Assessment of the impact of climate risks on agriculture in the context of global warming

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Abstract. Understanding the possible climate risks and potential economic losses of agribusiness in different regions is becoming a determining factor in the strategic planning of agricultural activities in the context of global warming. The purpose of this work was to assess the climate risks for agriculture in Russia. The study was conducted using techniques and tools of multivariate correlation analysis. The authors investigated the influence of deviations of the average monthly amounts of temperatures and precipitation from the average long-term values on the deviation of grain yields, using a set of data for 17 regions of the Central Federal district of Russia for the period of 2000-2019. The results showed that a smooth change in the parameters of heat and precipitation does not significantly affect the yield of grain crops. At the same time, increasing annual temperature variability and precipitation significantly reduce yields. An increase in the frequency of extreme events causes a growth in the probability of environmental and economic damage and the magnitude of climate risks. The maximum level of climate risk requires an appropriate adjustment of the agribusiness development strategy and the creation of an institution in society of fair compensation for damage caused by global warming factors.

1. Introduction

Climate change, taking place against the backdrop of global warming, has been one of the most pressing problems of world politics and economics in recent decades. According to experts, the global average annual temperature increased by more than 0.7°C over the period of 1986-2016 compared to 1901-1960 [1]. Many studies have allowed us to form an evidence base for the anthropogenic nature of the causes of climate change [2]. Most often, they are associated with changes in the aerosol and gas composition of the atmosphere, which occur as a result of human economic activity. This is expressed by an increase in the concentration of carbon dioxide, methane, freon, and a number of other greenhouse gases [3, 4]. Climate change factors have a significant impact on changes in terrestrial ecosystems [5], including soil fertility [6, 7], and agricultural production [8, 9].
Addressing the issue of climate change and global warming is the most urgent issue at the moment. The world community has been trying to solve the problem of climate change since the end of the last century, since the adoption of a number of UN resolutions on the protection of the global climate [10, 11]. At the moment, international initiatives are focused on a radical reduction of air emissions (by 50-80% by 2050). This is expected to be achieved by accelerating the transition to a low-carbon economy [12, 13].

However, effective results in this direction have not yet been achieved. The lack of solidarity between countries acts as a deterrent to solving the problem of global warming. Many countries have not yet ratified the Paris Agreement, and many countries see it as a means to achieve their own goals. In this regard, there is no reduction in greenhouse gas emissions [14].

The Fifth Assessment Report of The Intergovernmental Panel on Climate Change (IPCC) predicts that climate change will continue for a long time. Even if CO2 emissions are stopped, by the end of the 21st century, global temperature rise is highly likely to exceed 1.5-2.0°C relative to 1850-1900 [15]. Consequently, warming will continue to determine many economic, environmental and social parameters of social development in the foreseeable future, although it will manifest itself in various regions in different ways. The perception of the ongoing changes at the regional level is also different [16, 17, 18].

Agriculture is one of the sectors of the economy that is most sensitive to climate change. The key factors for agriculture are deviations of average temperatures and precipitation from the average long-term values and some other adverse hydrometeorological phenomena that cause a decrease in yield [19]. An important task today is the search and theoretical justification of ways to adapt agriculture to global climate change. One of the important directions is the forecasting of climate risks and the development of tools for their minimization [20, 21].

Understanding the possible climate risks and potential economic losses for agribusiness in different regions is becoming a determining factor in the strategic planning of agricultural activities. In accordance with this, the purpose of this work was to assess the climate risks for agriculture in Russia.

2. Materials and methods
The study is conducted using empirical tools such as description, comparison, measurement, observation, analysis, and induction. Quantitative assessment of the factors that determine the efficiency of agricultural farming was carried out by the method of multivariate correlation analysis based on the calculation of paired correlation coefficients, point correlation and their subsequent interpretation, as well as by means of regression statistics based on the calculation of regression coefficients, confidence intervals and the construction of a regression model. The statistical significance of the calculated coefficients was checked by finding the critical values of Student and Fisher, and then comparing them with the table values.

The authors considered a set of climate indicators that have the greatest impact on the performance of the agricultural sector. The authors focused on two groups of indicators: the average of the sum of annual temperatures and the amount of precipitation by region, which are common variables for analyzing the impact of climate change on agricultural production [22, 23]. The authors used data on deviations of the average monthly sums of temperatures and precipitation from the long-term average values. The authors used the data of yield fluctuation from the average values as an effective indicator. The calculations were carried out on the example of grain crops, which occupy more than half of the structure of crops, are the main agricultural crops in the region.

The authors investigated these relationships on a regional scale, using a combination of climate and agricultural statistics for 17 regions of the Central Federal district of Russia for the period of 2000-2019.

The general climate risk assessment model is presented as follows:

$$R = f(p_r, d),$$

(1)

where: $p_r$ - probability of occurrence of a risk event in a certain period of time; $d$ - potential damage to economic entities that are affected by risk factors (the cost of lost products and the expenses for eliminating or reducing the damage).
Authors considered potential yield losses as the damage value [24, 25].

3. Results and discussion

According to all modern climate models, Russia in the XXI century is waiting for warming, which will significantly exceed the global average. The greatest increase in surface temperature is planned in winter, it strengthens to the north and reaches a maximum in the Arctic. In the summer, the zoning of warming will not be expressed.

According to climatologists, in the XXI century, precipitation is expected to increase in the territory of the Russian Federation, and it will be most significant in winter. Geographically, the distribution of expected changes in precipitation in winter and summer is significantly different. For example, in winter, precipitation is projected to increase throughout the country, with an enhanced strengthening by the middle of the century in the eastern and northern regions.

By the middle of the XXI century, the lowest growing precipitation in summer is observed in the south, where there is a tendency to decrease. The increase in summer precipitation is most significant in the east and north of the Russian Federation. In the long term, global warming may change the frequency and intensity of extreme weather events. Highs and lows of air temperature will rise in most of the country; during all seasons, an increase in the number of days with extremely high air temperature and a decrease in the number of days with abnormally low air temperature at night will prevail [26].

According to many researchers, the process of climate warming will have a more positive impact on the economy of the Russian Federation, including agriculture [27, 28]. This is due to the fact that in the Russian temperate zone, bioresources have a lack of heat [29].

Since 2000, the agriculture of the Central Federal district has shown a stable trend of increasing the yield of grain crops both on the basis of the linear and polynomial trend equation (Fig. 1).

![Figure 1. Dynamics of grain yield in the Central Federal district of Russia, quintals per 1 hectare (according to Rosstat (https://rosstat.gov.ru))](image)

The average yield level for this period was 27.3 quintals per 1 hectare. The assessment of the influence of the parameters of heat supply and precipitation on the yield of grain crops in the context of separate regions of the Central Federal district did not reveal a significant relationship. The correlation analysis allowed the authors to establish an inverse relationship between the effective indicator (yield) and the factor indicators (temperature and precipitation).

According to the scale of Cheddock, it is characterized as weak. The linear correlation coefficient is -0.12 for precipitation, and -0.10 for temperature. The partial correlation coefficient is -0.14. There is a moderate inverse multicollinearity between temperature and precipitation -0.36. The lack of dependence of yield on natural conditions can be explained by a slight variability in the climatic conditions of the regions, which are compensated by the influence of technological factors.
There is a significant fluctuation in the yield, which cannot be explained by the technology or organization of production. The influence of random weather factors is obvious, but their long-term forecast is not possible. These include extreme temperatures in certain periods of time, heavy rains, winds, tornadoes, and other dangerous phenomena. The consequences of global warming for most of the planet and for Russia in particular depend on the growing number and strength of such meteorological phenomena. In Russia, the number of dangerous meteorological phenomena has increased about 2 times over the past 15 to 20 years [30].

The correlation and regression analysis makes it possible to identify the strength of the relationship between the variables Y (grain yield) and X1, X2, X3,... X12, which represent the deviations of the average monthly sums of temperatures from the average long-term values for a set of regions. Tables 1, 2 show the results of the analysis according to the data of the Tambov Region, one of the regions of the Central Federal District.

**Table 1.** Variance analysis of the influence of average monthly temperatures on yield

|       | df  | SS           | MS        | F        | Significance F |
|-------|-----|--------------|-----------|----------|----------------|
| Regression | 3   | 453.186228   | 151.062076| 12.3366718| 0.00561883     |
| Remains   | 6   | 73.4697716   | 12.2449619|          |                |
| Total     | 9   | 526.656      |           |          |                |

**Table 2.** The results of the regression of yield and average monthly temperature

|       | Coefficients | Standard Error | t-statistics | P-Value | Bottom 95% | Upper 95%  |
|-------|--------------|----------------|--------------|---------|------------|------------|
| Y-intersection | 3.680339     | 1.33330523     | 2.76031228  | 0.03284045 | 0.4178584 | 6.942819   |
| X1    | -0.18286     | 0.67684968     | -0.27016227 | 0.79608756 | -1.8390507 | 1.473332   |
| X6    | -2.09144     | 0.74799131     | -2.79608079 | 0.03132534 | -3.921713 | -0.26118   |
| X7    | -2.19215     | 0.84945871     | -2.58064372 | 0.04173332 | -4.2707009 | -0.1136    |

There is a strong relationship between yield and temperature in January (X1), June (X6) and July (X7), the multiple correlation coefficient is 0.9276. The paired correlation coefficients are respectively equal to 0.746635, -0.70752, -0.81265. The P value in all cases is below the specified significance level of 95%, which indicates that these coefficients have an impact on the change in the model. The regression model has the form:

\[ Y = 3.68 - 0.18X_1 - 2.09X_6 - 2.19X_7. \]

Temperature conditions during the growing season are especially important; they have a significant impact on the yield. The greatest strength is shown in the relationship between the harvest of grain crops and the temperature in July and June. Since the relationship is reversed, it can be argued that an increase in temperature in these months will lead to a reduction in the volume of products received. Exceeding the average monthly temperature in the region by 1°C leads to a decrease in yield by 2.09 quintals per 1 hectare. A similar situation in June leads to reduce in yield by 2.19 quintals per 1 hectare. It can be assumed that the increase in temperature in these months will affect grain production, which is directly influenced by warming, faster and more strongly than the industries that are subject to secondary and indirect effects.

The amount of precipitation in the region during certain periods of the year has a strong impact on crop productivity. Liquid and mixed precipitation are the most significant for agriculture. Advanced forecasting technologies can mitigate the impact of some weather events, but it is impossible to completely neutralize their effects.
Precipitation levels in March (X3), April (X4), August (X8), and December (X12) have the most significant impact on crop yields. The coefficient of multiple correlation between the yield of grain crops and the amount of precipitation in these months is 0.7197, which characterizes the relationship between the factors as high on the Cheddock scale (Tables 3, 4).

**Table 3.** Dispersion analysis of the effect of precipitation on yield

|         | df | SS    | MS   | F     | Significance of F |
|---------|----|-------|------|-------|-------------------|
| Regression | 4  | 272.805 | 68.20125 | 1.3433322 | 0.370177 |
| Remains | 5  | 253.851 | 50.7702 |       |                   |
| Total   | 9  | 526.656 |       |       |                   |

**Table 4.** The results of the regression of yield and precipitation

|         | Coefficients | Standard error | t-statistics | P-Value | Bottom 95% | Upper 95% |
|---------|--------------|----------------|--------------|---------|------------|-----------|
| Y-      | -0.520750    | 2.349033       | -0.22169     | 0.833327364 | -6.55913 | 5.517632 |
| X3      | 0.010261     | 0.200547       | 0.051166     | 0.961174493 | -0.50526 | 0.525784 |
| X4      | 0.116582     | 0.086818       | 1.342831     | 0.237060326 | -0.10659 | 0.339756 |
| X8      | -0.171550    | 0.109715       | -1.56355     | 0.178689091 | -0.45358 | 0.110487 |
| X12     | -0.141100    | 0.176177       | -0.80089     | 0.459543738 | -0.59398 | 0.311779 |

The regression model has the form:

\[ Y = -0.52 + 0.01X_3 + 0.11X_4 + 0.17X_8 - 0.14X_{12}. \]

The relationship between the yield and the amount of precipitation in March and April is direct. This is due to the positive effect of the increase in soil moisture reserves in the spring period on the energy of seed germination and subsequent plant growth. The dependence of the yield and the amount of precipitation in August and December is reversed, which confirms the conclusion that excessive precipitation can negatively affect the effectiveness of agricultural production. Excess moisture in August, as a rule, leads to difficulties with harvesting, associated with the lodging of the crop and the complication of the working conditions of the equipment during the harvesting period. The negative impact of excess moisture in December is determined by the high probability of wetting of winter grain crops in such conditions.

The analysis of the available data makes it possible to estimate the probability of deviation of the yield from the average values in the analyzed period (Table 5).

The percentile of the decline in yield relative to the average values in the region as a result of deviations in weather conditions during critical periods of time for the crop is 35. At the same time, up to a quarter of all cases are expected to fall in yield to 6.62 quintals per 1 hectare. Given that the average yield level in the region is 27.3 quintals per 1 hectare, the percentage of the lost crop may be 24.2 in each of these cases.

In 2019 prices, crop losses in the amount of 29.6 to 254.77 USD per 1 hectare of grain crops are possible. The annual course of environmental risk is estimated from 10.36 to 27.52. This allows us to predict the corresponding level of break-even of agricultural production by agribusiness entities.
Table 5. Assessment of the probability of yield deviation from the average values and the magnitude of the climate risk

| Percentile | Y     | Probability of damage occurrence | Average price level of 1 quintal of grain, USD | Potential damage per 1 hectare, USD | Climate risk |
|------------|-------|---------------------------------|-----------------------------------------------|------------------------------------|--------------|
| 5          | -15.32| 0.05                            | 16.63                                         | 254.77                             | 12.7386      |
| 15         | -7.52 | 0.15                            | 16.63                                         | 125.06                             | 18.7586      |
| 25         | -6.62 | 0.25                            | 16.63                                         | 110.09                             | 27.5227      |
| 35         | -1.78 | 0.35                            | 16.63                                         | 29.60                              | 10.3605      |
| 45         | 2.58  |                                 |                                               |                                    |              |
| 55         | 2.68  |                                 |                                               |                                    |              |
| 65         | 2.88  |                                 |                                               |                                    |              |
| 75         | 3.48  |                                 |                                               |                                    |              |
| 85         | 4.48  |                                 |                                               |                                    |              |
| 95         | 11.58 |                                 |                                               |                                    |              |

4. Conclusion

A gradual change in the parameters of heat and precipitation does not significantly affect the yield of grain crops in the context of individual regions of the Central Federal District of Russia. At the same time, increasing annual temperature variability and precipitation significantly reduce crop yields. Increasing the frequency of extreme events raises the likelihood of environmental and economic damage and the magnitude of climate risks. The maximum level of climate risk requires an appropriate adjustment of the agribusiness development strategy in order to minimize the permissible probability of damage.

Additional economic investments in the adaptation of agriculture to the effects of global warming will be driven by the changing probability of climate risk and limited by the need to ensure break-even production. Production is appropriate in all cases where additional economic costs combined with climate risk do not lead to loss making of agribusiness.

A stable agricultural economy should be prepared for the gradual increase in climate risks, which are determined by the factors of global warming. At the same time, in the context of a gradual increase in climate risks, ensuring a stable functioning agricultural economy requires the creation of an institution of fair compensation for damage caused by global warming factors.

References

[1] USGCRP 2017 Climate Science Special Report: Fourth National Climate Assessment, Volume I (Washington, DC, USA) 470 p. doi: 10.7930/J0J964J6.
[2] Clark P U et al 2016 Consequences of twenty-first-century policy for multi-millennial climate and sea-level change Nature Climate Change 6 360–369. doi:10.1038/nclimate2923.
[3] Myhre G D et al 2013 Anthropogenic and natural radiative forcing, In: Climate Change 2013: The Physical Science Basis (Cambridge University Press) pp 659-740. doi:10.1017/CBO9781107415324.018.
[4] Lacis A A, Schmidt G A, Rind D and Ruedy R A 2010 Atmospheric CO2: Principal control knob governing Earth’s temperature Science 330 356–359. doi:10.1126/science.1190653.
[5] Pecl G T et al 2017 Biodiversity redistribution under climate change: Impacts on ecosystems and human well-being Science 355 eaai9214. doi:10.1126/science.aai9214.
[6] Challinor A J, Watson J, Lobell D B, Howden S M, Smith D R and Chhetri N 2014 A meta-analysis of crop yield under climate change and adaptation Nature Climate Change 4 287-291. doi:10.1038/nclimate2153.
[7] Lin K C, Hamburg SP, Wang L et al 2017 Impacts of increasing typhoons on the structure and function of a subtropical forest: reflections of a changing climate Sci Rep. 7 4911.
https://doi.org/10.1038/s41598-017-05288-y
[8] Lobell D B and Field C B 2007 Global scale climate–crop yield relationships and the impacts of recent warming Environ. Res. Lett. 2(1) 014002

[9] Baldos U L C, Hertel T W and Moore F C 2019 Understanding the spatial distribution of welfare impacts of global warming on agriculture and its drivers American Journal of Agricultural Economics 101(5) 1455-72. doi:10.1093/ajae/aaz027

[10] General Assembly resolution 43/53 of 6 December 1988 (Protection of global climate for present and future generations of mankind) Retrieved from: https://legal.un.org/avl/ha/ccc/ccc.html

[11] General Assembly resolution 47/195 of 22 December 1992 (Protection of global climate for present and future generations of mankind) Retrieved from: https://www.un.org/ga/search/view_doc.asp?symbol=A/RES/47/195

[12] Kyoto Protocol to the United Nations Framework Convention on Climate Change Kyoto, 11 December 1997. Retrieved from: https://unfccc.int/sites/default/files/resource/docs/cop3/07a01.pdf

[13] Paris Agreement. Retrieved from: https://unfccc.int/sites/default/files/english_paris_agreement.pdf

[14] Zhilina I Yu 2019 How to avoid global warming and its consequences (Review) Social and humanitarian sciences: Domestic and foreign literature 2. Retrieved from: https://cyberleninka.ru/article/n/2019-02-009-i-yu-zhilina-kak-izbezhat-globalnogo-potepleniya-iego-posledstviy-obzor

[15] Climate Change 2013 The Physical Science Basis (Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA) Retrieved from: https://www.ipcc.ch/report/ar5/wg1/

[16] Karpunina E K, Petrov I V, Klimentova E A, Sozaeva J A and Korkishko I V 2020 Mechanisms of Self-Development of Subsidized Regions Proceedings of the 35rd International Business Information Management Association Conference pp 2282-93

[17] Karpunina E K, Lapushinskaya G K, Arutyunova A E et al 2020 Dialectics of Sustainable Development of Digital Economy Ecosystem Lecture Notes in Networks and Systems, 129 LNNS 486-496. DOI: https://doi.org/10.1007/978-3-030-47945-9_54

[18] Nikitin A, Klimentova E and Dubovitski A 2020 Impact of small business innovation activity on regional economic growth in Russia Revista Inclusiones 7(SI) 309-321

[19] Kunreuther H, Heal G, Allen M, Edenhofer O, Field C B and Yohe G 2012 Risk Management and Climate Change NBER Working Paper 18607. DOI: https://doi.org/10.3386/w18607

[20] Azadi H, Petrescu D C, Petrescu-Mag R M and Ozunu A 2020 Special issue: Environmental risk mitigation for sustainable land use development Land Use Policy 95 104488. DOI: https://doi.org/10.1016/j.landusepol.2020.104488.

[21] Thanh B Ph, Zhu Th X and Groeneveld van Ierland E 2020 Risk communication, women participation and flood mitigation in Vietnam: an experimental study Land Use Policy 95 104436. DOI: https://doi.org/10.1016/j.landusepol.2019.104436

[22] Lobell D B, Schlenker W and Costa-Roberts J 2011 Climate trends and global crop production since 1980 Science 333(6042) 616-20

[23] Rahman S and Anik A R 2020 Productivity and efficiency impact of climate change and agroecology on Bangladesh agriculture Land Use Policy 94 104507. DOI: https://doi.org/10.1016/j.landusepol.2020.104507.

[24] Dubovitski A A, Karpunina E K, Klimentova E A and Cheremisina N V 2019 Ecological and economic foundations of effective land use in agriculture: The implementation prospects of food security Proceedings of the 33rd International Business Information Management Association Conference pp 2687-2693

[25] Dubovitski A, Klimentova E, Nikitin A, Babushkin V and Goncharova N 2020 Ecological and Economic Aspects of Efficiency of the Use of Land Resources E3S Web of Conferences 210 11004. DOI: https://doi.org/10.1051/e3sconf/202021011004

[26] 2020 A report on climate features on the territory of the Russian Federation in 2019 (Moscow)
[27] Smolina S G 2013 Forecasts of the impact of climate change on the economy of industries and regions of Russia *Bulletin of the International Institute of Economics and Law* 1(10) 106-114

[28] Pegov S A, Smolina S G and Khomyakov P M. Global warming. What does it bring to Russia? Retrieved from: [http://federalbook.ru/files/FS/Soderjanie/FS-14/VII/Pegov.pdf](http://federalbook.ru/files/FS/Soderjanie/FS-14/VII/Pegov.pdf)

[29] Pavlenko V B 2017 The Paris Agreement as a threat to the national security of Russia *Astrakhan Bulletin of Environmental Education* 4(42)

[30] 2020 *A report on the scientific and methodological basis for the development of strategies for adaptation to climate change in the Russian Federation (in the area of competence of Roshydromet)* (Saint-Petersburg; Saratov: Amirit)