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About the Role of Digitalization of Agriculture in Reducing the Impact of Climate on the Technological Development of Crop Production

P B Akmarov¹, I I Rysin², O P Knyazeva³

¹Izhevsk state agricultural Academy, Izhevsk, Russia

²Udmurt State University, Izhevsk, Russia

³Izhevsk state agricultural Academy, Izhevsk, Russia

E-mail: knyazevaop@yandex.ru

Abstract. The article presents the generalized results of century-long observations of changes in the yield of grain crops of Udmurtia against the background of climate variation and the development of production technologies. The trends in the development of crop production are revealed and the influence of meteorological indicators on the efficiency of agriculture is proved. The correlations of grain yield with the temperature regime and moisture supply in certain periods of plant growth are considered. It is established that the climatic conditions of plant growth from April to June have the greatest role in the formation of the crop. There is a positive relationship between the yield and the average annual temperature of the previous year. Based on the analysis of time series of meteorological indicators for temperatures and precipitation in the summer period, trend equations are obtained, which prove the regularities of the growth of the average daily temperature and average monthly precipitation over a multi-year interval. A rather significant direct influence on plant growth of the average temperature of April, which determines the intensity of soil processes, has been revealed. At the same time, the existence of cyclic components in changes in temperature and precipitation is confirmed, and the frequency of these cycles is calculated. The tendency of reducing the role of natural factors in the formation of the crop with the use of innovative technologies and digitalization of the industry is proved. The possibilities of applying modern scientific achievements and technical solutions to reduce the role of climatic factors in the production of crop products are shown.

1. Introduction

In recent years, agricultural production in our country has had a stable positive dynamics both in crop production and in animal husbandry. The basis for the growth of agricultural production is a steady increase in the yield of agricultural crops, primarily grain [1]. Today, grain has become the strategic basis of the country's food security, as it fully meets the needs of the population, is the main export commodity and covers the needs of the livestock and poultry industries in feed feed. However, the growth potential of grain production is far from being exhausted.

2. Relevance

The yield of grain crops depends on many factors, including climatic and natural-economic conditions, technological features of cultivating the variety and the biological potential of crops [2]. It should be



noted that due to scientific and technological progress, improvement of technologies, improvement of varietal qualities of plants, grain yield is steadily growing. Thus, according to our observations over the past fifty years, the average grain yield in Udmurtia has increased by more than 2 times [3]. Here, technological factors primarily have a decisive influence, but the climate still has a significant role in the development of crop production. Therefore, it is necessary to determine this role and develop proposals for stabilizing the industry and reducing the impact of natural factors on productivity.

For Russia, with its huge land resources and extremely low efficiency of using the potential of agricultural production, the task of increasing land fertility and reducing risks from natural and climatic factors is crucial not only for the development of production, but also for ensuring the country's food security.

3. Problem statement

Among the climatic conditions, precipitation and ambient temperature are of the most significant importance for plant growth. These factors are decisive in the variation of yield, so much attention is paid to the study of their role and the regulation of the influence of natural factors [4]. Dangerous hydrometeorological phenomena also have a significant impact on crop yields, the number of which in our country, according to the Federal Hydrometeorological Service, increases annually by an average of 6-7% [5]. Studies show that climate change has led to an increase in the frequency and intensity of dangerous weather phenomena (hail, thunderstorms, heavy precipitation, squally wind, tornadoes, etc.), the unevenness of their territorial distribution and an increase in the material damage caused by them [6, 7, 8].

As can be seen from figure 1, despite the positive trend of grain crop yield growth in Udmurtia, in some periods there is also a decline in this indicator, which is due to meteorological indicators. Thus, the greatest decline in yield in 1995-1999 occurred during the period of the worst drought in 1995, when the average annual precipitation was only slightly more than half of the average annual norm. There was a similar decline in the period from 2010 to 2014, when there were periods of severe drought in 2010 and 2012. The air temperature, which is directly related to the intensity of solar energy, is also of great importance for the formation of the crop. Here, the influence of temperature is also superimposed on the light factor, as the most important stimulator of plant growth [9].

Figure 1 shows that the variation in the yield of grain crops over the years tends to increase. This is due not only to the increase in natural instability, but also to the development of production technologies. However, in recent years, this variation between the minimum (min) and maximum (max) yields has begun to decrease. We believe that this is due to more competent management of production processes based on the digitalization of technological and managerial processes.

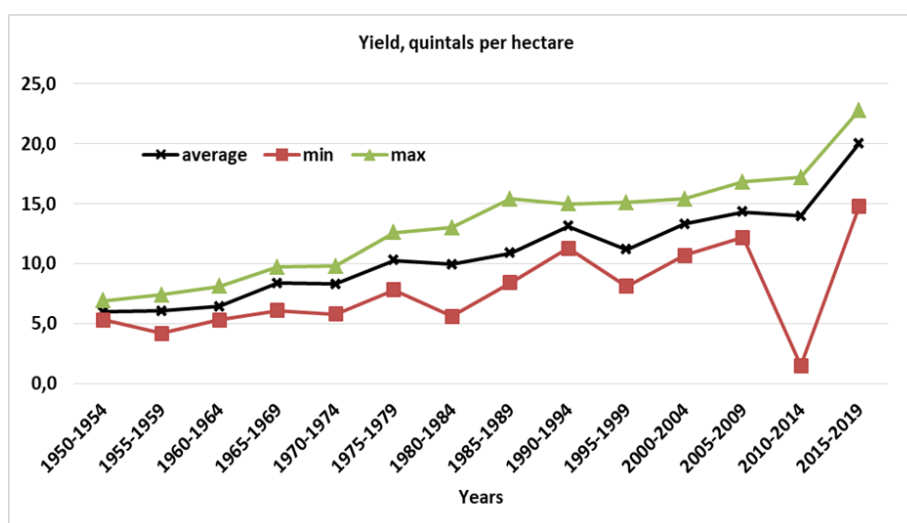


Figure 1. Dynamics of grain yield in Udmurtia.

4. The theoretical part

From a scientific and practical point of view, it is very important to determine the patterns of changes in climatic conditions in order to determine the potential for the development of crop production industries. We cannot significantly influence these conditions, but we can reduce the risk of adverse climate impact on human production activities by learning to predict natural processes and phenomena [10; 11].

Such a rough estimate can be made based on the analysis of time series. Long-term studies on individual indicators confirm that there are certain patterns in climate change. In addition to the confirmed long-term trends, they also have cyclical components, which is confirmed by the corresponding correlograms (figure 2).

It can be seen from the correlogram that the cyclic components for precipitation have a repetition period approximately every 7 years, and for temperature much less often—after 12 years. The autocorrelation coefficients at these intervals exceed 0.3 in absolute value, which indicates a fairly high significance of the presented regularity. At the same time, the negative value of the autocorrelation coefficient for April temperatures indicates opposite trends, that is, high average daily temperatures in April are likely to be followed by low temperatures of this period of the year in 12 years. The revealed trend may be related to the cycles of solar activity noted in the works of many scientists [12; 13; 14].

As previously noted, the amount of precipitation in June has the most significant influence on the formation of grain yield from climatic factors. The presented correlogram confirms the fact that in the territory of Udmurtia, high yield values associated with favorable climatic conditions are repeated approximately every 7 years.

While noting the significant role of climate influence on the development of crop production, it should still be taken into account that the technological conditions of production in agriculture can significantly reduce this role. For example, over the past 50 years, the yield of grain crops in Udmurtia has increased almost 2 times due to the introduction of new crop varieties, the use of advanced cultivation technologies and scientific achievements. If we show the relative influence of natural, climatic and technological factors on the development of agriculture, we can conclude that the share of the latter is significantly increasing in our time. We believe that in the conditions of digitalization of agricultural production, the climate impact can be reduced even more, primarily due to more accurate forecasting, increasing the accuracy and efficiency of management decisions.

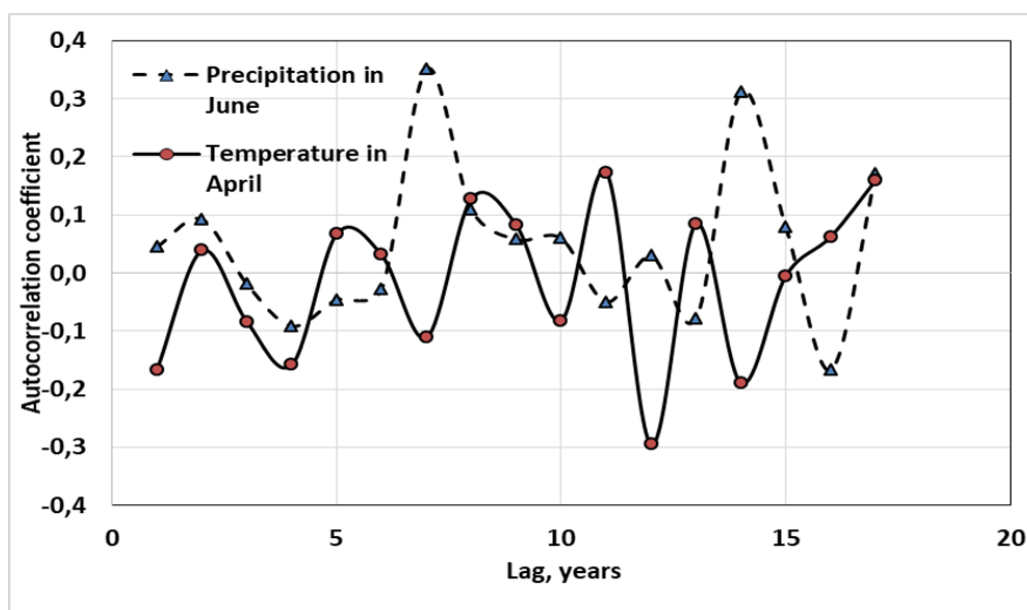


Figure 2. Correlogram of time series of climatic conditions in Udmurtia.

5. Research results

In order to highlight the role of climatic factors, we analyzed time series on grain yield in Udmurtia for the period from 1913 to 2018 and climatic factors based on meteorological observations for the period from 1951 to 2018 (provided by the Udmurt Center for Hydrometeorology and Environmental Monitoring) at three points located at weather stations in the cities of Izhevsk, Glazov and Sarapul. A fragment of these observations is shown in table 1. As you can see, the temperature spread over the years during the plant growth period is from two to three times, and the amount of precipitation may differ by more than ten times. The greatest variation is affected by April temperatures and precipitation in the summer period. Of course, such a significant variation cannot but affect the growth of plants. It is not for nothing that Udmurtia is considered a territory of risky agriculture, and therefore it is much more difficult to achieve stable yields in these conditions [15].

Table 1. Climatic conditions of plant growth in Udmurtia.

| Year | Average temperatures, °C | | | | Average monthly precipitation, mm | | |
|----------------|--------------------------|--------------|--------------|--------------|-----------------------------------|--------------|--------------|
| | April | May | June | July | May | June | July |
| 1951 | 8,74 | 10,78 | 17,29 | 18,23 | 70,63 | 22,32 | 55,01 |
| 1952 | 0,91 | 10,98 | 18,05 | 21,13 | 40,08 | 61,87 | 45,23 |
| 1953 | 6,40 | 11,37 | 17,25 | 20,05 | 67,50 | 25,51 | 43,06 |
| 1954 | 3,53 | 12,20 | 17,79 | 21,99 | 41,40 | 44,76 | 71,58 |
| 1955 | 1,73 | 11,59 | 16,70 | 16,35 | 69,96 | 36,02 | 50,67 |
| ... | ... | ... | ... | ... | ... | ... | ... |
| 2014 | 1,90 | 15,30 | 15,83 | 15,67 | 16,43 | 94,00 | 52,57 |
| 2015 | 3,62 | 14,53 | 19,20 | 15,38 | 44,37 | 53,27 | 119,37 |
| 2016 | 6,52 | 13,63 | 16,61 | 20,94 | 20,73 | 56,17 | 32,03 |
| 2017 | 2,53 | 9,07 | 14,53 | 17,87 | 39,37 | 91,60 | 119,70 |
| 2018 | 2,60 | 11,47 | 14,77 | 20,67 | 44,03 | 59,93 | 58,00 |
| Average | 3,62 | 11,71 | 16,57 | 18,66 | 44,20 | 61,55 | 67,91 |

The influence of climatic factors during the ripening period on the yield of products per unit area for the period from 1951 to 2018 is shown in Table 2. As we can see, the external conditions of plant growth in the month of June play the greatest role in the formation of the crop. At the same time, precipitation has a positive effect ($r = 0.45$), which is explained by the need of plants for moisture during the most intensive maturation. The temperature has a negative impact on the yield during this period ($r = -0.301$), since often the high temperature in June is associated with droughts, which leads to inhibition of growth, the development of diseases, the spread of plant pests.

Table 2. Correlation coefficients of climatic factors with the yield of grain crops in Udmurtia.

| Climate Factor | Month | | | | |
|----------------|-------|--------|--------|--------|--------|
| | April | May | June | July | August |
| Precipitation | 0,184 | 0,005 | 0,450 | 0,045 | 0,010 |
| Temperature | 0,117 | -0,002 | -0,301 | -0,149 | 0,012 |

However, it should be noted that in the conditions of Udmurtia, the yield of grain depends on a longer aftereffect of the climate. Thus, the coefficient of correlation of yield with the average annual temperature of last year exceeds 0.5, and with the average annual precipitation of last year is 0.24. And

this is due not only to a significant share of winter crops in the grain structure, but also to changes in the soil layer during the pre-planting period, its readiness for plant growth [16; 17].

Based on the results of the correlation analysis, we have constructed a linear regression model of the formation of the grain harvest from the above climatic factors and the technological factor caused by the innovative development of the industry.

The parameters of the obtained regression model allow us to conclude that the temperatures of June and July, as well as precipitation in the summer period, have the most significant impact on grain yield. However, the share of the influence of these climatic factors on the long-term trend of yield growth does not exceed 25 %, while technological factors have twice as strong an impact on the yield. Moreover, in recent years, with the introduction of scientific and technical achievements into production, the digitalization of the industry, the role of weather conditions has been weakening [18]. This is also confirmed by the results of the statistical analysis of the variation of signs, shown in table 3.

Table 3. Variation of the climate influence on the yield of grain crops.

| Years | Coefficient of variation | | |
|-----------|--------------------------|--------------------------|-------|
| | temperature in Apri | precipitation in June | yield |
| 1951-1962 | 0,742 | 0,480 | 0,182 |
| 1963-1974 | 0,704 | 0,399 | 0,222 |
| 1975-1986 | 0,824 | 0,411 | 0,245 |
| 1987-1998 | 0,922 | 0,379 | 0,215 |
| 1999-2010 | 0,463 | 0,539 | 0,190 |
| 2011-2018 | 0,502 | 0,313 | 0,251 |
| Average | 0,731 | 0,442 | 0,211 |

According to the results of long-term studies, the average yield of grain crops in Udmurtia increases by 0.17 quintals per hectare annually, with a confidence interval of this indicator from 0.13 to 0.21 at a 90% significance level. We believe that similar patterns are observed in other cultures.

In the selected twelve-year periods of temperature cycling, the coefficients of variation of climatic factors do not change significantly. At the same time, the yield variation increased sharply in the last time interval, which begins in 2011. It was during this period that modern technologies began to be actively introduced in agriculture, the digitalization of the industry began [19]. Consequently, the main reason for the increase in grain yields in these years was the technological transformation of production.

6. Conclusion

Technological development of crop production leads to a decrease in the influence of climatic factors on the results of production activities in the industry. The application of scientific achievements, the introduction of digital technologies accelerated this process. However, the peculiarities of agricultural production, due to the combination of biological, chemical and physical processes occurring in natural conditions, do not allow us to completely exclude the influence of climate. Therefore, when developing and applying new technologies, including digital technologies in agriculture, it is necessary to take into account certain laws of nature that have a significant role on crop yield [20].

Thus, according to the results of the study, we revealed the existence of cyclic components in changes in temperature and precipitation during the maturation of plants, and also calculated the frequency of these cycles. The obtained results can be used at the regional management level when developing plans for the development of agricultural production, for optimizing the structure of crops, for forecasting.

At the same time, the conclusions obtained as a result of research need to be constantly adjusted, since with climate change, the introduction of new technologies and scientific developments, the models of agricultural development will change. At the same time, digital methods should be more actively used

for the analysis, forecasting and development of optimal management decisions, combining these methods with the technological transformation of the industry based on the use of information technologies.

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