Air temperature, precipitation and agronomy in steppe zone of the Southern Urals

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Abstract. The climate and changes in air temperature and precipitation in the Southern Urals for 134 years according to the Hydrometeorological Service are considered. An increase in the average annual air temperature by 0.0185 °C per year was revealed - from +3.2 °C at the beginning of the study period to +5.7 °C in 2020, and a decrease in average annual precipitation by 24 mm up to 353 mm by 2020. An increase in air temperature occurred mainly in October-March by 3.2 °C, and a decrease in atmospheric precipitation in May-July by 15% to 104 mm, which significantly changed the conditions for natural biocenoses and agricultural practices. An increase in air temperature and a decrease in atmospheric precipitation enhances the aridization of the climate of the steppes of the Southern Urals and shifts the northern and southern borders of the steppe zone to higher latitudes. Appropriate adaptation of the pasture regime and haymaking in steppe biocenoses and rainfed farming is necessary. Winter sowing of grain crops of spring sowing in frozen ground with snow cover up to 10-15 cm is proposed. Under a stable snow cover, their seeds retain their germination and, with its melting, germinate in spring at freezing temperatures. The development of plants is provided with moisture at favorable temperatures in April-May. Podwinter crops of grain crops are more resistant to droughts and increase productivity by 1.5-2 times in comparison with spring crops.

1. Introduction

The formation of natural zones is determined by the provision of the main system-forming components: heat, water and geological environment. They are formed in accordance with the law of the minimum by J. Liebig, according to which the component that is in the minimum of providing the necessary conditions determines the type of vegetation that is most adapted to this minimum. With limited thermal resources and high water availability and geological conditions, humid zones - forest and tundra - have formed. The formation of arid zones is due to the relative scarcity of water resources. In conditions of a high supply of thermal energy and a flat relief, the shortage of water resources created conditions for the formation of drought-resistant biocenoses and their displacement of moisture-loving plants in humid zones. Differences in the level and mode of supply with thermal and water resources against the background of the relative stability of geological conditions determine the formation of diversity in the steppe zone and the productivity of biocenoses. Long-term and short-term changes in air temperature and atmospheric precipitation, which are the backbone components of the Southern Urals [1], determine the corresponding response of its natural and anthropogenic systems. Cognition of the changes going on in the atmosphere is the most important in understanding...
the processes taking place in biocenoses, plants and fauna of the steppes and the organization of anthropogenic activity in them. So far, there are no comprehensive studies of changes in air temperature and precipitation in the steppe zone in the southeast of the European part of Russia over a long period and their accounting in agronomy. This article attempts to solve this problem.

2. Materials and Methods
The system-forming components of nature in the steppe are considered - changes in air temperature and atmospheric precipitation over 134 years in the Southern Urals using instrumental observations at the meteorological station of Orenburg in 1887-2020, 39 years after the invention of the modern thermometer by Lord Kelvin and the establishment of the Main Physical Observatory - the main methodological and scientific center of the Hydrometeorological Service of Russia in St. Petersburg. The results of a study of more than a century of observation of rapidly changing air temperature and precipitation in space at one point (Orenburg) is permissible to extrapolate their long-term dynamics to the entire South Urals and adjacent steppe territories.

The variability and cyclicity of the climate and the weather conditions that form it by years, the autumn-winter period and the growing season of steppe vegetation and grain crops on arable land have been investigated by the methods of statistical processing with the construction of graphs. On experimental plots and on farms in the Pre-Ural and Trans-Ural parts of the Southern Urals, the adaptive ability of spring wheat to early winter sowing in frozen soil and the effective use of spring moisture reserves in it was studied.

3. Results and Discussion
The natural steppes of the Southern Urals are represented mainly by perennial grasses that make the most of the available natural conditions in terms of temperature, water resources and soils.

Steppe vegetation begins growing in spring with the appearance of water in the liquid phase and air and soil temperatures above 0 °C. In the South Urals, the awakening and vegetation of steppe vegetation begins in April and continues until the air temperature goes below 0 °C. The sum of air and soil temperatures above 0 °C, at which, according to our observations, seeds of spring wheat and a number of other cereal plants begin to germinate in spring on the surface and at a depth of 1-3 cm of wet soil, in the region it is more than 2600 °C with a minimum required of about 1000 °C. Consequently, temperature is not the minimum limiting factor in the development of plants in the steppe zone.

The sun is the natural source of energy for vegetation. In the steppe zone, the provision of vegetation with solar thermal energy is determined by the total luminosity of the Sun, the seasons and weather conditions. Oscillations in the luminosity of the Sun according to [2], [3] in 11-year cycles are 0.1% of its total luminosity, and therefore they do not significantly change the temperature conditions of vegetation. The main changes in heat supply, affecting vegetation, occur according to the seasons of the year. In Figure 1 shows the temperature conditions in the steppe according to the data of the Orenburg meteorological station for 134 years.

Annual air temperature trends show that it is gradually increasing. According to a linear trend in 1887, the average annual air temperature was +3.2 °C. Increasing by an average of 0.0185 °C per year, it increased to +5.7 °C by 2020.

During the year, the air temperature changes faster in the direction of increase in autumn-winter October - March on average by 0.0238 °C per year. Over 134 years, according to a linear trend, it increased by 3.2 °C from an average -8.8 °C in 1887 to -5.6 °C by 2020. During the growing season of the main crops in May-July, the average temperature increased 2 times slower at a rate of 0.0089 °C from +18.5 °C in 1887 to +19.7 °C by 2020. However, since 2000, the growth rate of air temperature in the considered growing season has increased 5 times to 0.045 °C per year, increasing it over 20 years by 0.9 °C on average to 20.3 °C in 2020.

Annual air temperatures deviate significantly from the trend line of the climatic norm. Their maximum (1925) values are 1.5 times higher than the climatic norm, and the minimum (1908 and
1969) are 2.2 times lower, which significantly affects the productivity of the biosphere, society and the economy of the steppe zone [11].

A joint analysis of the linear trend and polynomial 5 and 6 degrees of annual air temperatures for the 134-year period (Figure 1) revealed their cyclical nature. In 1887-1905 the air temperature rose above the linear climate trend. Then, until 1932, temperatures were on average close to the climatic norm of this period. In 1933-1990 its annual temperatures are on average below normal.

![Graph of Average Annual Temperature](image1)

![Graph of Average Temperature for the Period "OCTOBER-MARCH"](image2)

![Graph of Average Temperature for the Period "MAY-JULY"](image3)

**Figure 1.** Air temperature for the year, autumn-winter and growing seasons in Orenburg in 1887-2020, their linear and polynomial trends. On the X-axis - Years; on the Y-axis – Temperature.

In subsequent years, up to the present time, there is a cycle of rapid increase in air temperature, significantly exceeding the linear climate trend.

The high supply of heat to the Southern Urals increases the significance of atmospheric precipitation and changes in them for the biosphere, both climatic and short-term factors. For steppe
vegetation, they are the most important component of nature. In Figure 2 graphically presents their number for the year, in the autumn-winter and growing seasons, and their trends for 1887-2020.

The linear trend of annual atmospheric precipitation characterizes changes in their supply to the Southern Urals. In 1887 there were an average of 377 mm, while decreasing along the trend by an average of 0.1768 mm/year, by 2020 the average amount of precipitation was 353 mm/year. Consequently, over 134 years in Orenburg, the average long-term annual norm of atmospheric precipitation decreased by 24 mm, which is 6.4% less than their amount at the beginning of the study period.

**Figure 2.** Atmospheric precipitation per year, autumn-winter and growing seasons in Orenburg in 1887-2020, their linear and polynomial trends. On the X-axis – Years; on the Y-axis – Precipitation.
Polynomial trends of the 5th and 6th degrees, which together determine the position of the climate trend line, show the presence of long-term cyclical changes. Less than normal (291 mm) precipitation fell in 1887-1894.

In the following years 1895-1923 their number has become on average more than the norm (410 mm). In the next cycle 1924-1968 they decreased to 350 mm per year. In 1969-2010 the average annual amount of atmospheric precipitation corresponded to the climatic norm, which had decreased to 373 mm. After 2010, another cyclical decrease in atmospheric precipitation began.

The sums of annual atmospheric precipitation, as well as air temperatures, in the 134-year period significantly deviate from the climatic norm. The maximum (731 mm) and minimum (185 mm) annual precipitation is 2 times more or less than the climatic norm. Deviations of precipitation from the climatic norm significantly affect the biosphere, society and economy. According to W. Koppen [[4]], M.I. Budyko [[5]], a long-term decrease in the amount of atmospheric precipitation changed in the past and continues to change in the present the species composition of the biosphere and the conditions of human life. This led to a stricter natural selection and high rates of evolution, especially the evolution of higher nervous activity [[6], [7]]. It is known that climatic conditions and changes in them have a significant impact on the efficiency of human economic activity [[8], [9]]. Agriculture significantly depends on the climate and its changes [[10]].

For the steppes of the water-deficient Southern Urals, the distribution of atmospheric precipitation over the seasons is important. Climatic norm of atmospheric precipitation in October-March in 1887-2020 (Figure 2), like the annual, decreased on average by 0.0692 mm per year. Over 134 years, their average amount decreased by 9 mm (-5.2%) and by 2020 the average amount of atmospheric precipitation in the autumn-winter period decreased to 164 mm/year. However, they decreased more slowly than the average amount, increasing their share in the annual balance of atmospheric precipitation. In the mode of fallout of autumn-winter atmospheric precipitation, cyclicity was revealed. In 1887-1912 atmospheric precipitation in October-March fell less than the climatic norm. In 1913-1920 the trend lines of the 5th and 6th degrees were above the linear trend characterizing the climate of the autumn-winter period. In 1921-1968 the amount of autumn-winter precipitation was less than the climatic norm, and in the subsequent period up to 2004 more than the norm. In 2005-2020 their number is close to the norm.

Analysis of climatic conditions of vegetation of steppe plants and early spring grain crops in the Southern Urals in May-July 1887–2020 shows that during this period atmospheric precipitation decreased by 0.1321 mm/year (Figure 2). As a result, in 134 years they decreased by 18 mm (-15%) and by 2020 their number decreased to 104 mm/year. The atmospheric precipitation during this growing season of steppe plants and spring grain crops decreased by 9% faster than their annual amount, and by 10% in the autumn-winter period. Their share in the average annual balance of atmospheric precipitation has significantly decreased. The conditions for plants in natural biocenoses and on arable lands have changed.

As a result of an increase in air temperature and a decrease in the amount of atmospheric precipitation in the South Urals, the aridization of the steppe climate is increasing. The northern and southern boundaries of the steppe zone are shifted to higher latitudes [[11]]. Changes in the climate have necessitated a corresponding adaptation of the pasture regime and haymaking in steppe biocenoses.

A significant decrease in the amount of atmospheric precipitation and an increase in air temperature during the growing season of the main crops increased the riskiness of the applied agricultural technologies for spring sowing. Their yield decreases and the death of crops from droughts increases. With spring sowing of spring grain crops, significant losses of melt water and early spring atmospheric precipitation for evaporation when the soil dries to a favorable moisture content for pre-sowing field work and sowing. During this period, 80–100 mm of moisture evaporates unproductively from the soil. As a result, early grain crops use only part of the autumn-winter precipitation and, on average, 104 mm of precipitation in May-July, providing an average yield of 0.8-1 t/ha [[11]]. In the Orenburg region in 2010–2020, the average yield of spring wheat is 0.66 t/ha within 0.14-1.16 t/ha. In these
years, 339 mm/year fell in the district with fluctuations from 239 to 456 mm, which can provide 1.5-2.0 t/ha. For such a yield, an agronomic system is needed that ensures the effective use of the entire annual amount of precipitation [1, 10].

At the first stage, it is necessary to increase the efficiency of using autumn-winter atmospheric precipitation, which falls by 40% more than during the growing season of early grain crops. By fundamental and applied research, we have revealed a high safety of germination of seeds of a number of grain crops of spring sowing in frozen ground under a snow cover [12]. Analysis of climatic and weather conditions (Figure 1) shows the stability of the snow cover in the steppes of the Southern Urals. Together, these factors create conditions for maintaining the germination of seeds with a moisture content of less than 16% in the field conditions of the region. We propose a technology for sowing grain crops in autumn and winter in freezing and frozen soil at a shallow depth using grain seeders with disc and anchor openers with snow cover up to 10 cm or more.

During winter sowing of grain crops, spring thawed waters are effectively used by germinating seeds of spring wheat, barley and other crops at positive temperatures. Sowing of spring wheat in the winter gives good shoots and the subsequent development of plants in conditions of the early spring period favorable in terms of humidity and temperature. The developed root system consumes soil moisture from a depth of up to 1.5 meters and effectively uses low atmospheric precipitation in June-July. Winter crops are less damaged by droughts. Under production conditions, on winter crops of spring wheat in 2017 favorable for precipitation, a grain yield of 3.5 t/ha was obtained per 18 hectares, and in severely arid 2018, 1.3-1.5 t/ha were obtained per 100 hectares, which is 1.5-2 times more yield in the fields of spring sowing. In 2020, winter crops of spring wheat in the farms of the Orenburg region on an area of more than 3000 hectares produced grain of 1.4-2.2 t/ha with its high quality [12].

Consequently, the Orenburg region is not a zone of risky farming, as many experts of the region have been affirming for many years, but a risky farming system used, designed mainly for June and July rains, which are not constant and vary from year to year from absence to 150 mm, causing corresponding fluctuations in agricultural productivity cultures [10]. Atmospheric precipitation over the year is less variable.

The proposed natural system of agronomy, based on the effective use in arid conditions of all annual atmospheric precipitation and its component part, needs to continue studies of the moisture regime in the soil, its processing for optimal planting of seeds in frozen soil with seeders to a depth of 2-3 cm, quantity, timing and fertilization technologies due to an increase in the removal of nutrients by an increased yield. Research on increasing the set of crops for winter sowing, their forms and varieties that effectively use winter and summer atmospheric precipitation is important. It is necessary to test and select agricultural machinery capable of operating on frozen and snowy soils.

In the Orenburg region, research on the production of crop products is carried out separately and there is no system for their introduction into production. It is required to solve a number of problems of using nature-like systems of human management in natural steppe biocenoses and on arable lands for the effective use of systemic precipitation and soils of the Southern Urals.

4. Conclusion
In the Southern Urals for 134 years, the annual precipitation decreased by an average of 24 mm to 353 mm/year and the average annual air temperature increased by 2.3 °C. There is an aridization of its climate.

The atmospheric precipitation during the growing season of grain crops in May-July decreased by 15% to 104 mm/year. The climatic norm of winter atmospheric precipitation decreased by 5% to 164 mm/year.

For 1887-2020, the climatic norm of air temperature during the growing season increased by 1. °C, and in winter by 2.8 °C.

The science and practice of agronomy in the steppe zone of the Southern Urals must take into account changes in climate. Due to the decrease in atmospheric precipitation in the spring-summer period, it is necessary to use winter precipitation more effectively. With a stable snow cover in the
steppe zone, autumn-winter crops of grain crops effectively use atmospheric precipitation, are less damaged by droughts and increase their productivity by 1.5-2 times.

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