Irrigation Development as a Measure to Combat Climate Change Risks

Anton Strokov[1], Alisher Mirzabaev[2], Alexey Belugin[3], Sergey Kiselev[4]

[1] Eurasian Center for Food Security at Lomonosov Moscow State University, Shosseynaya street 60-11, 109383, Moscow, Russia, strokov@ecfs.msu.ru

[2] Center for Development Research at the University of Bonn, Walter-Flex-Straße 3, D-53113, Bonn, Germany, almir@uni-bonn.de

[3] Faculty of Economics at Lomonosov Moscow State University, Leninskiye gory 1 bld. 46, 119991, Moscow, Russia, belugin89@mail.ru

[4] Faculty of Economics at Lomonosov Moscow State University, Leninskiye gory 1 bld. 46, 119991, Moscow, Russia, servikis@gmail.com

Abstract

Replacing a rainfed cropping system with an irrigated one is widely assumed to be an effective measure for climate change adaptation. But some finding suggests that reassessing climate change risk in agriculture is crucial not to overestimate potential of irrigation-based adaptation. Climate change influences production of cereals in Russia but this general perception of beneficiary effect of a warmer climate is unlikely to hold, primarily due to increasing risk of droughts in the most important agricultural areas of the country. Since Russia is a major crop producer which influences world grain prices, it is important to investigate how climate change can affect the potential growth of grain production in Russia and especially in the Southern regions of Russia, of the Black sea and Volga river basins. To achieve this, the present study seeks to answer two research questions: 1) will climate change have a positive impact on grain production in Russia? If not, 2) could the negative impacts of climate change on grain production and national food security be minimized through expanding irrigation? Using IMPACT-3 model, we analyse three scenarios for agricultural development in Russia until 2030 in the context of climate variability or change. The base scenario assumes no alteration both in the currently irrigated areas and in climate. The irrigation scenario considers the expansion of irrigated areas in the Black Sea and Volga River basins by 15% till 2025 in the context of climatic changes. The dry scenario incorporates the potential risks of global warming without the expansion of irrigated areas, resulting in the reduction of wheat, rice and vegetables yields by an average of 10-15% by 2030. The irrigation scenario projections show doubling of gross agricultural output in 2030 as compared to the dry scenario. The consumer prices under the same irrigation scenario are projected to be lower only by 5%. Expanding irrigation under wheat may lead to competition with wheat production in rainfed areas. As a consequence, the rainfed areas under wheat may decrease, whereas the production of irrigated wheat may grow. However, this growth may not fully compensate the lost rainfed production and thus may lead to lower growth rates of overall wheat production in Russia, with wide-reaching implications not only for domestic consumers, but also for the international grain market. The estimation results in the welfare module indicate that the first scenario (that of irrigated areas expansion) is more profitable for agricultural producers since their profit increases by 11%, and consumer welfare due to consumer prices decrease also increases slightly by 0.4%. The agricultural producer welfare surplus doesn't influence the consumers welfare in the proportional way because, there are other factors affecting this in Russia such as long distance between the producers and consumers, which lead to high transport costs and also the oligopoly issues on the retail market. Thus, to have a full positive impact from irrigation development Russia has to improve the situation in other spheres of economy.

Keywords: IMPACT-3 model, scenario analysis, irrigation, welfare module

1. Introduction

Global warming and consequent climatic changes have been a hot topic in the scientific literature and public discourse for more than two decades. One of the key issues relates to the impacts of climatic changes on water more specifically, will we have enough water if the climate gets dryer? And what will happen to the soils – will climate change affect organic matter in the soil, will it influence the crop yields, will we have enough water to sustain increasing yields to feed the growing population. So this complicated interactions - climate change, water, soils and people’s wellbeing is the crux of climate change related research.

There is increasing evidence of environmental changes in ecosystem processes and functions, yet poor understanding of the relative contributions of land use and climate change to ecosystem services variations. Evidence shows that growing temperature influences more water use in agriculture and affects land use shifts (Pan et al., 2015). Where future changes are uncertain, the sign of the yield change is uncertain as well. Growing temperatures could reduce crop yields in the nearest future (Ummenhofer et al., 2015). At the same time we have to understand that future is uncertain and that we have to apply and model different climate scenarios in order to have a broader view of a range of possible outcomes (Thompson et al., 2015).

Climate change can also affect land use change, which will have impact on soils (Schmitz et al., 2014). Some models use climate data, land use change data, soil data and show the interconnections, in fact, on Russia as an example (Smith et al., 2007). The relationship between organic matter (OM) lability and temperature sensitivity is disputed, with recent observations suggesting that responses of relatively more resistant OM to increased temperature could be greater than, equivalent to, or less than responses of relatively more labile OM (Conant et al., 2008). Recent research showed that there's still uncertainty in soil carbon–climate feedback predictions and some projections could overestimate this interaction (Tang and Riley, 2014). Nevertheless, it is shown that if the temperatures rise there is more probabilities of more frequent draughts directly affecting soils fertility and, thus, also reducing crop yields. So we need to find some ways to sustain yields and protect the soils which could be done with optimized water management.

Water resources are also scarce. Climate change will have potentially significant effects on freshwater quality due to increases in river and lake temperatures, changes in the magnitude and seasonality of river runoff, and more frequent and severe extreme events. These physical impacts will in turn have economic consequences through effects on riparian development, river and reservoir recreation, water treatment, harmful aquatic blooms, and a range of other sectors (Boehlert et al., 2015). Global warming can affect hydrology, morphological changes to river channels and water capacity in river and sea basins, which can support the development of some regions, but challenge other ones, which face often draughts (Lotsari et al., 2015). Replacing a rainfed cropping system with an irrigated one is widely assumed to be an effective measure for climate change adaptation. However, many agricultural impact studies have not necessarily accounted for the space-time variations in the water availability under changing climate and land use. Moreover, many hydrologic and agricultural assessments of climate change impacts are not fully integrated. Other finding suggests that reassessing climate change risk in agriculture is crucial not to overestimate potential of irrigation-based adaptation (Okada et al., 2015).

There are studies focusing particularly on Russia's climate change influence and mitigation (Skrylnikova et al., 2014; Kiselev et al., 2013). Russia has a lot of fertile land but due to climate variability there is high inter-seasonal variability in crop yields (Dronin and Kirilenko, 2013). Farming in higher latitudes is generally believed to benefit from a warmer climate due to extended growing seasons, reduced risk of frost, availability of more productive cultivars, and an opening potential of farming in northern locations. Climate change influences production of cereals in Russia but this general perception of beneficiary effect of a warmer climate is unlikely to hold, primarily due to increasing risk of droughts in the most important agricultural areas of the country. (Dronin and Kirilenko, 2011). Since Russia is a major crop producer which influences world grain prices, it is important to investigate how climate change can affect the potential growth of grain production in Russia and especially in the Southern regions of Russia, of the Black sea and

Volga river basins. To achieve this, the present study seeks to answer two research questions: 1) will climate change have a positive impact on grain production in Russia? If not, 2) could the negative impacts of climate change on grain production and national food security be minimized through expanding irrigation?

To answer these research questions, we evaluate the potential scenarios of expanding irrigated areas in Russia and their impacts on agricultural output in the country. We use an updated IMPACT-3 modelling suite (Rosegrant, 2012), including also the welfare module, with the help of which we are able to estimate the impacts of expanded irrigation not only on agricultural crop yields and, consequently, on agricultural incomes (i.e. producer surplus), but also to identify any changes in the consumer surplus and the total welfare of the society.

2. Research area

Russia is rich in land resources and the present national polices are focused on increasing the agricultural production, as evidenced by the National Program for Agricultural Development and Regulating the Markets of Agricultural Products, for 2013-2020, hereinafter referred to as the National Program-2020 (National Program-2020, 2012). The big extent of Russia's territory and consequent differences in agro-climatic zones will make the impacts of climate change highly differentiated, requiring more complex and nuanced approaches in climate change adaptation (Projecting Global Climate Change, 2009). Therefore, various scenarios of agricultural development and impacts of climatic changes need to be analysed for their effects on agricultural output, consumer markets and the national economy, as a whole.

The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) enables to conduct scenario projections for agricultural development at the country level in the context of climate change (Rosegrant et al., 1995). Climate change projection estimations for Russia have already been made within this model with interesting results (Kiselev et al., 2013). Most notably, it is forecasted that by 2050 some Northern territories, the Tyumen Region, for instance, may become favourable for growing potato, barley and wheat due to the agro-ecological shifts. At the same time, some Southern regions, for instance, the Krasnodar region, may face more draughts and lower grain yields by a up to - 15% (Kiselev et al., 2013).

The latter case is problematic for agricultural production in Russia, as the majority of Russia's most productive agricultural farms are presently located in these southern regions, specifically, in the Volga and Black Sea basins. Being presently mostly rainfed, one potential adaptation option in these areas against recurring droughts would be through expansion of the supplemental irrigation for growing crops. Naturally, the related economic consequences of such shifts need to be properly analysed.

In this context, the expansion of irrigated areas in Russia offers a number of opportunities and is deemed a vital part of the National Program-2020, within the scope of the Federal Target Program "Agricultural Lands Melioration Development in Russia for 2014-2020" (Resolution №922, 2013). Irrigated agriculture not only enables to improve crop yields and profitability in the short term, but when properly applied, helps to improve soil fertility and limit soil degradation (Scientific Basis for Soil, 2013; Shchedrin and Balakay, 2014). Expanding irrigated lands shall have notable impacts on the production of rice and vegetable crops (Balakay, 2011; Vaneyan and Menshikh, 2012; Shchedrin and Balakay, 2014; Shchedrin, 2012). In Russia's central and southern regions, with irrigation, grain yields could rise by up to 40-50%, as compared to the current levels (Schierhorn et al., 2014).

Irrigated agricultural lands make up only 3% of the Russian cultivated lands (Report, 2014). Irrigation areas or irrigation units are those territories (or fields), which actually have any irrigation infrastructure. Of these available irrigation areas, only about 40% are in the actual use (Table 1). This may be due to outdated equipment that many agricultural producers are unable to repair or to replace because of difficult economic conditions (Shchedrin and Balakay, 2014). As noted in the Report on the Status and Use of Agricultural Lands prepared by the Russian Ministry of Agriculture for 2013, in 2012 "more than half of irrigation units (2.4 million ha) require improving including

2,2 million ha requiring reconstruction and technical re-equipment works" (Report, 2014). More than 70% of the irrigated lands with unsatisfactory meliorative condition are located in the Southern and North-Caucasian Federal Districts.

Table 1. Irrigated areas in Russia, as of January 01, 2012

Federal Districts	Irrigated Lands, thousand ha	from which reconstruction required
Central	480.7	352.5
Southern	1076.5	559.8
North Caucasian	1049.7	629.7
Total in the Russian Federation	**4284.6**	**2373.4**

Source: (Concept, 2012). Note: The ratio in the Central, Southern, North Caucasian Federal Districts represents 61% of total irrigated areas, including 65% of those where reconstruction is required.

As it is clear from Table 1, most irrigated areas are located in the Southern Federal District, that is the region, on the one hand, having favorable conditions for agricultural production (fertile lands, available water resources, warm climate), but also suffering from frequent droughts, which is a risk for agriculture. Therefore, optimizing the condition of irrigation facilities may be a solution for boosting future agricultural output. However, there are some indications that the quality of irrigated areas is deteriorating. According to the aforementioned Report on the Status and Use of Agricultural Lands for 2013, in 2010, 47% of irrigated acreage was not used, and in 2012 – 52% of them were not used.

Irrigation units enable agricultural producers to lessen climate risks primarily in the case of droughts. According to the National Report in 2010 when our country suffered from droughts in European Russia on rainfed territories, the wheat yields decreased by 37% as compared to the previous year, and on irrigated lands only by 12% (National Report, 2013). Thus, irrigation may not fully compensate extreme natural and climatic conditions but substantially decrease the losses and provide for output increases as compared to rainfed fields. The output from an irrigated hectare may be 2 – 5 times higher than from rainfed fields, and (Concept, 2012).

Table 2. Crop yields changes with irrigation

Crop	Region	Yield growth with irrigation, as compared to rainfed yields	Source
Wheat	Rostov	By 30%	Drobilko et al., 2009
Potato	Rostov	By 20%	Kalygin, 2005
Vegetables	Saratov	By 100%	Ovchinnikov and Gavrilov, 2010
Cabbage	Moscow	By 32%	Vaneyan and Menshikh, 2012
Sunflower	Saratov	By 25%	Bessmol'naya, 2011
Soybean	Krasnodar	By 50%	Gutrits, 2005
Grain Maize	Krasnodar	By 100%	Balakay and Orel, 2005
Sugar Beet	Rostov	By 100%	Yakovenko, 2006

The yields on irrigated lands are usually higher than on rainfed areas (see Table 2). Besides, irrigation not only influences the yield growth but also helps to store humus, preserving land's long-term fertility. To achieve full effect from irrigation one also needs proper drainage facilities, otherwise the land could quickly become salinized.

Figure 1. Russia's rivers and sea basins.

Note: in the left corner VOG_RUS is the Volga river basin, BLA_RUS is the Black Sea basin.

In the Volga River and Black Sea basins (on Figure 1 they are VOG_RUS and BLA_RUS areas, respectively), being the most developed Russian agricultural regions, irrigation is extensively applied in experimental farms and slowly but steadily is coming to large and medium sized agricultural enterprises as well, particularly in those producing rice and vegetable - highly water-demanding crops (Ovchinnikov and Gavrilov, 2010; Shchedrin and Balakay, 2014). The expansion of irrigated areas is occurring slowly due to high capital costs, financed through the limited public funds. Presently, the state property share in the number of irrigation units and waterside structures is over 60%.

In the Rostov Region, irrigation is used to cultivate wheat, potato and sugar beet with high yields; in the Krasnodar Region it is used for rice, grain maize and other grain crops; in the Saratov Region, irrigation is applied in sunflower cultivation (see table 2).

A number of studies in Russia show that irrigation preserves the soil cover structure providing favorable conditions for agriculture production for years to come (Zhaparkulova, 2014; Scientific Basis, 2013; Nevenchannaya, 2011; Ovchinnikov and Gavrilov, 2010). However, irrigation only cannot save land from erosion, sealing and soil fatigue. Complex approach is required and fertilizers shall be used together with irrigation (Gaikalova, 2006; Shuravilin et al., 2007). Annual adding of 6-8 tons of manure per 1 ha of cultivated land shall stop soil degradation processes and start soil fertility recovery (Shchedrin, 2005).

However, uncontrolled and excessive irrigation has certain risks of land degradation (Nikolaeva et al., 1995; Prikhod'ko et al., 1999; Prikhod'ko, 1994), particularly of secondary salinization, which in long term shall lower the yield and make soils unfit for agricultural use (Kalinichenko et al., 2012). In this regard, one should mind the used water quantity in agricultural production and make regular monitoring of soils acidity. So, scientifically based irrigation implementation and rational systematic exploitation may favour the moisture conservation in soil and higher land productivity, leading to increase of crop yields.

3. Methods

IMPACT-3 model is a deterministic model (Figure 2), where irrigation has a positive effect on output. The irrigated lands improve soil output. However, while interpreting projection results one should not consider the effect of irrigation separately, but in interaction with other production inputs.

The major characteristics of the IMPACT-3 model are:

1) This is a dynamic model, i.e. it has a time parameter that reflects any processes occurring in the system over time.

2) This is a simulation model since it is used for identifying prospective development pathways and for analyzing the sensitivity of the outcomes by varying some or all model parameters.

3) This is a deterministic model since each input parameter set corresponds to well-defined and definitely determined output parameter set.

IMPACT-3 model is an integrated structure and consists of several sub-modules. IMPACT-3 enables to take into consideration temperature and precipitation impact, the effect of soil quality and composition plant, and consequently, on agricultural crops yield via the integrated DSSAT model (Jones et al., 2003). IMPACT-3 includes hydrological data on rivers, water reservoirs and water resources' volumes in specific territories taking into consideration hydrologic cycle at the global level with the help of methodology by Zhu et al., (2012). Model's general structure is provided in Figure 2. Its upper and side parts contain input indices: production, export, import, prices, calibrated elasticities, water volumes, water consumption by various crops and other indices characterizing various scenarios. The equations of the model can be observed in Rosegrant, 2012.

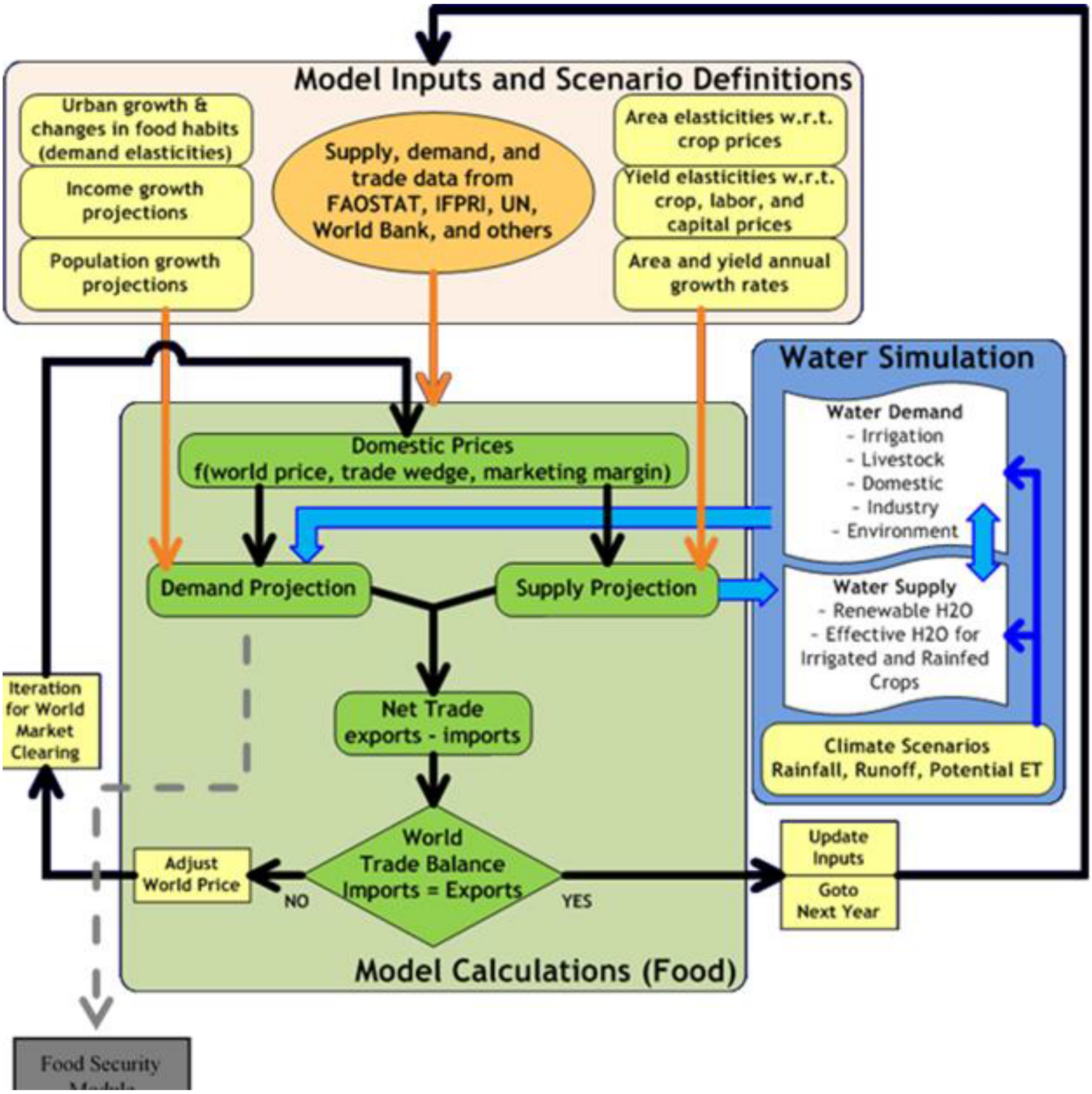

Figure 2. IMPACT-3 model structure

Coming back to Figure 2, we shall mention that to estimate the climate changing impact we use GFDL, HadGEM, IPSL, MIROC climate scenarios based on general circulation climate model (GSM). Each scenario consists of a set of parameters and determines the precipitation amount and average temperatures for specific territories in the base year and thereafter during the whole forecasting period. Table 3 sums up module characteristics giving a clear indication of modules differences: some of them show temperatures relatively high ("+" sign), in others they are relatively low ("–" sign) etc.

Table 3. Distinctive features for IMPACT-3 composite climate models

Climate model	**Precipitation**	**Temperature**
GFDL	-	-
HadGEM	-	+
IPSL	+	-
MIROC	+	+

The first two of the aforementioned climate scenarios (GFDL and HadGEM) are of the main interest for our analysis since they shall face the decline of precipitation amount and, consequently a great necessity shall arise to use irrigation in order to preserve agricultural production.

IMPACT-3 model is disaggregated taking into consideration river basins, in other words there are no common regions and federal districts. Since the majority of Russian agricultural industry is located exactly in the Volga River and Black Sea basins, we shall analyze these two regions. The Base Scenario assumes current irrigated areas preserving and rainfed areas slight decreasing, but crops yield in 2030 shall be changed depending on applying one or the other module (Tables 4 and 5).

Table 4. Agricultural crops yield in the Volga river basin in 2030 (Comparing GFDL and HadGEM climate scenarios)

Crops Name	**GFDL**	**HadGEM**	**HadGEM / GFDL Ratio**
	Tons per 1 hectare	Tons per 1 hectare	**%**
Barley	2.86	2.9	101.4
Corn	6.68	6.03	90.3
Rice	3.37	3.25	96.4
Wheat	2.95	2.85	96.6
Sugar Beet	42.13	41.17	97.7
Vegetables	30.75	29.5	95.9
Sunflower	2.1	2.11	100.5
Potato	15.7	15.26	97.2

Note: Authors' estimations made in the Base Scenario

Table 5. Agricultural crops yield in the Black sea basin in 2030 (Comparing GFDL and HadGEM climate scenarios)

Crops Name			
	GFDL	**HadGEM**	**HadGEM / GFDL**

	GFDL	HadGEM	Ratio
	Tons per 1 hectare	Tons per 1 hectare	%
Barley	4.01	4.09	102.0
Corn	6.66	6.04	90.7
Rice	4.56	4.41	96.7
Wheat	5.53	5.48	99.1
Sugar Beet	52.24	52.24	100.0
Vegetables	20.19	19.38	96.0
Sunflower	2.12	2.13	100.5
Potato	13.3	12.63	95.0

Note: Authors' estimations made in the Base Scenario

The tables show that HadGEM is a drier scenario. We shall apply irrigation expanding conditions for this scenario, and analyse the changes throughout Russia.

To make interconnections we shall use the Base Scenario and the Dry one focusing on possible drought risks. It enables to visually demonstrate any effect of expanding irrigated fields widening or the failure to expand irrigation.

4. Results and Discussion

The Base Scenario (base) assumes the preservation of the current irrigated areas and a slight decrease in rainfed areas. Scenario 1 (scen1), being the Irrigation Scenario, assumes irrigated lands expansion in the Black Sea and Volga River basins. According to our estimations, taking into consideration the implementation of Federal Target Program "Agricultural Lands Melioration Development in Russia for 2014-2020" by 2025 the irrigated areas shall be increased by 15%. Scenario 2 (scen2) being the Dry Scenario assumes the preservation of the current irrigated areas and yield declines by 15% due to climate changing. In all scenarios the rainfed arable land is declining, due to a world wide trend.

The impacts of such changes were estimated in the Model up to 2025. During 2026 – 2030 we have not entered any areas increasing parameters but analysed only the changes being the consequences of climatic factors. Table 6 specifies that after 2025 irrigated areas shall still be increasing though we do not set such increasing exogenously. This effect due to the model's responding to the production profitability on irrigated lands under drought conditions. In other words, reasonable economic behaviour in the context of climate warming involves increasing of irrigated areas.

Table 6. Projections on irrigated fields and rainfed areas in Russia (in 2 main basins), thousand ha

Indices Names	Volga River Basin	Black Sea Basin	Volga River Basin	Black Sea Basin	Volga River Basin	Black Sea Basin
	2015		2025		2030	
Rice	10	126	11	142	11.5	148
Vegetables, irrigated areas	97	124	136	172	244	304
Vegetables, rainfed areas	130	166	98	120	54	63
Wheat, irrigated areas	331	522	470	734	841	1,301

Wheat, rainfed areas	4,960	6,071	3,893	4,590	2,263	2,535
Total crops, irrigated areas	848	1,156	1,442	1,472	1,829	2,584
Total crops, rainfed areas	12,291	15,225	10,297	12,568	6,088	7,431

Note: estimation results subject to the *Irrigation Scenario* (***sc1***)

In general, vegetables and wheat cultivation would be substantially increased on irrigated fields. Wheat share grown in irrigated fields would amount to 45% of the whole planted area in 2030. In 2030, in the Volga River and Black Sea basins, there would be overall decreasing of rainfed planted areas under agricultural crops. It is due, firstly, to more frequent droughts and, secondly, to lower efficiency of rainfed farming as compared to irrigated farming under the same conditions.

In this case, the model results point at higher sensitivity of wheat responses to favourable and unfavourable conditions as compared to vegetables. The effect of irrigated acreage expansion when growing rice is less evident since rice is grown only when fields are irrigated.

The expanding of irrigated lands in main agricultural regions has its effect on whole Russia, as demonstrated below. Having high yields, irrigation increase promotes production development, and for consumers it results in much lower prices for agricultural products. When analyzing price indices we use constant prices of 2005 since that year is the base one for the model when estimating the three analysed crops.

While interpreting the results some caveats need to be taken into account. IMPACT-3 model is based on harmonization and calibration of a great number of indices. This is why the program authors (IFPRI, USA) prefer to select data for a single year and run the model based on that data. At present IMPACT-3 is operating with the database of 2005 using the data for crops production, cropped lands, producer and consumer prices, import and export volumes, etc. The data for Russia correspond to the official data by the Federal State Statistics Service and Federal Customs Service.

Owing to the fact that the base data in the model substantially differs from the official data, some of the received projection results may not always be consistent with absolute production levels over the years. In particular, forecasting production volumes for rice for 2030 in Russia have been actually achieved in 2012. We saw this when we compared the projections for different years with official statistics for the years that already passed. It must be noted that as from 2004-2005 rice cultivated areas in Russia increased for 10 years till 2014 almost by 50%, which IMPACT model couldn't predict in any scenario. However, these relative variations, in our opinion, provide a plausible view of the possible development trends for major agricultural crops and display both irrigation development in Russia and potential risks in the case of the Dry Scenario. The scenario results calculated for basins are summed up at the national level.

The expansion of irrigated lands in the Black Sea and Volga River basins positively affects the rice production throughout the country. Figure 3 displays that even upon the irrigation program ending in 2025 in Scenario 1 (*Irrigation* scenario), the rice production is still increasing. This is due to the fact that rice is a warm-weather and water-demanding crop and rational irrigation enables to keep the effect over quite a long term. Investments made to cultivated areas before 2025 shall give their results so the producers shall ramp up production on the irrigated areas even after 2025 when there are no more investments.

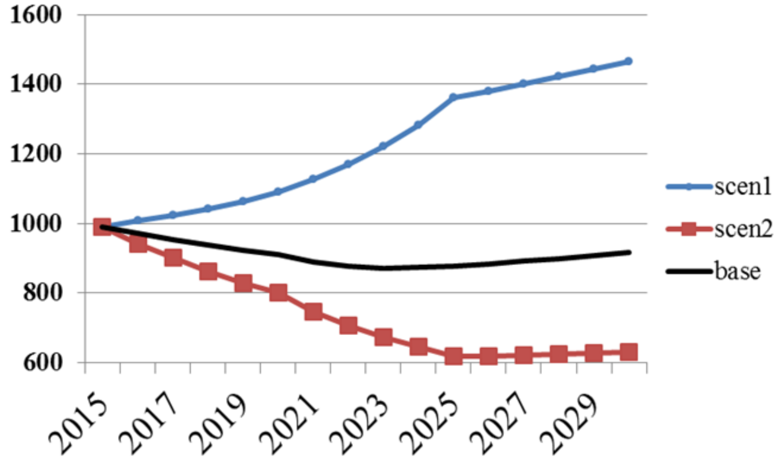

Figure 3. Rice production projections in Russia in thousand tons

Since the Dry (Shocking) Scenario (scen2) initially assumes the reduction of rainfed areas and lower yields, it shall result in production declines that are demonstrated on Figure 3: there is a wide gap between production indices in the Irrigation and Dry Scenarios. In 2030 the Dry Scenario results in rice production being 2.5 times less than in case of Irrigation Scenario.

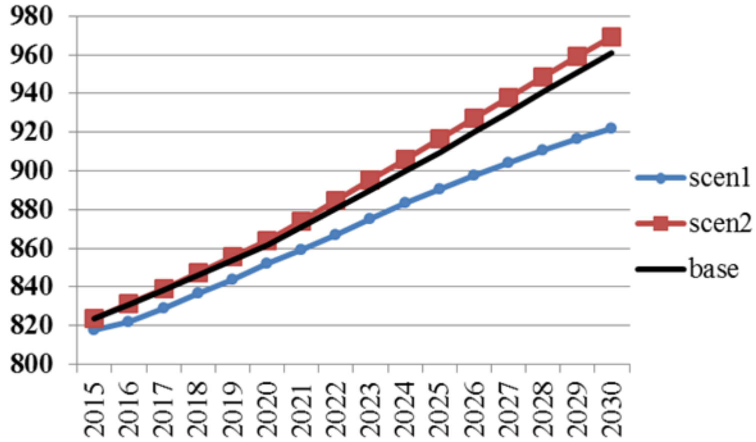

Figure 4. Rice consumer prices in Russia in USD per ton (in constant 2010 prices)

Rice consumer prices in the Dry Scenario shall be 5.4% more than in the Irrigation Scenario (Figure 4). This is due to the fact that the model has been calibrated with low price elasticity of supply, typical for rice. Thus, a sharp slump in production does not result in a proportionate growth of rice prices.

However, Figure 4 makes it clear that rice consumer prices in Irrigation Scenario assuming production growth are lower than the rice prices in the Dry Scenario. It means that the model properly reacts to the given scenarios and complies with the demand properties, whereby increase in the supply quantity of goods leads to declines in their prices.

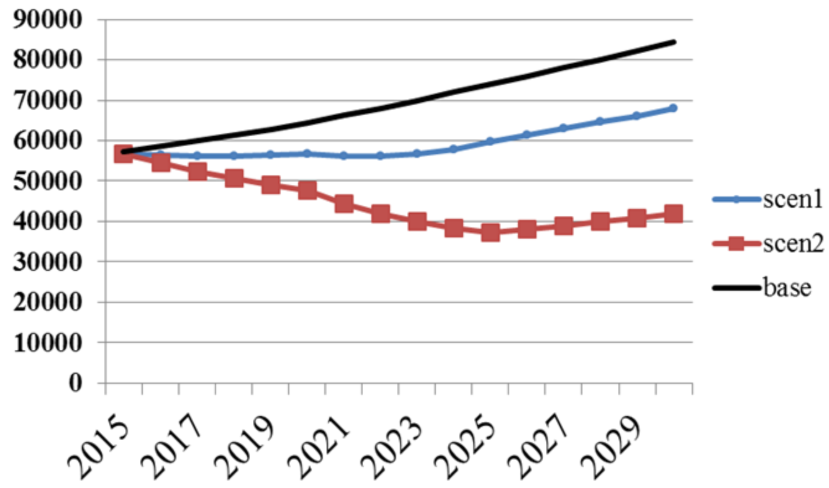

Figure 5. Wheat production projections in Russia in thousand tons

We have received rather exceptional results for wheat (Figure 5). Production dynamics in the Base Scenario are higher than production indices in the Irrigation Scenario. That means that, production volumes in the first case are higher than in case of irrigated areas increase. Somehow in the case of wheat irrigation does not have such positive effect on country's aggregate production. Experience has proven that wheat yield greatly depends on the area with winter sowing and the quality thereof that is not set in the model. This is of great practical consequence.

The expansion of irrigated areas of wheat leads to a competition with rainfed farming. The model deals with the investments made to the irrigation farming being the motivation to grow wheat on irrigated fields. This is why rainfed farming becomes less profitable for farmers relative to irrigated production of wheat (we have included the scheme thereof in Section “Welfare Module” and as Figure 10). As a consequence of such transformations, rainfed wheat production would decline, and irrigated wheat production would grow. However, that leads to lower growth rates for the overall production of wheat in Russia in the Base Scenario as compared to the Irrigation one.

As we have noticed in the situation with rice, the Dry Scenario decreases wheat production. However, after 2025 wheat production would be restored faster than rice production, and this is due to the fact that wheat better resists to draughts. But still in the Dry Scenario wheat production in twice lower than in the Irrigation scenario in 2030.

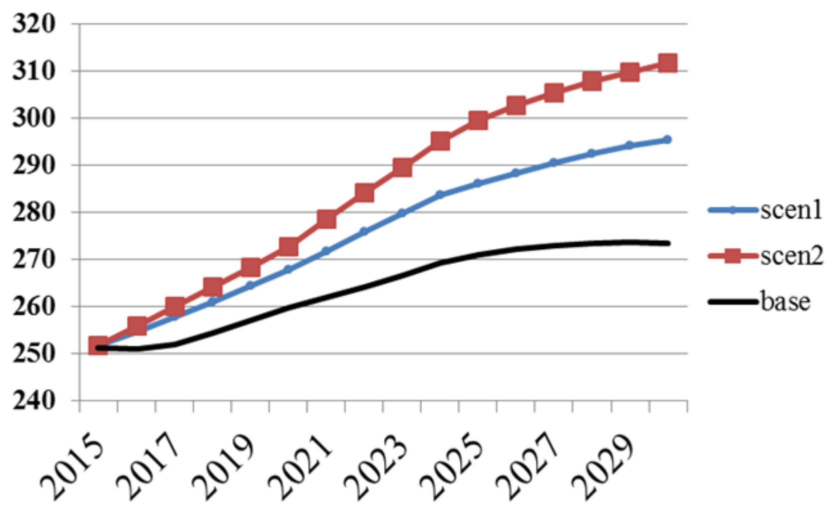

Figure 6. Wheat consumer prices in Russia in USD per ton (in constant 2010 prices)

Figure 6 reflects wheat price behaviour. Everything is consistent here: the Base Scenario offers the highest supply volume, so the prices are lower. In case of drought (scen2) the prices are growing faster and are higher than in other scenarios. Thus, it is clear that in the Dry Scenario in 2030 wheat prices are 5% higher than in the Irrigation Scenario and 12.7% higher than in the Base Scenario (Figure 6).

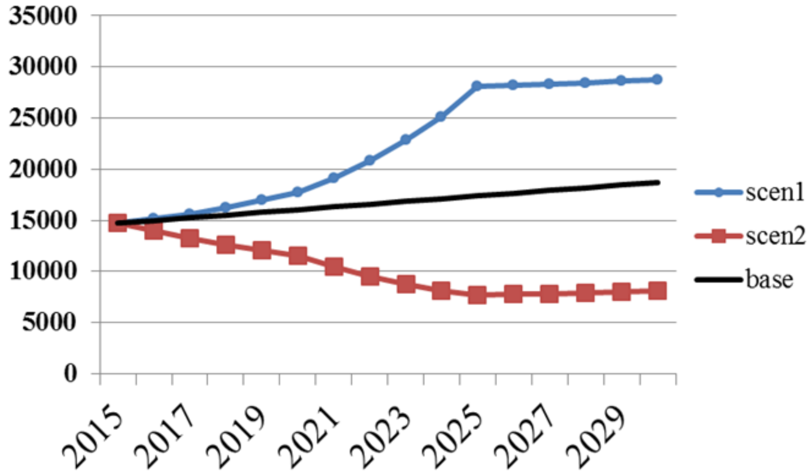

Figure 7. Vegetables production projections in Russia in thousand tons.

Figure 7 reflects the forecasts for vegetables production in Russia. High return is evident in the Irrigation Scenario resulting in production fast growing up to 2025. However, the growth is remarkably slowing down since the given programs for irrigation farming are ceasing. In other words, in case of vegetables there is no long-lasting constant effect from irrigated areas expansion.

The Dry Scenario gives a negative effect, and after 2025 vegetable production is recovering slightly since vegetables in general are very moisture-loving and non-resistant to drought. By 2030 the Dry Scenario provides 3.5 times less vegetables production than the Irrigation one.

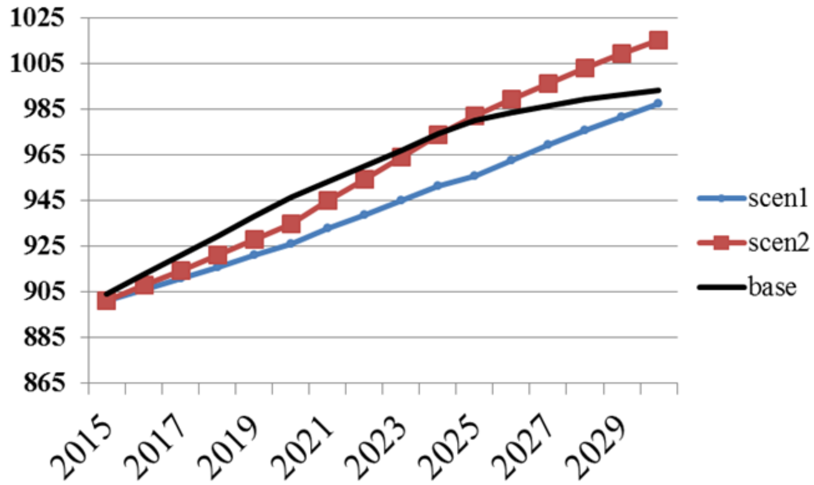

Figure 8. Vegetables consumer prices in Russia in USD per ton (in constant 2010 prices).

Vegetables price behaviour is similar to rice and wheat (Figure 8). In 2030 the prices for vegetables in the Dry Scenario are forecasted by 2.5% higher than in the Irrigation Scenario. But in the base scenario there is a bend of the curve after 2025, which reflects the priority of producers to decrease vegetable prices in order to fulfil the consumers necessity in nutrition.

Thus, it is clear that in case of the Irrigation Scenario the gross output in 2030 may increase by 2 or 3 times than under the conditions assumed by the Dry Scenario. In this case consumer sector prices shall be lower by 5% reflecting the standard situation for agricultural markets having inelastic demand. In case production starts decreasing due to drought risks the prices shall be rising that reflects economic functions.

Now we shall analyse the welfare module and draw conclusions as to how the used scenarios affected producers, consumers income and that of the whole society in Russia.

In the course of Scenarios 1 and 2 welfare module has been used to estimate how investments into agriculture may affect the agriculture producers and consumers and the whole country's welfare. Applying the welfare module, we may provide recommendations to government agencies being able to make more informed decisions considering advantages and disadvantages for various society groups.

Welfare module includes conventional economic laws enabling to estimate the benefit from some or other investment projects both for producers and for consumers. As for demand side, consumer income is estimated in order to discover the changes in consumers surplus due to changing market conditions expressed in production and price behavior for agricultural products. Figuratively speaking, consumers surplus is shown lower than the demand curve and above the market price for each agricultural product kind. Thus, consumer surplus is estimated directly through the quantity of demand and prices (Figure 9).

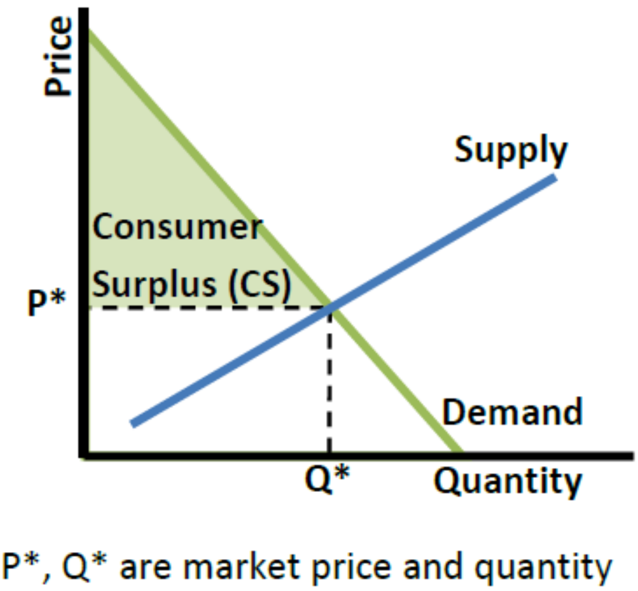

Figure 9. Consumer benefit scheme

Producer surplus is a zone above the supply curve and under the equilibrium price. However, it may not be calculated directly so it is estimated as the difference of agricultural products sales and production costs, i.e. the area below the supply curve (Figure 10).

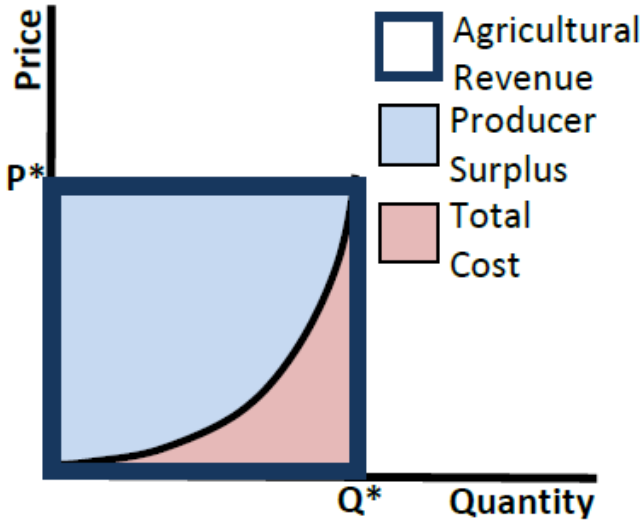

Figure 10. Producers benefit scheme

The overall welfare of society consists of combining consumer and producer surpluses in all spheres of agricultural industry. Thus, consumer and producer surpluses change from one scenario to another.

Taking into consideration the implementation parameters for Federal Target Program "Agricultural Lands Melioration Development in Russia for 2014-2020", we assume 1 billion USD of investments into irrigation infrastructures in the studied area. The discount rate of 13% is used, corresponding to the currently prevailing rates. The estimation results indicate that the first scenario (that of irrigated areas expansion) is more profitable for agricultural producers since their profit increases by 11%, and consumer welfare due to consumer prices decrease also increases slightly by 0.4%. The agricultural producer welfare surplus doesn't influence the consumers welfare in the proportional way because, there are other factors affecting this in Russia such as long distance between the producers and consumers, which lead to high transport costs and also the oligopoly issues on the retail market. Thus, to have a full positive impact from irrigation development Russia has to improve the situation in other spheres of economy.

5. Conclusions

Expansion of irrigated agricultural lands in Russia may substantially affect the production volumes, but only slightly influence the country's welfare. Irrigation enables not only to increase the yields and agricultural profitability, but in case applied correctly, encourages soil fertility improvements.

With the help of IMPACT-3 partial equilibrium model we have estimated and analysed the Irrigation and Dry Scenarios of agricultural development in Russia up to 2030.

The results demonstrate opportunities and challenges for the Russian agriculture. In case of the Irrigation scenario there will be shift in production from rainfed areas to irrigated areas. Under the Irrigation scenario gross output in 2030 may be higher by more than 2 times than under the Dry Scenario. In this case the consumer prices may decline by 5%. The Dry Scenario visually demonstrates global warming possible risks with wheat, rice and vegetables yields decreasing by a mean of 10% by 2030.

Rice and vegetables are deemed more sensitive to irrigation than wheat. Thus, their production in the Irrigation scenario is higher than in the Base and Dry scenarios. Wheat is more drought-resistant. Therefore, wheat production volumes in the Base Scenario exceed production volumes under the Irrigation scenario. It means that in the case of growing wheat on irrigated lands does not have an overall net positive impact on the total production volumes due to decreases in rainfed areas under wheat.

Acknowledgements. The paper was composed with financial support from the Russian Scientific Foundation, Project №14-38-00023 entitled “Land Degradation Control in the Eurasian Region”. The authors hereby express their thanks to IFPRI colleagues: Sherman Robinson, Daniel Mason-D'Croz, Shahnila Islam, who in January 2015 held an IMPACT-3 model workshop in Moscow, where the authors of the paper were trained to work with the model and evaluated the scenarios for this paper.

References

About the Course of Implementation Measures for 12 months of the 2014 provided by Federal Target Program “Agricultural Lands Melioration Development in Russia for 2014-2020”. Ministry of Agriculture of the Russian Federation. Moscow. (2015). [in Russian Language]

Balakay, G.T., 2011. Irrigation provides stable grain production. Agricultural Farming, № 5, pp. 29-31. [in Russian Language]

Balakay, G.T., Orel., VA., 2005. Watering Ways Influencing Grain Maize Growing, Development and Yield. Ways to Increase Irrigated Areas Efficiency, in Scientific Papers Collection with the Materials of the International Research and Practice Seminar “Soybean Cultivation Experience and Prospects at Russia’s Southern Irrigated Areas” December 15-16, 2005, Novocherkassk. [in Russian Language]

Bessmol'naya, E.A., 2011. Sunflower Irrigation Regime in the Povolzhye drought-ridden chernozem steppe. Synopsis of the Ph.D. Thesis. Saratov. [in Russian Language]

Boehlert, B., Strzepek, K.M., Chapra, S.C., Fant, C., Gebretsadik, Y., Lickley, M., Swanson, R., McCluskey, A., Neumann, J.E., Martinich, J., 2015. Climate Change Impacts and Greenhouse Gas Mitigation Effects on U.S. Water Quality. Journal of Advances in Modelling Earth Systems, Vol. 7, Issue 3, pp. 1326-1338.

Conant, R.T., Drijber, R.A., Haddix, M.L., Parton, W.J., Paul, E.A., Plante, A.F., Six, J., Steinweg, J.M., 2008. Sensitivity of Organic Matter Decomposition to Warming Varies With It's Quality. Global Change Biology, Volume 14, Issue 4, pp. 868–877.

Concept of Federal Target Program “Agricultural Lands Melioration Development in Russia for 2014-2020”. Ministry of Agriculture of the Russian Federation. Moscow. (2012). [in Russian Language]

Drobilko, A.D., Eletskiy, A.S., Sapronova, I.V., Drobilko, Y.A., Shevchenko, P.D., 2009. Peculiarities of Winter Wheat Cultivation after Various Preceding Crops in the course of Irrigation // Russia's Grain Farming, № 2. [in Russian Language]

Dronin, N., Kirilenko, A., 2011. Climate Change, Food Stress, and Security in Russia. Regional Environmental Change, Vol. 11, pp. 167-178.

Dronin, N., Kirilenko, A., 2013.Weathering the Soviet Countryside: the Impact of Climate and Agricultural Policies on Russian Grain Yields, 1958-2010. Soviet & Post-Soviet Review, Vol. 40, Issue 1, pp. 115-143.

Gaikalova, L.V., 2006. Land and Water Resources Rational Using in the Irrigation Farming in the Astrakhan Region. Messenger of the Astrakhan State Technical University, № 5. [in Russian Language]

Gutrits, L.S., 2005. Water and Nutrition Regime Influencing Soybean Yields. Ways to Increase the Irrigated Areas Efficiency, in Scientific Papers Collection with the Materials of the International Research and Practice Seminar “Soybean Cultivation Experience and Prospects at Russia’s Southern Irrigated Areas” December 15-16, 2005. Novocherkassk. [in Russian Language]

Jones, J., G. Hoogenboom, C. Porter, K. Boote, W. Batchelor, L. Hunt, P. Wilkens, U. Singh, A. Gijsman, and J. Ritchie, 2003. The DSSAT cropping system model. European Journal of Agronomy Volume 18, № 3-4, pp. 235-265.

Kalinichenko, V.P., Bezuglova, O.S., Solntseva, N.G., Skovpen, A.N., Chernenko V.V., Ilyina L.P., Boldyrev A.A., Shevchenko D.V., Skvortsov D.A., 2012. Negative Impact of Irrigation on Soil and Prospects and Abilities of Applying Subsurface Impulse Continual and Discreet Irrigation Paradigm. Scientific Journal of the Russian Research Institute for Melioration Problems, № 2. [in Russian Language]

Kiselev, S., Romashkin, R., Nelson, G.C., Mason-D'Croz D., Palazzo, A., 2013. Russia's Food Security and Climate Change: Looking into the Future. Economics The Open-Access, Open-Assessment E-Journal, № 39.

Kulygin, V.A., 2005. Soil Rotary Tillage at Potato Plantations during Irrigation. Ways to Increase Irrigated Areas Efficiency, in Scientific Papers Collection with the Materials of the International Research and Practice Seminar “Soybean Cultivation Experience and Prospects at Russia’s Southern Irrigated Areas” December 15-16, 2005. Novocherkassk. [in Russian Language]

Lotsari, E., Thorndycraft, V., Alho, P., 2015. Prospect and Challenges of Simulating River Channel Response to Future Climate Change. Progress in Physical Geography, Vol. 39, Issue 4, pp. 483-513.

National Program for Agricultural Development and Regulating Markets of Agricultural Products for 2013-2020., (2012). Ministry of Agriculture of the Russian Federation, Moscow. [in Russian Language]

National Report of the Implementation in 2012 of the National Program for Agricultural Development and Regulating Markets of Agricultural Products for 2008-2012., (2013). Ministry of Agriculture of the Russian Federation, Moscow. [in Russian Language]

Nevenchannaya, N.M., 2011. Irrigation Influencing the Moisture Distribution in the Profile of Meadow Chernozem Soil. Young Russia: Advanced Technologies shall be Implemented into Industry, № 5, pp. 234 – 237. [in Russian Language]

Nikolaeva S.A., Blynskaya I.V., Voznesenskaya E.A., Rozhdestvenskaya S.O., Rozov S.Y., 1995. Soils Tolerance Theory Development in the Steppe Zone in the Course of Irrigation. Scientific Report under Grant No. № 95-04-11864-a provided by the RFFI. [in Russian Language]

Okada, M., Iizumi, T., Sakurai, G., Hanasaki, N., Sakai, T., Okamoto, K., Yokozawa, M., 2015. Journal of Advances in Modeling Earth Systems, Vol. 7, Issue 3, pp. 1409-1424.

Ovchinnikov, A.S., Gavrilov A.M., 2010. Increasing Irrigation Farming Efficiency in Drought Conditions in the Russian South-East . News of the Nizhnevolzhskiy Agricultural University, No. 2. [in Russian Language]

Pan, T., Wu, S., Liu, Y., 2015. Relative Contributions of Land Use and Climate Change to Water Supply Variations over Yellow River Source Area in Tibetan Plateau during the Past Three Decades. PLoS ONE, Vol. 10, Issue 4, pp. 1-19.

Prikhod'ko, V.E., Manakhova, E.V., Manakhov, D.V., Bezuglova, O.S., Sokolova, T.A., 1999. Irrigated Areas: Functioning, Degradation, Monitoring. Scientific Report under Grant No. 97-05-65437-a provided by the RFFI. [in Russian Language]

Prikhod'ko, V.V., 1994. Irrigated Areas: Functioning, Productivity, Ecology. Scientific Report under Grant No. 94-05-17518-a provided by the RFFI. [in Russian Language]

Projecting Global Climate Changes and Risks in the Russian Agricultural Industry. Multi-authored Monograph edited by I.B. Uskov, V.P. Yakushev. RASHN, Moscow. (2009). – Page 518. [in Russian Language]

Report on the Status and Use of Agricultural Lands prepared by the Russian Ministry of Agriculture for 2013. (2014). Ministry of Agriculture of the Russian Federation, Moscow. [in Russian Language]

Resolution N 922 adopted by the Government of the Russian Federation on October 12, 2013 (amended on January 15, 2015) “About Federal Target Program “Agricultural Lands Melioration Development in Russia for 2014-2020”. – 2013. [in Russian Language]

Rosegrant, M.W., M. Agcaoili-Sombilla, and N.D. Perez., 1995. Global Food Projections to 2020: Implications for Investment. Discussion Paper, № 5. Washington, D.C.: International Food Policy Research Institute.

Rosegrant, M.W., 2012. International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) Model Description. IFPRI. Washington, DC. http://www.ifpri.org/sites/default/files/publications/impactwater2012.pdf. (accessed 11.06.2015)

Schierhorn, F., Faramarzi, M., Prishchepov, A., Koch, F., Muller, D., 2014. Quantifying yield gaps in wheat production in Russia. Environmental Research Letters, №9.

Shchedrin, V.N., 2012. Irrigation Problems and Prospects in the Rostov Region. Scientific Papers Collection/ Forest and Water Industry Melioration Role in the Agricultural Sector Development, Zernograd. pp. 567-579. [in Russian Language]

Shchedrin, V.N., 2005. Southern Federal District Irrigated Lands Effective Use Problems (by the example of the Rostov Region). Ways to Raise the Irrigated Lands Efficiency, in Scientific Papers Collection with the Materials of the International Research and Practice Seminar “Soybean Cultivation Experience and Prospects at Russia’s Southern Irrigated Areas” December 15-16, 2005, Novocherkassk. [in Russian Language]

Schmitz, C., van Meijl, H., Kyle, P., Nelson, G.C., Fujimori, S., Gurgel, A., Havlik, P., Heyhoe, E., Mason D'Croz, D., Popp, A., Sands, R., Tabeau, R., van der Mensbrugghe, D., von Lampe, M., Wise, M., Blanc, E., Hasegawa, T., Kavallari, A., Valin, H., 2014. Land-Use Change Trajectories Up to 2050: Insights from a Global Agro-economic Model Comparison. Agricultural Economics, Vol. 45, Issue 1, pp. 69-84.

Scientific Basis for Soil (Lands) Degradation Preventing in Russian Agricultural Lands and their Fertility Reproducing Systems Forming in the Adaptive and Landscape Specific Agriculture. Volume 1-3. Dokuchaev's Soil Institute. (2013) – 1465 p. [in Russian Language]

Shuravilin A.V., Starikov V.Z., Skorikov V.T., 2007. Principal Cultivation and Irrigation Methods Influencing Soils Agrophysical Properties and Winter Wheat Productivity in the Povolzhie. Messenger of the Peoples’ Friendship University of Russia, № 4, pp. 35- 39. [in Russian Language]

Shchedrin V.N., Balakay G.T., 2014. Current Situation and Prospects in Melioration Areas in the Russian South. Scientific Journal of the Russian Research Institute for Melioration Problems, № 3(15), pp. 1-15. [in Russian Language]

Skrylnikova, N., Lozhnikova, A., Muravyov, I., Kirpotin, S., Ozheredov, Y., 2014. Forecasting the Local and Global Socio-Economic Impact of Climate Change in the Boreal and Arctic Regions of Siberia. International Journal of Environmental Studies, Vol. 71, Issue 5, pp. 774-778.

Smith, P., Smith, J., Franko, U., Kuka, K., Romanenkov, V., Shvetsova, L., Wattenbach., M., Gottschalk, P., Sirotenko, O., Rukhovich, D., Koroleva, P., Romanenko, I., Lisovoi, N., 2007. Changes in mineral soil organic carbon stocks in the croplands of European Russia and the Ukraine, 1990–2070; comparison of three models and implications for climate mitigation. Regional Environmental Change, Vol. 7, Issue 2, pp. 105-119.

Tang, J., Riley, W., 2015.Weaker Soil-Carbon Feedbacks Resulting from Microbial and Abiotic Interactions. Nature Climate Change, №5, pp. 56–60.

Thompson, D., Barnes E., Deser, C., Foust, W., Phillips, A., 2015. Quantifying the Role of Internal Climate Variability in Future Climate Trends. Journal of Climate, Vol. 28, Issue 16, pp. 6443-6456.

Ummenhofer, C.C., Xu, H., Twine, T.E., Girvetz, E.H., McCarthy, H.R., Chhetri, N., Nicholas, K.A., 2015. How Climate Change Affects Extremes in Maize and Wheat Yield in Two Cropping Regions. Journal of Climate, Vol. 28, Issue 12, pp. 4653-4687.

Yakovenko E.A., 2006. Sugar Beet Irrigation Rational Regime Development. Polythematic Network Electronic Journal of the Kuban State Agricultural University, № 21. [in Russian Language]

You, L., and Wood, S., 2006. An entropy approach to spatial disaggregation of agricultural production. Agricultural Systems 90, № 1-3, pp. 329-347.

Valkov, V.F., Kolesnikov, S.I., Kazeev, K.S., 2008. Climatic and Soil Changes in the Russian South. News from Higher Education Institutions, in Natural Sciences Series, № 6, pp. 88-92. [in Russian Language]

Vaneyan, S.S., Menshikh, A.M., 2012. Irrigation Development for Vegetable and Melons in Various Russian Soil and Climate Zones. Scientific Papers Collection in Vegetables and Melons Growing for the 80th Anniversary, Russian Academy of Agricultural Science. [in Russian Language]

Zhaparkulova, E.D., 2014. Soils Fertility Increasing in Case of Irrigation. Science Way, № 10. [in Russian Language]

Zhu, T., Ringler, C. and Rosegrant, M., 2012. Development and Testing of a Global Hydrological Model for Integrated Assessment Modelling, International Food Policy Research Institute, Washington, DC.