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Accelerated adaptation of spring wheat to climate change necessary

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Abstract. Associated with global warming environmental changes lead to an increase in the frequency of extreme weather conditions, while the enormously hot weather observed during the last years led to enhanced grain yield variability in many countries, to a gross production decrease, and growing in the number of the hungry in the world. For these reasons, the reducing the crop production industry dependence on weather fluctuations has to become the main task for agricultural science that will become even more relevant if to take into account the further increase in the population (up to 9.73 billion by 2064) as it will require an additional increase in agricultural production by more than 30%. The analysis of weather conditions in Samara region over a 31-year period in the decade context indicates significant negative changes in temperature conditions and precipitation during the notional vegetation of early grain crops (May-August). The near future forecast according to the linear regression equations (1990-2020) confirms a further temperature background increase during the notional vegetation to 22.1 °C on average per decade (+3.0 °C to the long-term average data for the 1980s) and a precipitation reduction to 113.2 mm (-49.8 mm). However, despite the high adaptive capabilities of cultivated crops, we believe that today it is necessary to correct the current breeding programs for high potential productivity, paying special attention to the creation of varieties with high drought and heat resistance that will require the search for new sources and methods of their identification.

1 Introduction

According to the ecological classification, abiotic factors are divided into climatic, edaphic, orographic, hydrographic, and chemical. For plant production and breeding, in particular, the most important of these factors are climatic and edaphic. If the humanity can exert certain effects on the second edaphic factor by agrochemical and technological methods, we are not able to influence the first factor – climatic, where the main components for rain-fed (non-rain-fed) conditions are light, temperature, and humidity. However, these unregulated

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factors primarily affect the crop and variety ability to grow in certain ecological niches and the ripening and fruiting possibility.

Climate changes, intensively observed in the post-industrial period, are noted by many researchers in the world as global warming. Today, this environmental factor as we see leads to an increase in the frequency of extreme weather events worldwide, including heat waves, droughts, heavy rains [1], as well as floods [2]. According to J. Hansen et al. [3] the frequency of extremely hot weather in the world has increased approximately 50 times compared to the decades before the year 1980, and the areas affected by it have increased from 0.1-0.2% of the globe's surface in 40 years to almost 10% [3]. Only in the last 20 years, scientists explain 31-51% of the variability in wheat yield in Western Europe, 23-66% in Eastern Europe, and more than 75% in southern Spain by climatic variability [4].

In Russia, most of the cropland is located in areas unfavourable for the cultivation of a certain crop. In particular, it belongs to the areas of risky arid agriculture. Therefore, the dependence of the industry on agroecological conditions here is very high, and this dependence is likely to increase and become even more unpredictable in the coming decades.

In the near future, Russian and world scientific community has to pay close attention to that, putting the issues of stable increase in agricultural production in the first place. The current slow progress in increasing crop yields, from 0.8 to 1.0% per year, does not allow solving the problem of hunger (for 2020) of almost one billion planet inhabitants [5]. Taking into account the world's population increase, which, according to some forecasts, will peak at 9.73 billion people in 2064 [6], this will require an additional increase in crop production by at least 30%.

Thus, we believe that the current world agricultural science has to solve as much as possible the issues of reducing the dependence of the industry on weather fluctuations that significantly exceed the limits of average long-term observations. In the last decade, even European studies have detected that heat stress for them is a limiting factor for the adaptation of wheat to climate change in Europe [7]. In the conditions of some parts of Eastern Europe and Asia or various regions of Russia where in some summer months the hydrothermal coefficient is less than 0.1 (desert conditions), sensitivity to drought and dry winds is no less important factor than sensitivity to heat stress [8]. Therefore, one of the most important directions in solving this problem is undoubtedly the creation of plant varieties adapted to environmental changes, which would be characterized by agroecological adaptability associated with greater fitness of new varieties and hybrids to local, rapidly changing climatic conditions and cultivation technologies.

In order to solve the global problems of reducing the crop production dependence on extreme weather conditions and a stable grain yield increase in the future, a special attention should be paid to scientific and practical breeding as well as to the development of changes in the breeding work strategy for the coming years. According to Y. Kushnir et al. [9], climate forecasting in the short term – from a year to a decade – makes it possible to adapt and ensure resistance to climate change. So, in modern realities, we consider it necessary to constantly analyse changes in environmental conditions in a particular region and, that is very important, to correctly determine the trend and the rate of change of the constituent factors in the short term.

2 Materials and methods

Data from the Ust-Kinelsky meteorological post on the average daily air temperature and precipitation for May, June, July, and August (the notional growing season of early grain crops) for the 31-year period (1990-2020) of the author's breeding work with soft spring wheat were used to analyze the weather conditions of Samara region. The linear regression equations of the average daily air temperature and precipitation were calculated in Excel by plotting and determining trend lines using, respectively, the data of the average daily air temperature and the precipitation amount by month and in total for four months.

3 Results and Discussion

A retrospective analysis of regional weather conditions in the context of decades over 31 years indicates sharp changes in the climatic factor in Samara region according to the Ust-Kinelsky meteorological post.

Analysing the notional growing season as a whole for spring grain crops (May-August) and particularly for soft spring wheat for three decades, we noted a significant change, primarily in the temperature background over these years.

The first period (1990-1999) turned out to be warmer on average by +0.33 °C each year compared with the average long-term data for the 80s of the 20th century (conditionally – before the highly industrial period). At the same time, the number of years with a relatively cooler (less than 18.1 °C) temperature regime – five years (1990, 1992, 1993, 1994, 1999) and warmer – five years (1991, 1995, 1996, 1997, 1998 G.) were equal, which is quite acceptable for the conditions of the continental climate of Samara region and the Middle Volga region as a whole.

The second analysed period (2000-2009) was already warmer on average by +0.57 °C, which is not much higher than the previous decade but the number of cool years was already much less – two years (2002 and 2003) out of ten.

But if to speak about the third, eleven-year period (2010-2020), it differs significantly from the previous decades and it turned out to be much warmer than the previous ones – by +2.11 °C per year. This deviation is 6.4 times higher than in the first period. At the same time there was not a single year with a temperature background below the average annual values.

It has to be particularly noted that during the three decades of the research, the growing season with a negative deviation of the average daily air temperature from the average annual values (that is below 18.1 °C) was observed in the region 17 years ago – in 2003 for the last time (-0.3 °C to normal). The incoming data of 2021 indicate record values of the average daily air temperature for May – 20.8 °C (+6.7 °C to the average annual norm), June – 22.9 °C (+4.2 °C), July – 23.5 °C (+2.8 °C), August – 24.7 °C (+5.8 °C), which causes some concern about the current situation.

Theoretically, against the background of an increase in the average daily air temperature, we should expect some growth in the precipitation amount. Analysing the amount of precipitation by month and in general for the growing season (May-August) of three decades, the following can be noted.

Actually, in the first period (1990-1999), we observed a slight increase in the temperature background and some growth in the precipitation amount by month from +0.49 mm to +14.30 mm an average for all months against the background. In general, during the growing season, it was plus 16.63 mm, with a spread over the years: from a shortage of precipitation -74.3 mm in 1998 to a significant increase of +162.0 mm in 1990.

In the second decade (2000-2009), against the background of a further increase in the average daily air temperature in May-August compared with the previous period plus 0.24 °C, we detected a slight shortage of precipitation on average over 10 years for two months – May (-2.15 mm) and August (-10.13 mm). But at the same time, nevertheless, each spring wheat vegetation during this period conditionally took place with a slight precipitation excess. On average during the growing season it can be assumed that 13.95 mm of precipitation fell more than the average annual norm.

However, the third studied period (2010-2020) was particularly distinguished by the lack of precipitation in almost all the months. At the same time, we noted a significant shortage of precipitation in July – minus 14.15 mm (a total of 155.7 for 11 years) and in August – minus 9.31 mm (a total of 102.4 mm), up to almost normal average deviations in May - minus 2.59 mm and in June - plus 2.21 mm and this was against the background of a significant increase in the temperature background. It should also be noted that the average increase in the last period of the average daily air temperature for May-August by +2.11 °C (to the norm) most likely led to the fact that we observed a certain precipitation deficit for the conditional vegetation – minus 23.94 mm (the total precipitation deficit over 11 years was 263.3 mm).

Thus, it is necessary to note a decrease in precipitation during the growing season of spring grain crops (May-August) during the 31-year study period. If in the first decade, against the background of a slight increase in air temperature, the maximum precipitation excess during the growing season from the average annual norm was 162 mm (99.4%) in the favourable 1990 year, in the second (2006) – 106.0 mm (65.0%), then in the third decade (2017) – only 60.9 mm (37.4%). Consequently, favourable precipitation in May and summer months of the year lost more than 100 mm of precipitation in 31 years for the notional vegetation of early grain crops, and this was against the background of a significant increase in air temperature.

Further climate warming on the Earth, according to various researchers, will last at least until 2100 and the threshold of an increase of 1.5 °C is likely to be reached by 2040 whereas previously it was assumed by 2050 [3]. Of course, these data indicate global changes throughout the year. In the context of our research, it was important to analyse the spring-summer months of the growing season for making strategic decisions in the breeding of early grain crops.

According to the available meteorological data, linear regression equations were calculated in Excel: by temperature $y = 0.078x + 17.88$ ($R^2 = 0.216$) and by precipitation $y = -2.043x + 197.0$ ($R^2 = 0.075$) for the studied 31-year period for the notional vegetation of spring grain crops. Based on these equations, a forecast was made for the next ten years (30% of the analysed period).

In general, according to an optimistic scenario in which more drastic changes in weather conditions over the past decade (a polynomial trend) were deliberately ignored, weather conditions during the notional vegetation period of early grain crops (May-August) might change by 2030 as follows:

- The average air temperature for the period May-August is expected to be 21.1 °C (+3.0 °C to the average annual norm). At the same time, by analogy with the period 2010-2020, we will observe higher fluctuations in values over the years towards high indicators of the average daily air temperature and lower values will be close to the average long-term data (18.1 °C). Thus, in the coming decade, we can expect an increase in the average daily air temperature for the notional vegetation to 24.1 °C in some years, which is 6.0 °C higher than the long-term norm and only 0.9 °C higher than the abnormally hot 2010 – 23.2 °C (in 2021, the average air temperature for 4 months was 23.0 °C). It is very likely that the estimated mark of 24.1 °C will be reached in the region in the coming years.
- According to the total precipitation amount, we had a slight decrease since 1990 in the maximum values from 325.0 mm to 223.9 mm in 2017. The amount of precipitation during the May-August period by 2030, according to calculations,

may decrease to an average of 113.2 mm (-49.8 mm to the long-term average values). Over the past 11 years (2010-2020), we have already had an average of 139.1 mm, which is 23.9 mm below the norm, including 2010 when the shortage of precipitation was 105.3 mm, 2014 – 72.7 mm, 2016 – 64.0 mm, 2019 – 52.4 mm. There was also a 51.6 mm shortage of precipitation for 4 months in 2021.

The analysis of regional agrometeorological conditions indicates significant changes in weather conditions in such a short period. In the world, against the background of the catastrophic consequences of global warming and especially alarming environmental hazards associated with highly productive agriculture known as the "green revolution" of the 1960s, the great importance of enriching the genetic fund with the "Crop wild relatives" (CWR) is claimed [10]. To enhance agronomic characteristics in breeding programs, old wheat varieties become a valuable genetic resource for diversity and specific adaptation to local environmental conditions [11].

Nowadays, the breeding programs of many Russian institutions are mainly aimed to create varieties with high productivity potential. They have a limited source material of highly productive genotypes for breeding that leads to obtaining genetically homogeneous material by breeders which is poorly adapted to drastic changes in weather conditions caused by global warming.

4 Conclusion

We suppose that, despite the high adaptive capabilities of cultivated plants, it is already necessary to create more and more drought- and heat-resistant crop varieties for the coming decades. To do that, it is necessary to change the approach to the source material study: from the diversity of varieties to genotype responses to contrasting weather phenomena. And this will most likely require adjustments to breeding programs.

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