Current climate conditions and their impact on agricultural production in Stavropol Krai

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Abstract. Stavropol Krai is located within Ciscaucasia and has an area of 6,616 thousand ha. Massive utilization of the territory, associated with the increased man-induced impact on the environment, caused the aggravation of negative processes in the agroecosystems of the region. Throughout all agroclimatic zones of the region, air temperature tends to increase, which is illustrated by both linear and polynomial trends. In 2010 there was also a rise in air temperature. A warmer spell, notably during the effective vegetation period, led to the precipitation falling in the form of short-term intense showers that generally contribute to erosion advancing. Given the prior climate conditions, the studies resulted in the arrangement of cultivated land, based on its agricultural validity, into four categories in hectares and percent of the area of agricultural land.

1. Introduction

The paper is based on a series of field studies conducted in the cultivated land of Stavropol Krai in 2000–2017. Land monitoring data suggest that there has been an increasing tendency towards a deterioration in the quality of land in Russia. The main negative processes involve erosion, deflation, waterlogging, salinization, desertification, flooding, colonization of agricultural land by shrubs and trees, and other processes leading to the lost fertility of agricultural land and consequent removal from economic turnover.

Stavropol Krai is located within Ciscaucasia and has an area of 6,616 thousand ha. The region includes 26 administrative districts and 10 sub-regional cities. The region is deemed to be a zone of risky agriculture, where moisture availability is a crucial factor hindering agricultural production. The average annual rainfall (about 530 mm) across the region as a whole indicates a proper moisture supply. However, there are hyperarid and arid zones in the region, with the amount of precipitation per year to amount to 300–400 mm. An integral climate index reflecting the conditions of heat and moisture supply of the vegetation season and, therefore, the possibility of agricultural activities is referred to as the hydrothermal coefficient (HTC). It is the ratio of precipitation for a period of effective vegetation to the sum of the temperatures for the same period. Being ranked, it forms the basis for the allocation of agroclimatic zones. Within Stavropol Krai, the HTC ranges from 0.5 in a hyperarid agroclimatic zone to 1.3 in a zone with sufficient moisture (piedmont zone), though a high HTC is rarely recorded across the region.
Massive utilization of the territory, associated with the increased man-induced impact on the environment, caused the aggravation of negative processes in the agroecosystems of the region. This is evidenced by the feedback from soil, reclamation and geobotanical surveys, systematically carried out in the region over the past 50 years. A significant degree of utilization combined with natural factors entailed the degradation of soil and vegetation over a large area [1-4].

2. Materials and methods
The target area is divided into four climatic zones (hyperarid, arid, unstable moisture, sufficient moisture). The average air temperature in the region is –3...–5 °C in January, +17...+25 °C in July, and the average annual temperature is + 10.4 °C. The monthly average temperature of the region has a synchronous pronounced cycle with one peak during warm weather. January is the coldest month and July is the warmest month. In most areas, a frost-free period can last more than 190 days, and the sum of effective temperatures varies from 2.570 °C in the foothills to 3.800 °C in the plain-like areas, which creates favourable conditions to cultivate a wide range of crops. The vegetation season in Stavropol Krai lasts 200–234 days. Climate conditions within agroclimatic zones are illustrated in Table 1.

| Index                              | Zone                  |
|------------------------------------|-----------------------|
|                                    | Hyperarid (I)         | Arid (II)            | Unstable moisture (III) | Sufficient moisture (IV) |
| Altitude, m                        | 10–100                | 100–200              | 200–650                 | 300–900                  |
| Average annual air temperature, °C | 10.8–11.1             | 10.7–11.2            | 9.7–11.0                | 8.0                      |
| Average annual precipitation, mm   | 387–458               | 433–482              | 559–636                 | 665                      |
| Hydrothermal coefficient (HTC)     | 0.63–0.72             | 0.64–0.81            | 1.0–1.09                | 1.79                     |
| Moisture index (MI)                | 0.18                  | 0.19–0.21            | 0.27–0.31               | 0.47                     |

The agroclimatic scheme of Stavropol Krai was compiled based on climatic data characterizing the reference period of 1931–1960. However, during the time following its compilation, the climate somehow changed, and as did their impact on landscapes until 2010 [1, 3, 5, 6].

3. Current climate conditions and their impact on agricultural production
The climate formation in Stavropol Krai is influenced, firstly, by its location in the southern part of the temperate zone, which determines significant amounts of incoming solar energy, and, accordingly, the thermal regime in the region. The second strongest factor in climate formation is the relief at large, which is quite twofold. On the one hand, the high-mountainous Major Caucasian Range that stretches relatively close to the south is a principal climate divide to prevent tropical air masses from freely propagating to the north, thereby intercepting the Arctic masses in winter and mild summers to the south. On the other hand, there is an auxiliary climatic divide at the regional level, known as the Stavropol Upland, which prevents the propagation of moist air masses from the Black Sea to the east in summer and dry air from the Caspian Sea in winter.

The Ciscaucasia climate within Stavropol Krai as a whole is characterized as temperate continental. The geographic location of the region determines high values of total solar radiation (over 100 kcal/cm²) and annual radiation balance (36–39 kcal/cm²). The thermal regime of the region is formed largely due to the relief. The coldest areas are associated with maximum heights (Stavropol Upland, foothills, low- and mid-mountains of the Greater Caucasus). The warmest areas are the
northwestern and eastern parts of the region, where average annual temperature goes above 11 °C. A location-induced total atmospheric circulation is characterized by pronounced seasonal patterns. In summer, the western air masses from the Black Sea prevail, and in winter, due to the formation of an inland maximum, the eastern ones from Siberia and Kazakhstan are dominant. Moreover, in the first case, sea air is transported, while in the second – continental air. Figure 1 illustrates annual temperature fluctuations for 1965–2017 by the basic weather stations within the agroclimatic zones of the target area.

The above data clearly suggest that air temperature in all agroclimatic zones tends to rise, which is illustrated by both linear and polynomial trends. The second feature of this process is a rise in temperature in 2010, which broke its maximum for 1966. The next feature is that nearly until the middle of 1980 there was a rather large interannual variability of air temperature with some tendency to decrease. Around the mid-1990s, there was a steady rise in temperature being much less volatile from year to year than before the mid-1980s. Since 2010, the temperature was steadily higher than the average for the period under review. Figure 2 illustrates annual rainfall fluctuations for 1965–2017 for agroclimatic zones in Stavropol Krai.

Figure 1. Annual temperature fluctuations for agroclimatic zones of Stavropol Krai for a period of 1965–2017
As with the air temperature, the amount of precipitation also tends to increase to varying degrees. It is least expressed in the hyperarid zone, while in the others it is more clearly visible. However, unlike temperatures, changes in precipitation are not so synchronous. In the arid zone and the zone of unstable moisture, the highest precipitation with significant fluctuations were recorded in the mid-1980s. Current precipitation is generally close to normal with much less interannual variability than in previous years. In the zone of sufficient moisture, the precipitation regime was quite stable. Finally, in the hyperarid zone, fast-changing precipitation, as well as yearly fluctuations, has been explicitly decreasing in recent decades.

The most interesting conclusion is related to the changes in HTC (Fig. 3). A linear trend illustrates the stability of this indicator, despite its significant yearly fluctuations. Despite the current trends towards climate change, agricultural conditions over a long period totally remain quite stable. However, a rise in air temperature should be reflected through some integral climatic indicators, such as the sum of effective temperatures, the amount of precipitation for this period, the sum of the temperatures in the cold period and the precipitation in the cold period.
Figure 3. HTC fluctuations for agroclimatic zones of Stavropol Krai for a period of 1965–2017

A rise in air temperature, particularly during the period of effective vegetation, led to the precipitation falling in the form of short-term intense showers that generally contribute to erosion advancing. The greatest air temperature rise occurred in 2006-2010, and during this period the amount of precipitation was also maximum, except for Alexandrovsky District. Thus, current climate conditions foster degradation processes in the cultivated land of Stavropol Krai [6–10].

4. Conclusion
Since late 20th century, there was a steady rise in temperature throughout all agroclimatic zones of Stavropol Krai, and that exceeded all earlier values. A last-decade rise in air temperature occurred to varying degrees for all months and seasons of the year, and was also accompanied by an increase in the amount of precipitation. Nevertheless, the nature of humidification, expressed through the hydrothermal coefficient, has remained virtually unchanged. However, the period of effective vegetation increased, and so did the intensity of precipitation, especially in the warm season.

Monitoring of the principal negative processes and the quality of cultivated land based on the analysis of climate conditions made it possible to articulate a new scientific direction – zoning of agricultural land based on the effect of degradation processes and agricultural validity. Zoning of agricultural land is necessary to streamline its further use and develop appropriate measures for the protection, preservation and improvement of the quality. Given the prior climate conditions, the studies resulted in the arrangement of cultivated land, based on its agricultural validity, into four categories in hectares and percent of the area of agricultural land:

- highly valid – 1,733,581 ha (30.5 %);
- valid – 2,194,588 ha (38.6 %);
- hardly valid – 1,103,703 ha (19.8 %);
- invalid – 626,062 ha (11.1 %).
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