Evaluation of the Impact of Climatic Changes on the Development of Agriculture of European North Russia

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Abstract. Observations indicate that global warming may be currently taking place, which has accelerated markedly since the 1970s. Research on the implications of climate change has shown that the greatest effect is to be expected in the following sectors of the regional economy: agriculture, transport infrastructure, utilization of coastal resources, energy, forestry, tourism, fish industry and water. Studies for Russia, which is overall a relatively cold country, showed that climate change has a direct effect on production in agriculture and it may be either positive or negative in different regions of the country. To assess the effect of climate change on agriculture in European Russia we distinguished climatic zones with similar temperature and precipitation values. Several models of the dynamics of agricultural production and yield depending on climatic characteristics, farming practices and socio-economic characteristics were built. As a result, the positive impact of climate change on crop yields in Russia has found only partial confirmation. A greater effect can be manifested by increasing the level of management and transition to modern technologies, and gradual shift to the north of grown crops. This will accordingly require increased investment in agricultural science to implement new projects in line with the changing external environment.

1. Introduction

Substantial temperature fluctuations have been noted through the history of meteorological observations. Studies of lake bottom sediments have demonstrated even stronger temperature fluctuations during tens of millennia. Observations suggest that there is possible ongoing climate warming, which has accelerated notably starting the 1970s. The first decade of the 21st century was record warm for the entire 160 years of observations.
Mean annual air temperature in the European North has been growing for nearly 100 years. In the recent decades the ice-covered period on lakes in the European North has become shorter. Lake Onego now frees of ice some 8-10 days earlier than several decades ago. Mean annual air temperature in Karelia has risen by 1-2 degrees since the late 1980s, but no further rise is currently observed [1].

An elevated air temperature in Karelia ‘figure 1’ is observed in the period from January to June; in July to October both positive and negative trends have been seen; and since November the tendency in the entire Karelia has been for a cooling.

![Figure 1. Changes in mean annual air temperature in Karelia in 1752–2000; 30-year moving averages.](image)

Warming is happening at different rates in other regions of Russia, too. In the Far East, mean winter temperature has increased over the past 30 years (compared to the period 1951-1980) and the heating season (mean daily temperature below 8 degrees) has been shortened. In Magadan the heating season became 6 days shorter, and in Chukotka’s capital Anadyr it decreased by 10 days, from 311 to 301 days [2].

Research on the implications of climate change has shown that the greatest effect is to be expected in the following sectors of the regional economy: agriculture, transport infrastructure, utilization of coastal resources, energy, forestry, tourism, fish industry, and water supply.

Warming has not only positive but also negative effects. Increase in the number of hot days causes higher human mortality. In Moscow, the threshold mean daily air temperature for pushing up mortality is 25º. In the hot summer of 2010 mortality increased in a majority of Russian regions. In Karelia in July 2010 it was 12.5% higher than in the preceding year. The 2010 summer conditions caused massive mortalities among farm-reared trout, cutting its output in Karelia down by nearly 20%.

The implications of climate change have been most extensively studied for agriculture. The aspects studied most often were farmers’ incomes and the yield of various crops. Various types of equations have been used to this end.

The studies have shown that the effect of climate characteristics is significant and non-linear. It has also been suggested to consider the levels of management and technology as factors for this effect [3]. Substitution of one crop with another, more productive one, in the case of a rise in mean temperature in the region was demonstrated to bring a positive effect [4]. Evidence was gathered that in some
regions the yield can be increased owing to an improvement of climate conditions and the use of more productive and heat-demanding crops, whereas in southerner regions the conditions will be deteriorating [5]. For China, it was shown that the yields of maize and wheat declined in southern provinces, while the yields of rice and soybeans were growing in north-eastern and northern provinces [6].

The climate change implications for agriculture in developing countries have most often been assessed as negative. This negative effect stems from poor adaptability. The climate conditions in these countries have already changed to warmer and more arid. Studies show the yields in these countries have been growing in their northerner regions for some crops. Studies of climate change effects in colder countries of the world have been insufficient, and they have rarely taken into account the possible actions people can take to adapt to the change.

In the 1980s, the Computing Centre of the USSR Academy of Sciences carried out research on the effects of climate change and decision-making on the yield of grain crops. Such studies were done in different regions of Russia [7]. An increase in the yield of winter crops was observed in many regions. Studies for the territory of Russia, which is overall a relatively cold country, showed that climate change has a direct effect on production in agriculture, especially on the yield of grain crops, and the effect varies across latitudes and longitudes.

Calculations for different regions produce ambivalent results, so the question arises about the ratio of gain in grain output in some regions of the country and the loss of yield in others [7]. The positive effects will possibly alone for the negative climatic effects in other regions, especially in southern regions of European Russia. The negative effect of climate change on agriculture is largely due to warming in southern regions of the country, the unfavorable regime and uneven spatial distribution of precipitation. It is expected that regions with high grain yields will become more frequently exposed to extreme weather conditions (droughts, hurricanes, etc.), and drought periods during the growing season will be getting longer as the climate continues to change.

Climate change will cause summer in northern regions to become wetter, although flooding is already a real threat there. This factor can reduce the positive effect of climate warming on crop yields in northern regions. Russia is among the regions where the heat stress will be growing, but it has only slight detrimental effect on wheat, which is Russia’s major crop. The study of the effect of various factors on farmland dynamics in European Russia over the past three decades found no proof that climate factors have caused an increase in farmland abandonment.

When studying the southern regions of Russia, it was shown that one of the key factors is growing degree days, which had a positive effect in low temperature regions and a negative effect in high temperature regions. The nationwide averaged effect was negative. A rise in winter temperature by at least 1°C causes the yield of cereal grain crops to increase by nearly three percent. An increase in the share of precipitation at the onset of the growing season also has a positive effect of grain yield, while excessive moisture during the harvest season reduces the yield. An increase in precipitation during the sowing of winter cereal grains also produces a negative effect on grain yield [8].

A majority of scientists agree that the overall effect of climate change on agriculture, and especially on grain cultivation, will be more on the negative than on the positive side. However, studies on the possible measures for adaptation to the changing climate have been few. Recommendations for farms and farmers on how to adapt to the new climate conditions have been few. Studies on the role of science in adaptation to climate change have been few. Furthermore, it is unlikely that agricultural
producers will in the long-term proceed with their business as usual, without having to adapt to changes in the production sphere.

Agriculture has gone through a dramatic decline in the early 1990s, but has been developing since the late 1990s, with increased investments, improved management and new technology. As a result, the output of a majority of crops has been growing in Russian regions. This growth has so far been unstable, not least because of change in weather conditions.

The effect of ongoing climate change may be either positive or negative in different regions of the same country. The yield of some crops may increase under climate warming, given that more productive and thermophilic crops are cultivated. New branches of agriculture may be adopted in northern and mountainous regions of Russia. At the same time, some southern regions, on the contrary, may suffer a reduction in crop yields.

Let us remark that climate change can affect agricultural production both directly, via changes in climate conditions, as well as indirectly, for instance through changes in global market prices for agricultural products.

2. Methodology

There are different approaches to the assessment of the effect of climate change. The most widely used approach is based on the estimation of the effect of short-term (annual) change of weather conditions (fixed-effects model). It takes little account of the possibility of long- or mid-range adaptation of agricultural activities to changes in climate conditions. Another approach utilizes the method of estimating differences in the mid-term change of climate parameters (long-difference model). In this case, differences between the average parameter values for distant time periods are compared. In fact, adaptation to ongoing climate change is incorporated in the assessment [8, 9].

A tendency has formed for an increase in mean annual temperature and precipitation covering most of the Russian territory, pointing to changes in climate conditions and suggesting that this tendency may continue. In this situation, econometric analysis can be applied to study the effect of climate change on agriculture in Russia, as a global exporter of agricultural products. It is particularly important to investigate the regions of Russia noted for short and cool farming seasons that restrain yields.

To assess the effect of climate change on agriculture in European Russia we distinguished climatic zones with similar temperature and precipitation values. A total of five climatic zones were distinguished – with mean annual temperature of 0 to +5 (two zones different in the patterns of annual temperature change), +5 to +10 (two zones different in precipitation levels), and above +10. Regions with low temperatures and minor contribution of agriculture were excluded from the study.

The zone in Northwest Russia (non-chernozem zone), delimited by mean annual temperatures of 0 to +5 degrees and annual precipitation of 550 to 700 mm, was studied in more detail. Originally, it comprised 23 regions, from Karelia to the Sverdlovsk Region.

Analysis of 1990-2015 data from individual regions of this zone showed that it should be subdivided into two groups of regions – northern non-chernozem subzone (Karelia, Komi, Arkhangelsk, Vologda, Leningrad, Novgorod, Murmansk Regions), and southern non-chernozem subzone. These groups responded absolutely differently to climate change.

Several models of the dynamics of agricultural production and yield depending on climatic characteristics, farming practices and socio-economic characteristics were built within the study [11]. The models considered mean temperature, growing degree days (mean daily temperature above 10
degrees), and total precipitation over different periods (year, season, specific months). The effect of the following factors was also analyzed: application of mineral and organic fertilizers per hectare of crop, area planted, amounts and changes of investments in agriculture, GRP dynamics, and others.

To plot the yield functions, climate characteristics were analyzed for deviation from optimal values or for increments. We added the neutral technical progress concept, and here, like in production functions, it was represented by time dependence. Computations were run for regions individually and for the groups of regions simultaneously.

Calculations were most often performed by using the linear function and including quadratic dependence on temperature and precipitation. The assumption was that there exist certain optimal values of temperature and precipitation deviation from which causes a decline in yields:

\[ Y(t) = A(t) + b \times T(t) + d \times R(t) + e \times M(t) + f \times X_i(t), \]
\[ Y(t) = A(t) + a \times T^2(t) + b \times T(t) + c \times R^2(t) + d \times R(t) + e \times M(t) + f \times X_i(t), \]

where \( Y \) is the yield; \( A(t) \) is neutral technical progress; \( T \) is temperature (mean or degree days); \( R \) is precipitation; \( M \) is the amount of fertilization (mineral or organic) relative to 1996 (sometimes it is the area planted); \( X_i \) is the socio-economic and other characteristics; \( t \) is the year, \( a, b, c, d, e, f \) are the parameters determined in the course of the calculations.

If the optimal value could not be determined from function (2) it was deemed to be outside the considered interval and the calculations were then run using the linear dependence (1).

Second approach. If climate variables for several periods were considered simultaneously, the formula (1) in a more general form for panel data will be somewhat more complex:

\[ Y(t) = A(t) + \sum_j b_j \times Z_j(t) + \sum_i f_i \times X_i(t) + q_l + w_t, \]

where: \( X_i \) is the socio-economic and agricultural practice characteristic; \( Z_j \) is the climatic characteristic, \( q_l \) is the variable of the region \( l \); \( w_t \) is the variable of the year \( t \).

Formula (3) enables a comparison of mean characteristics between different periods. The calculations were also performed using the linear incremental function:

\[ \Delta Y(t) = B(t) + a \times \Delta T(t) + b \times \Delta R(t) + \sum_i c_i \times \Delta X_i(t), \]

where: \( \Delta Y \) is the yield increment from the previous year; \( \Delta T \) is the temperature increment from the previous year, \( \Delta R \) is the precipitation increment from the previous year, \( \Delta X \) is the increment of socio-economic and other characteristics.

Deviations from mean values over the studied period were considered for yield, temperature and precipitation. Optimal values obtained from other models and deviations from them were also used in the calculations. Calculations were performed also with multiplicative functions.

Information for the calculations was taken from statistical reference books published by the Federal State Statistics Service, as well as data collected by RAS institutes, Federal Service for Hydrometeorology and Environmental Monitoring (Roshydromet), other organizations and authorities. The study analyzed data on the yields of cereal grains, potato, vegetables and other crops along dynamic series, for spatial and panel data since 1990. Functions (1) - (4) were plotted for the three major crops (cereal grains, potato, vegetables) by using standard statistical packages. Calculations were also run for agricultural production indexes, and for horticulture and animal farming separately.
Changes in the yield in response to various factors were plotted to determine the type of the relationship.

3. Materials
Grain yield in the investigated non-chernozem subzones had been declining until the early 2000s and then started growing, which is similar to the change of the regions’ GRP. Cereal grains ‘figure 2’ are mostly raised by corporate farms. Hence, a significant factor for these regions has been changes in the levels of management and technology (they are, to a considerable extent, determined from per capita GRP). The observed changes in grain yield ‘figure 3’ were influenced also by changes in the area planted.

**Figure 2.** Cereal grain yield in regions of the North-Western Federal District, hundredweight/hectare.

**Figure 3.** Relationship between GRP and cereal grain yield.
Potato yield ‘figure 4’ in the 1990s was changing rather chaotically, fluctuating without any clear trend. Positive changes in the economy in the early 2000s caused a slight and short-lived rise in the yield. A probable reason for the absence of steady growth is that a high proportion of potato is produced by household plots, where no technological change is taking place. One should also mention a severe drop of the yield in the eastern part of the non-chernozem zone in 2010.

![Potato yield in regions of the North-Western Federal District, hundredweight/hectare.](image)

**Figure 4.** Potato yield in regions of the North-Western Federal District, hundredweight/hectare.

The pattern of change for vegetable yields ‘figure 5’ has been different from other crops: after a short decline in the early 1990s, it switched to growth (except for the Pskov Region and Mordovia). The increase in the yield is largely explained by the investments agricultural companies made in modern technology.

![Vegetable yields](image)
Figure 5. Vegetables yield in regions of the North-Western Federal District, hundredweight/hectare.

After a sharp rise in 1999, agricultural production indexes of Northern regions declined until 2003, and then started growing slowly. In the mid-2000s agricultural production in a majority of the regions was declining ‘figure 6’.

Figure 6. Changes in the agricultural production index in regions of Northwest Russia.

The plots for panel data from different zones as related to temperature or precipitation were analyzed to determine whether there is a correlation, and whether the effect of the given factor on the yield is positive or negative. Concerning, for instance, potato yields in the two non-chernozem subzones, Figures 7 and 8 show that as the degree days increase, potato yield declines in the southern subzone of the non-chernozem zone but most probably grows in the northern subzone. For each of the 19 regions these plots have the region’s potato yield increment from the previous year on the ordinate and the increment of degree days from the previous year on the abscissa.
Figure 7. Potato yield increment from the previous year in the southern subzone as related to the increment of degree days.

Formula (4) is vividly illustrated by plots in figure 8, demonstrating that there is a relationship between temperature rise and agricultural characteristics.

Figure 8. Potato yield increment from the previous year in the southern subzone as related to the increment of degree days.

When studying the development of agriculture along time series, calculations were performed for each region to determine the effect of climate change and other factors on the indexes of agricultural production, horticulture and animal farming, on the yields of cereal grains, potato, vegetables and other crops. It was found as a result that within the same region the effect of climate change can be ambivalent for different crops and different indexes. For the same index or the same crop the effect of
climate change can be directed differently in different regions. Different factors prove to be significant for different indexes and crops. The most significant factors for each given index or crop are the same in a majority of the regions.

According to the calculations, the temperature rise has had a negative effect on agricultural production dynamics in the southern parts of the non-chernozem zone, whereas for nearly all northern regions the effect of change in mean temperature and degree days was minor, and for the Leningrad Region it produced a positive effect ‘figure 6’.

The results for cereal grain crops were similar – calculations using the incremental model demonstrated a significantly negative effect of degree days on the yield in the southern subzone versus the neutral effect in the northern subzone. The quadratic model showed that there is an optimal temperature and it is situated within the considered temperature interval, but for the southern subzone it is considerably lower, so that only a slight temperature rise will produce some positive effect and as the temperature rises further the yield will be declining. A temperature rise apparently requires a change to other cultivars and crops, more productive and thermophilic. This transition is hampered by the low potential of agricultural science in most of the regions as a result of the reforms and funding cuts that have taken place.

For potato yields, the effect of temperature rise has been negative in the southern part, and mostly positive, although slightly and insignificantly, in the northern part. Quadratic equations show that the optimal temperature is fairly low, considerably lower than the current average, meaning that a temperature rise will negatively affect the yield (table 1). For the southern subzone the equation in addition to temperature and precipitation retained also organic fertilizers (with minor significance) and the GRP index. For the northern part the climate characteristics have had minor significance, just like the GRP index, and in addition to them the equation retained mineral fertilizers.

For vegetable yields, a negative effect of the temperature rise was found in the southern subzone, and the positive effect of temperature and precipitation change in the northern subzone proved to be insignificant. Calculations using the quadratic formula confirmed that the optimal temperature value for the northern subzone is notably higher than the current values and a further temperature rise will promote the yield, but the significance level of the coefficients is low. The optimal precipitation value is considerably higher than the average over the period in question, suggesting that some increase in precipitation will have a positive effect. For the southern subzone the optimal precipitation value is below the average for the considered period, which means, in contrast, that a slight decrease in precipitation will have a positive effect, a further decline will reduce the yield, and an increase in

Figure 9. The rate of agricultural production increment in the Leningrad Region compared to the previous year (%) as related to the increment of degree days.

The rate of agricultural production increment in the Leningrad Region compared to the previous year (%) as related to the increment of degree days.
precipitation will cause the yield to drop. Increase in the yield of vegetables is to a considerable extent associated with the investments of agricultural companies in modern technology.

### Table 1. Estimates of the parameters of functions (2) for potato for the southern and northern subzones.

|       | a     | b    | c    | d    | e    | f    | R^2  | F   |
|-------|-------|------|------|------|------|------|------|-----|
| south | -1.09 | 32.7 | -6.25| 30.0 | 0.07 | 0.35 | 0.41 | 26.6|
| north | -0.3  | 8.1  | -1.42| -3.06| 8.21 | 0.04 | 0.36 | 7.4 |

The effect of the winter temperature on the cereal grain yield in the model (4) was higher than in the model (3). This fact most probably indicates that agricultural producers have managed to adapt to warmer winters, for instance by increasing the share of winter crops. Estimates have shown that wide application of both mineral and organic fertilizers is definitely beneficial for promoting the yield of cereal grains. This impact can be interpreted as both a technological and a structural component of change in Russian agriculture. According to estimation by the fixed-effects model, cereal grain yield will decrease under the climate change impact by up to 10% by 2050. The long-difference model suggests there may be a growth till 2020, but decrease after. This means that only a moderate warming can increase the yield of grain crops in Russia even if various measures are taken to adapt.

We investigated the effect of innovation on adaptation to climate change in the regions. Two factors descriptive of agricultural science were chosen, i.e. the number of researchers and internal running costs. The calculations were performed using the incremental formula (4). According to the results, science does produce a positive effect (the stronger is the science, the higher is the growth of agricultural production and the lower is the negative impact of climate change), but its significance is minor. Statistical characteristics improved only slightly compared to the basic model (with only temperature and precipitation effects). The hypothesis that where agricultural science is well-developed a temperature rise would have a positive effect on agricultural production indexes did not prove out.

### 4. Conclusion

One can say that the hypothesis about the positive effect of climate change on the yield of agricultural crops in Russia, as a northern nation, was confirmed only partially for the investigated regions. The increase in cereal grain yields owing to climate warming will be minor and will happen if the temperature rises slightly. For potato and vegetables, climate change may result in some increase in the yield, within 5-10% in some regions. More effect is to be expected from improved management and adoption of state-of-the-art technology, modification of the sown area structure, gradual northward shift of the crops cultivated, change to late-ripening and more productive varieties and new, more heat-loving crops, and all that already now requires investments in agricultural science to enable implementation of new projects to respond to changes in the environment.

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