Statistical study of the impact of climate warming on productivity

A P Zinchenko¹, O B Tarasova¹,³ and N I Pyzhikova²
¹ Russian State Agrarian University - Moscow Timiryazev Agricultural Academy, 49 Timiryazevskaya street, Moscow, 127550, Russia
² Krasnoyarsk State Agrarian University, 90 Mira street, Krasnoyarsk, 660049, Russia

E-mail: obtarasova@gmail.com

Abstract: The global warming had a significant impact on agriculture in Russia over the past decades, what causes an urgent need for scientific analysis of warming impact on agriculture production and its efficiency. On the example of published data concerning weather conditions of grain crops cultivation in Tambov Region, methodical questions of statistical estimation of their influence on the level and variation of productivity are considered. Within the framework of metrological support, techniques are offered for constructing the qualitatively homogeneous time series of productivity and climate factors, alignment of rows and assessment of the degree of influence of air temperature and precipitation during the vegetation period on the productivity based on the correlation analysis of deviations of characteristics from the aligned series. It is recommended to use the offered approaches as the metrological support for the analysis of dynamics of productivity in all subjects of the Russian Federation, and differences in the level of productivity between them.

1. Introduction

In the report of Roshydromet [1] about climate changes, it is noted that its further warming ‘with modern moisture and soil fertility by the middle of the 20th century should lead to an increase in the bioclimatic potential and productivity of grain crops on the territory of Russia’. In this regard, for science and practice, the task of assessing the impact of the ‘ongoing global warming’ of the climate on the plant growing production, the productivity of grain and other crops becomes relevant.

Federal State Statistic Service (Rosstat), after severe droughts in 2010 and 2012, published on our proposal data on the amount of precipitation and average air temperature in the regions of Russia [2] for May, June, and July, as the main part of the growing season of plant growing. The conducted statistical analysis [3] showed a great influence of climate and weather conditions of individual years on the differences in crop productivity in the subjects of the Russian Federation. On the vast territory of Russia, the degree of their influence was significantly different, what requires the development of methods and statistical assessment of the impact of climate warming on the gross fees and the crop productivity in each region.

For the analysis, it is necessary, first of all, to obtain a sufficiently long dynamic series of air temperature and precipitation during the growing season, as well as crop yields. Comparable data on yields is published by Rosstat, and on weather conditions indicators can be obtained for each subject of the Russian Federation by conducting a special sample and summarizing Roshydromet data on the
amount of precipitation and average air temperature for individual months of the growing season – at least for May, June and July, or including also April, August and September.

In scientific publications in 2019 comparable data for Tambov Region on the average yield of grain and leguminous crops (\( y \), centners per one hectare harvested -c/ha), the amount of precipitation for April-August (\( x_1 \), mm) and the amount of average monthly air temperatures for these 5 months of the growing season (\( x_2 \), °C) in the beginning for 2007-2018 [4], and then for 1995-2018 [5] with the addition of a sign of the sum of indicators of relative humidity (\( x_3 \), %) for April-August.

The conclusions obtained by the author in the process of analysis were contradictory, so the purpose of the proposed article is to consider and justify the methodological features of the analysis of such dynamic series of yields and weather conditions.

2. Evaluation of the conclusions of published works

According to the data for 12 years from 2007 to 2018, without converting the initial features according to the LINEAR EXCEL program, the author obtained a correlation equation of the relationship between the yield of grain and leguminous crops with the indicators of weather conditions \( y = 37.4 + 0.05 x_1 - 0.22 x_2 \). It is believed that to assess the impact of a single factor, the number of observations should be at least 8-10 units, and in this case, it is clearly insufficient, although the connections were statistically reliable. According to the data for 24 years, taking into account the sign of relative humidity (\( x_3 \)) correlation equation was \( y = 6.77 + 0.05x_1 + 0.14x_2 - 0.01x_3 \). For a longer dynamic series, the effect of temperature increase on yield growth was, as can be seen, positive, and not negative, as in 2007-2018. In both cases, the average value of the (\( y \)) characteristic reproduced by the equation at the average values of factor characteristics and the regression coefficients obtained differed from the actual level. The low level of yields for 2018 is questionable, although there were no clear signs of severe drought.

Included in the equation yield factor (\( x_3 \)) - relative humidity of air is the interaction of air temperature and precipitation (calculated by us according to the original data of the author, the pair correlation coefficients \( r_{y,x_3} = (-0.59) \) and \( r_{x_1,x_2} = 0.44 \) are statistically reliable at this number of 24 observations), and does not allow to reveal the full impact of air temperature rise and climate warming on productivity. It is advisable to exclude this feature from the analysis, which will also increase the number of observations by 1 factor to 10 or more. It should also be noted the incorrectness of the form used in the works of the sign (\( x_3 \)) - the sum of the average daily temperatures for 5 months. For each month, not the average daily temperature is taken, but its sum for the growing season covers 5 days, so it should be divided by 5, and the regression coefficients of (\( a_{x_3} \)) obtained in the process of analysis should be increased by 5 times, respectively, from (-0.22) to (-1.10) c/ha per 1 degree of the average daily temperature for 12 years and from +0.14 to +0.70 C/ha for 24 years; the closeness of the correlation will not change.

The main disadvantage of the considered publications is, in our opinion, the underestimation of the features of the dynamic series and the analysis of correlations in them.

3. On the methodology of the statistical study of yield factors in dynamic series

The principal feature of the dynamics series is, as is known [6], the relationship of the level of the same characteristics at different times or periods of time, the dependence of subsequent levels on the previous ones. The natural relationship of the initial levels of a number of (\( y_t \) ) with levels shifted by one date (\( y_{t-1} \)), two dates (\( y_{t-2} \)), etc., called autocorrelation, arises due to the presence of a steady trend of growth or decline in the level of productivity, as well as for other reasons. A natural change in the yield was due to a simultaneous influence on the crops of complex interrelated factors, both internal (quality of seeds, fertility and fertilizer soil, the nature of farming, the effects of diseases and pests of plants, structure of crops, groups of crops, etc.) and external (the number and nature of precipitation, air temperature and relative humidity, strength and duration of sunlight, wind, occurrence of frost, etc.). The presence of a trend in a series of dynamics is estimated using the correlation coefficient between yield (\( y \)) and time-year number (\( t \), and the presence of autocorrelation by the pair correlation
coefficients between shifted levels of the dynamic series, which were statistically reliable with confidence.

4. Analysis results
In the series for 1999-2000 according to [5] was the analysis of when the yield of grain and leguminous crops the amount \((y)\) of rainfall for April-August \((x_1)\) and adjusted average daily air temperatures over these 5 months \((x_2)\). (table 1).

**Table 1.** Yield and weather conditions for the years 1999-2018.

| № of a year | Year | Yield c/ha \((y)\) | Precipitations, mm, \((x_1)\) | Temperature °C, \((x_2)\) |
|-------------|------|-----------------|-----------------|-----------------|
| 1           | 1999 | 14.0            | 140.9           | 16.0            |
| 2           | 2000 | 15.2            | 186.7           | 15.7            |
| 3           | 2001 | 20.9            | 179.5           | 16.5            |
| 4           | 2002 | 20.4            | 105.9           | 15.5            |
| 5           | 2003 | 21.8            | 208.5           | 14.5            |
| 6           | 2004 | 17.6            | 168.4           | 14.7            |
| 7           | 2005 | 20.4            | 128.5           | 16.1            |
| 8           | 2006 | 20.5            | 131.9           | 15.6            |
| 9           | 2007 | 20.4            | 140.0           | 16.5            |
| 10          | 2008 | 30.8            | 130.0           | 16.4            |
| 11          | 2009 | 27.5            | 145.8           | 15.4            |
| 12          | 2010 | 13.8            | 34.8            | 19.9            |
| 13          | 2011 | 22.5            | 153.5           | 16.9            |
| 14          | 2012 | 21.6            | 188.9           | 17.9            |
| 15          | 2013 | 30.9            | 184.0           | 17.0            |
| 16          | 2014 | 31.7            | 174.4           | 16.7            |
| 17          | 2015 | 32.0            | 268.9           | 17.9            |
| 18          | 2016 | 32.6            | 393.0           | 18.9            |
| 19          | 2017 | 29.6            | 203.8           | 16.7            |
| 20          | 2018 | 20.9            | 203.2           | 18.5            |

The analysis of the yield series showed that there is a clearly expressed and statistically reliable autocorrelation, the coefficient of which at the shift of the series on one date was 0.550 at a critical value with an error of 5% 0.468, and with an error of 1% 0.590. The yield indicators at the alignment of the series tend to increase from the year number \((t)\) \(y_t = 15.9 + 0.696t\) with the correlation coefficient \(r_{yt} = 0.665\).

The average daily air temperature also significantly increases \(x_{2t} = 15.04 + 0.155t\) (at the actual \(r_{x_{2t}} = 0.662\) and the critical level \(r_{0.01} = 0.575\)) and it can be argued that over the past 20 years in the region under consideration there is significant warming of the climate during the growing season. Precipitation increases: \(x_{1t} = 119.9 + 5.107t\) at \(r_{x_{1t}} = 0.430\), but with an error probability of about 8%. The relationship between the amount of precipitation and the average daily temperature is weak, the correlation coefficient between them is only 0.200, which can be due to local precipitation and stormwater precipitation.
The equation of multiple correlation of deviations from the trend has the form \((y - y_t) = 0 + 0.026(x_1 - x_{1t}) - 1.977(x_2 - x_{2t})\). The equation is sufficient for F-criterion =4.78 with a probability of 0.98, the coefficient of multiple correlation \(R=0.600\) is also reliable. The net regression coefficient of yield deviation under the influence of an increase in the average daily temperature by 1°C is (-1.977) centners per one hectare harvested and is reliable with a probability of 0.96, that is, it can be unambiguously argued that climate warming negatively affects the yield of grain crops in the Tambov Region at an average level of precipitation deviation. An increase in precipitation by 1 mm increases the yield by only 0.026 c/ha with a probability of 0.91, what is significantly less than it was found in published works [4,5] 0.05 C/mm. An annual increase in precipitation by an average of 5.11 mm increases the yield by only 5.11 x 0.026=0.13 c/ha. what does not compensate for its decline due to an annual increase in air temperature by 0.155 x (-1.977) = (-0.31) c/ha. As a result, due to climate warming, the annual yield of grain crops is reduced by (-0.31) +0.13=(-0.18) c/ha with a total average annual increase of 0.696/ha, therefore, the overall increase in yields in the region is achieved by improving other factors.

The work considered in the article [4] was prepared for publication in early 2019, when there were only preliminary data on the yield of grain and leguminous crops in the Penza Region and the yield for 2018 was taken understated and, apparently, incomparable in terms of a set of crops. Now Rosstat has published the final data on the level of the yield of grain and leguminous crops for 2019 33.6 c from 1 ha. and also clarified it for 2017 to 40.7 c. Therefore, in order to obtain more reasonable conclusions about its dependence on weather conditions in this article, the dynamic series of yields was refined. its alignment was carried out and in the above order, the dependence of yield deviations from the trend on the deviations of weather conditions given in table 2 was studied.

Received new trend of the yield was \(y_t = 13.79 + 1.020t\) that is, its average growth 1.020 c/ha was higher than previously published data 0.696 c/ha when the coefficient of pair connection with a year 0.805 (formerly 0.648), 64.8 % of the yield variation is 48.4% (0.6962 x100) was depending on the year (standard error level of 4.65c/ha). The coefficient of auto-correlation of the yield level at its shift by 1 year was also higher - 0.675 against 0.550, which strongly requires the alignment meant of the series and the correlation of their residues from the trend.

The correlation equation of the relationship of deviations from the trend of yield and weather conditions according to the updated data \((y - y_t) = 0 + 0.020(x_1 - x_{1t}) - 2.446(x_2 - x_{2t})\) is reliable at the correlation coefficient \(R=0.668\). Consequently, 44.6% of the variation of its deviations from the trend is due to deviations of weather conditions instead of 36.0% previously. When the average daily air temperature increases by 1°C, the yield decreases by an average of 2.446 c/ha with a probability of 99%, and an increase in precipitation by 1 mm increases the yield by 0.020 c/ha with a probability of only 86%. It can be assumed that due to the tendency of weather conditions, the yield decreases on average per year by (-0.28) c/ha instead of the previously calculated -0.18 c.

### Table 2. The deviation of actual levels of symptoms from aligned in a straight-line one.

| Year | Yield, C/ha, \((y - y_t)\) | Precipitation, mm \((x_1 - x_{1t})\) | Temperature °C, \((x_2 - x_{2t})\) |
|------|-----------------------------|---------------------------------|-----------------------------|
| 1999 | -2.64                       | 15.89                           | 0.85                        |
| 2000 | -2.14                       | 56.58                           | 0.33                        |
| 2001 | 2.87                        | 44.27                           | 1.00                        |
| 2002 | 1.67                        | -34.44                          | -0.20                       |
| 2003 | 2.37                        | 63.06                           | -1.33                       |
| 2004 | -2.52                       | 17.85                           | -1.27                       |
| 2005 | -0.42                       | -27.16                          | -0.04                       |
| 2006 | -1.01                       | -28.86                          | -0.70                       |
5. Conclusion
Thus, the peculiarities of the statistical analysis of the relations in time series, the presence of autocorrelation, the alignment of the rows of yields and indicators of weather conditions of individual years over 20 years of the qualitatively similar period of Russia development, a correlation analysis of the relationships of deviations of characteristics of trends has allowed to establish a significant correlation of productivity of grain and leguminous crops with climate warming in Tambov Region. The findings can be used by agricultural authorities in the economic analysis, forecasting and development of specific measures to improve the efficiency of production.

6. Recommendations
Taking into account the wide variety of natural conditions in the vast territory of Russia, the Ministry of Agriculture of the Russian Federation in conjunction with Rosstat and Roshydromet, is proposed to study the impact of average daily air temperature and precipitation during the growing season on the productivity of individual crops (winter wheat, spring wheat, barley, oats, corn for grain, potatoes, vegetables, herbs, etc.) for the last 20 years for each subject of the Russian Federation. For statistical analysis of the differences between the subjects of the Russian Federation in crop yields, crop productivity and the impact of modern climatic conditions on them Rosstat is proposed to present in statistical collections on agriculture data on average daily air temperature and precipitation for the growing season, at least for May, June and July, just as it was in the information for 2011 and 2013.

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| Year | Retrived from | 2017 | 2018 |
|------|---------------|------|------|
| 2007 | -1.81         | -25.87 | 0.09 |
| 2008 | 7.89          | -40.98 | -0.19 |
| 2009 | 3.90          | -30.28 | -1.30 |
| 2010 | -10.50        | -146.39 | 2.98 |
| 2011 | -2.50         | -32.80 | -0.15 |
| 2012 | -4.09         | -2.50  | 0.69  |
| 2013 | 4.51          | -12.51 | -0.32 |
| 2014 | 4.62          | -27.22 | -0.82 |
| 2015 | 4.22          | 62.18  | 0.19  |
| 2016 | 4.12          | 181.17 | 1.03  |
| 2017 | 0.43          | -13.14 | -1.24 |
| 2018 | -8.97         | -18.85 | 0.40  |