-12	-45	-21	-11
Ungheni	15.3	-20	-18	-17	-51	-34	-24	-95	-47	-23
Southern AEZ										
Cantemir	12.7	8	8	8	20	13	11	34	20	11
Causeni	10.2	-12	-8	-14	-32	-15	-16	-42	-21	-16
Cimislia	12.6	-28	-29	-23	-65	-49	-35		-63	-36
Leova	13.7	1	0	1	6	-1	0	7	-1	0
Stefan Voda	15.6	-6	-5	-8	-13	-9	-9	-16	-10	-10
Taraclia	14.9	8	5	7	16	9	10	27	14	9
UTA	15.1	9	7	6	18	10	8	33	16	9

Autonomous adaptation by farmers, through the advancement of sowing and harvesting dates and the use of longer cycle varieties (Moriondo et al., 2011; Moriondo et al., 2010; Olesen et al., 2011) could result in a general improvement of European wheat yields in the 2030s compared to the 2000s (Donatelli et al., 2012). However, farmer-sowing dates seem to advance slower than crop phenology (Siebert, Ewert, 2012), possibly, because earlier sowing is often prevented by lack of soil workability and frost-induced soil crumbling (Oort et al., 2012). Simulation studies, which anticipate on earlier sowing in Europe, may thus be overly optimistic. Further adaptation options include changes in crop species, fertilization, irrigation, drainage, land allocation and farming system (Bindi, Olesen, 2011). At the high range of the projected temperature changes, only plant breeding aimed at increasing yield potential jointly with drought resistance and adjusted agronomic practices may reduce risks of yield shortfall (Olesen et al., 2011; Rötter et al., 2011; Ventrella et al., 2012). Crop breeding is however challenged by temperature and rainfall variability, since (i) breeding has not yet succeeded in altering crop plant development responses to short-term changes in temperature (Parent, Tardieu, 2012) and (ii) distinct crop drought tolerance traits are required for mild and severe water deficit scenarios (Tardieu, 2012).

Adaptation to increased climatic variability may require an increased use of between and within species genetic diversity in farming systems (Smith, Olesen, 2010) and the development of insurance products against weather-related yield variations (Musshoff et al., 2011). Adaptive capacity and long-term economic viability of farming systems may vary given farm structural change induced by climate change (Mandryk et al., 2012; Moriondo et al., 2010b).

CONCLUSIONS

The impact assessment performed on national level allow conclude that the negative effect of global warming, according to the CMIP 5 Ensemble of 21 GCMs for RCP 8.5, RCP 4.5, and RCP 2.6 emission scenarios in the XXI century will not be offset by increase of precipitations. In these circumstances, without undertaken any adaptation measures, it can be expected by 2100: a significant drop in the productivity for grain corn, from 34% (RCP 2.6) to 67% (RCP 4.5); and winter wheat, from 22% (RCP 2.6) to 46% (RCP 4.5); a medium drop in the productivity for sunflower from 16% (RCP 2.6) to 57% (RCP 8.5), respectively for sugar beet, from 9% (RCP 2.6) to 37% (RCP 8.5); and for tobacco, from 10% (RCP 2.6) to 30% (RCP 8.5), in comparison with the average productivity of the Republic of Moldova's major agricultural crops in the most recent period of 1981-2010. Due to changes in climatic conditions in the Republic of Moldova, by the end of the XXI century, the cultivation of grain corn and winter wheat will be impossible according to the RCP 8.5 high emission scenario.

Additionally to the national level was assessed the impact of temperature and precipitation during the growing season on agricultural crops productivity in the RM's territorial administrative units (district level), in order to distinguish the most and least vulnerable districts to climate change.

According to projections, the most vulnerable districts for cultivation of winter wheat will be Basarabeasca, Taraclia, Cimislia, Causeni, Cahul, and Stefan Voda in Southern, and Dubasari, Anenii Noi, Hincesti, Ialoveni, Nisporeni, Criuleni, Telenesti and Orhei, in Central AEZs, in which productivity of the winter wheat may decrease from 19-26% (RCP 2.6) to 52-63 % (RCP 4.5) by 2100.

The least vulnerable districts for cultivation of winter wheat production will be Donduseni, Briceni, Riscani, Soroca, and Singerei in the Northern AEZ; and Ungheni, Calaras and Soldanesti in Central AEZs, in which productivity of the winter wheat by 2100 could decrease from 8 to 28% (RCP 2.6) and/or from 69 to 94% (RCP 8.5).

Due to climate change the most vulnerable for grain corn cultivation would be the Central and in less extent the Northern and Southern AEZs. The most vulnerable districts will be Orhei, Anenii Noi, Straseni, Ialoveni, Nisporeni, Telenesti, Ungheni, Calarasi, Criuleni and Dubasari; and UTA, Basarabeasca, Cahul, Taraclia, and Stefan Voda in Southern AEZ, in which productivity of the grain corn may decrease by 2100 from 28 to 50% (RCP 2.6) and/or up to 58-91% (RCP 4.5).

The significant drop in grain corn yield from 65 to 100% (RCP 8.5) is projected in Northern AEZ by 2100 relative to 1981-2010 reference period. The least vulnerable districts to climate change will be Donduseni, Drochia, Falesti, and Ocnita in Northern; Rezina, and Soldanesti in Central, and Leova in Southern AEZs, in which productivity of the grain corn may decrease by 2100, in dependence of the assessed emission scenario from 7 to 23% (RCP 2.6) and/or from 25 to 49% (RCP 8.5). Without adaptation, due to changes in climatic conditions in the most districts of the Republic of Moldova, by the end of the XXI century, the cultivation of grain corn and winter wheat will be impossible according to the RCP 8.5 high emission scenario or economically not cost effective under the RCP 4.5 medium emission scenario.

The most vulnerable for sunflower cultivation without application of adaptation measures, would be Central AEZ and in less extent Northern and Southern AEZs. According to projections, the most vulnerable districts will be Ialoveni, Hincesti, Straseni, Telenesti, Anenii Noi, Dubasari, and Orhei in Central AEZ, in which productivity of sunflower by 2100 may decrease from 23 to 37% (RCP 2.6) and/or from 44 to 76% (RCP 4.5). The least vulnerable for sunflower cultivation districts will be Floresti, Falesti, Riscani, Briceni, Donduseni, Drochia, Edinet, Ocnita, Singerei, and Soroca in Northern AEZ in which productivity of sunflower may decrease by 2100, from 4 to 15% (RCP 2.6) and/or from 17 to 40% (RCP 4.5). Without adaptation measures due to changes in climatic conditions in the most districts of the Republic of Moldova, by the end of the XXI century, the cultivation of sunflower will be impossible or economically not cost effective according to the RCP 8.5 high emission scenario.

According to projections, without application of adaptation measures, the most vulnerable districts for sugar beet cultivation will be Glodeni, Drochia, Falesti, Floresti, and Singerei in Northern; Telenesti, Orhei, and Rezina in Central AEZs, in which productivity of sugar beet may decrease by 2100 from 14 to 27% (RCP 2.6) and/or from 65 to 87% (RCP 8.5).

The least vulnerable districts for sugar beet cultivation will be Briceni, and Donduseni in Northern; and Ungeni in Central AEZs, in which productivity of the sugar beet may increase by 2100 from 2 to 9% (RCP 2.6) and/or from 9 to 34 % (RCP 8.5), in comparison with the 1981-2010 reference period. Without application of adaptation measures, the most vulnerable to climate change tobacco areas in the Republic of Moldova would be Northern, Central and in less extent Southern AEZs. The most vulnerable districts for tobacco cultivation will be Donduseni, Briceni, Ocnita, Edinet, Soroca, Floresti, Riscani, and Glodeni in the Northern; Nisporeni, and Ungheni districts in Central; and Cimislia in Southern AEZs, in which tobacco productivity could decrease from 23 to 56% (RCP 2.6) and/or from 47 to 98% (RCP 4.5).

The least vulnerable districts for tobacco cultivation will be Cantemir, Leova, Taraclia and UTA Gagauzia in Southern AEZ, in which productivity of tobacco may increase by 2100 from 9 to 11% (RCP 2.6) and/or from 7 to 34% (RCP 8.5), in comparison with the 1981-2010 reference period. Without adaptation measures, due to changes in climatic conditions, by the end of the XXI century the cultivation of tobacco in Donduseni, Briceni, Edinet, Soroca, Glodeni, Floresti, Ocnita, Riscani, Nisporeni, Ungheni and Cimislia districts will be either impossible according to the RCP 8.5 high emission scenario, or economically not cost effective according to RCP 4.5 medium emission scenarios.

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