Climatic adaptation as priority of sustainable development of the agrifood system in the southern regions of Russia

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Abstract. The article presents current and prospective estimates of the climatic changes parameters and their contradictory impact on the productivity of the agrifood system in the country's southern regions. In the period up to 2030-2050, against the background of an increase in heat supply and duration of crop season, a mixed arid-humid type of moistening will have been predicted with an increase in aridization towards an increase in the frequency of droughts, including soil ones, as well as increased harmfulness of certain types of agricultural pests and pathogens. A new climate-adapted paradigm of sustainable development of the agrifood system in the South of Russia, based on Climate-Smart Agriculture, is proposed. The priority measures of climatic adaptation of the agrifood system in the South of Russia are grounded in connection with the growth of the spacing of winter crops, heat-loving, fruit and berry crops, vineyards; water-saving and moisture-retaining technologies; phytosanitary measures for the prevention and control of climate-dependent pests; agrotechnical methods of increasing the adaptive potential of crops to climate change; climate-adaptive schemes for the use of pastures; engineering of highly productive and climate-resistant agrophytocenoses and agroecosystems. Measures to stimulate climatic adaptation of the agrifood system in the South of the Russian Federation should involve the development and inclusion in the sectoral State Program of the Russian Federation of the *Adaptation of Agriculture of the Constituent Entities of the South of the Russian Federation to Climate Change* pilot section with an annual competition of regional agro-climatic projects based on budget COFUND; financing farms for the implementation of climate-adapted and related agricultural activities, climate insurance.

1 Introduction

One of the key principles of the sustainability of the agrifood system (AFS), according to FAO [1], is to ensure its resilience to external disturbances, or, in other words, to maintain and/or increase its productivity by preventing, mitigating or overcoming risks, adapting to changes and recovering from shocks. The implementation of this principle is especially important in the context of the adaptation of the AFS to natural and, above all, climatic disasters, the consequences of which, according to WMO estimates, are economic burdens on world agriculture in the amount of from 50 to 100 billion US dollars, with 2/3 caused by climatic and weather stresses [2].

Such a complex problem is especially obvious for the national AFS, the sustainable development of which, in the conditions of the climate aridization [3] predicted by the Federal Service of Russia on Hydrometeorology and Monitoring of the Environment for the period of 2031–2050, will proceed against the background of an intensification, e. g., in the main granaries of the South of Russia, of natural water deficit, erosional soil processes, temperature fluctuations, thereby actualizing the development and application of climatically adapted technical, technological and organizational and economic solutions in the local AFS of the Southern regions of the country.

In this regard, the purpose of the study is to assess the impact of climate change on the stability of the AFS in the Southern regions of the country and to substantiate measures to level them.

2 Materials and methods

The framework of the study is based on conceptual, though mostly assessment, works devoted to the impact of climate on the agricultural sector. The results of a scientific search for international teams under the auspices of the IPCC, FAO [4-7,18,19], individual foreign scientists [8-12], as well as representatives of the Russian economic and agricultural science [13-17] turned out to be productive.

The instrumental and methodological basis is implemented by a spatial-dynamic and cause-and-effect analysis of empirical and statistical data, estimates by the Federal Service of Russia on Hydrometeorology and Monitoring of the Environment, characterizing the variability and influence of climatic factors on the

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parameters of the AFS development in the constituent entities of the Southern Federal District (SFD) and North Caucasian Federal District (NCFD).

3 Results and Discussion

For the AFS in the Southern regions of the country, the climatic changes over the period from 1976 to 2012, statistically verified by the Federal Service of Russia on Hydrometeorology and Monitoring of the Environment, are generally characterized by positive trends, but with some contradictions in a number of positions. Thus, there is an increase in the average temperature of the cold period of the year by 0.3°C (Southern Federal District) and 0.1°C (North Caucasian Federal District) (national average by 0.4°C), heat supply of agricultural crops by 153°C x day/10 years (SFD) and 139°C x day/10 years (NCFD) (national average by 96°C x day/10 years), and, as a result, the duration of the growing season by 3.8 days (SFD) and 4.5 days (NCFD) (national average by 4 days) [3].

On the one hand, estimates of water availability demonstrate an increase in the total precipitation in spring and autumn, respectively, by 13.25 and 6.54 mm/10 years (SFD), by 4.07 and 7.14 mm/10 years (NCFD) (national average by 5.03 and 0.56 mm/10 years). On the other hand, there is a decrease in the total precipitation in summer by 4.6 mm/10 years (SFD) and 1.7 mm/10 years (NCFD) (national average by 1.7 mm/10 years), spring deposits of moisture in plough-layer by 0.4 mm/10 years (SFD), 0.6 mm/10 years (NCFD) national average by 0.5 mm/10 years); finally, an increase in the number of days of the growing season with the top soil moisture of less than 10 mm per 0.5 days (SFD) and a decrease by 1.7 days (NCFD) (national average +2.4 days) [16].

As a result, a decrease in the aridity index and an increase in the soil moisture coefficient are noted, which favorably distinguishes the APS of the South from others in the European part of Russia, where there is a decrease in moisture content in the summer and, as a consequence, in the moisture supply of agricultural crops [3].

In general, the above-mentioned combination of thermal factors and moisture had a positive effect on the yield of the main grain crops in most of the territory of the agricultural zone of Russia, including the AFS of the South, where an increase in the yield of winter wheat is registered by 3.1-4.9 hundred kilograms per hectare/10 years (national average by 2.6 hundred kilograms per hectare/10 years), cereals and grain legumes by 1.9 hundred kilograms per hectare/10 years, and in the Stavropol Territory by 3.2 hundred kilograms per hectare/10 years [17].

Meanwhile, an increase in the degree of climate aridity in the spring and summer seasons against the background of warmer winters, as well as the concentration of traditional habitats of gregarious locust forms within the boundaries of the AFS of the South of the Russian Federation, is accompanied by an increase in cases of their mass reproduction, which took place, e. g., in 1990-2002. The enormous damage to crop production from the infestation of locusts in physical term is estimated by the damage to crops on an area, like in 1999, of about 1 million hectares and phytomass 5-10 times higher than directly destroyed vegetation, and the annual direct costs of locust pest control in the Stavropol Territory alone amounted to about 2.8 billion rubles (in 1997 prices) [17].

In general, the results of the variable climatic forecasting of the Federal Service of Russia on Hydrometeorology and Monitoring of the Environment demonstrate a change in the moisture content of the grain zone of Russia according to the mixed arid-humid type. In the period of 2031-2050, if we compare with 2011-2030, aridization will become more intensified and will expand, especially within the boundaries of the AFS in the South of the Russian Federation, with an increase in the frequency of droughts, including soil ones.

Such conditions, generally favorable for winter cereals, as shown above, will negatively affect the yield of spring crops, a decrease in which in the Southern APS is predicted by 5-10% in 2011-2031, by 30-50% in 2080-2091 [17].

Under warming conditions, an increase in harmfulness on crops of certain types of agricultural pests and pathogens is expected due to a change in food preferences from wild plants to agricultural ones (beet flea beetle, wart-biter, bush-cricket, certain species of non-gregarious locusts), an increase in the number of generations per season (codling moth, San Jose scale, Colorado potato beetle, phytophthora), displacement of development phases to earlier dates (oriental fruit moth, locust pests, phytophthora), expansion of the habitat (e. g., spread of the Mediterranean fruit fly throughout the South), mass reproduction (primarily, of the locusts that are traditional for the Southern regions).

Meanwhile, such assessments are supported by the concern of farmers in the Southern regions of the country. In particular, surveys of agricultural producers in the Stavropol Territory, conducted by the authors in November and December 2020, showed that in the list of socio-ecological and economic problems ranked by importance, regardless of the climatic zone of location and type of organization, the lead was taken by “a negative impact of climate change on agricultural production” (average score 4.6 out of 5.0). Moreover, 85.4% of respondents associate such an impact with an increase in losses of agricultural products, 78.0% – with a decrease in crop yields, 68.3% – with the threat of mass reproduction of pests and diseases.

In addition, the results of the surveys confirmed that in the practical activities of farmers, the issues of ensuring sustainable development are closely correlated with extreme natural and climatic factors. Thus, farmers from the extremely arid areas of the Stavropol Territory demonstrated multiples of greater awareness of sustainable development compared to their colleagues from the area of satisfactory moisture, 83.3% versus 33.3% (among the respondents).

However, in the course of SDG 2030 ranking in the system of business priorities of the companies represented in the survey, SDG 13 (Climate Action) was ranked 14th out of 17 places, no less than 56.1% of respondents stated the importance of this problem as well as the lack of corporate practice to solve it. This indicates that despite the awareness of climatic risks in the sustainable development of the agrarian business, measures to level them have not been properly reflected yet in the activities of agricultural enterprises.

Obviously, such a situation requires the activation of constructive, risk-oriented management and climate-adapted economic decisions (Table 1).

Table 1. Climatic Adaptation Measures for the Agrifood System of the South of the Russian Federation.

Directions	Adaptive Measures
Growth in average temperatures and moisture supply in winter, autumn-spring periods	increase in the area of winter cereals, early and late-ripening varieties, underwinter sowing of vegetable, green, fruit and berry plantations, postharvest and green manure crops, vineyards;
Increase in the sum of active temperatures, duration of the growing season	expansion of areas of heat-loving high-intensity crops (sunflower, sweet corn, soybeans, sugar beets, etc.), subtropical agriculture is not excluded;
Growth of aridization in general, frequency of droughts, including soil ones	introduction of water-saving and water-retaining technologies, expansion of areas for drip and drip-root irrigation in perennial plantations; development and implementation of technologies, optimal norms differentiated by crops, and irrigation management systems; use of treated wastewater in irrigation (gardening);
Increased harmfulness of climate-dependent species of pests and pathogens of agricultural crops	strengthening of phytosanitary monitoring of crops and control, especially for quarantine climate-dependent insect pests with habitats in the South, such as the fall webworm, oriental fruit moth, San Jose scale; regular updating of the national list of quarantine objects and development of a quarantine list for all regions of the South located in the border zone of the areas of distribution of climate-dependent pests; due readiness of the quarantine and plant protection services of the South to prevent import from abroad and spread on the territory of the country, to the mass reproduction of agricultural pests, pathogens
Climatically adapted agroinnovations	breeding varieties and expanding the area of crops resistant to drought, high temperatures, pests; increasing the adaptive potential of crops to unfavorable climatic changes due to agrotechnical methods for optimizing water-air and light regimes of cultivation and feeding; development and implementation of climate adaptive schemes for the use of laylands; engineering of highly productive agrophytocenoses and agroecosystems resistant to unfavorable climate changes

In domestic agricultural experience, it is necessary to state the implementation of a fundamentally new paradigm of sustainable development of national and, above all, local AFS, in particular for the South of Russia, the economic basis of which will be climatically optimized agriculture, or, according to FAO, Climate-Smart Agriculture, CSA, which provides agricultural production with a higher resilience and immunity to environmental stresses and shocks caused by climate change [18, 19].

Moreover, such systems, having been diversified in terms of technical and technological, productive, organizational, resource principles, will provide not only the innovative susceptibility of agricultural production (see Table), but also multiple synergetic environmental and economic effects, such as reducing greenhouse gas emissions, carbon sequestration, increasing the efficiency of use of water and other resources, improving soil quality and fertility, restoring degraded land, increasing biodiversity and producing ecosystem services.

An example of an innovatively and climatically oriented approach in the AFS of the South of the Russian Federation is the *no-till* technology, which, as field practice in the Volgograd Region and the Stavropol Territory shows [20], not only allows accumulating more productive moisture in the soil, expanding the list of crops, introducing steaming fields, increasing the gross harvest and yield of winter cereals, significantly reducing the consumption of fuels and lubricants and the number of workers, but also stabilizing the mineralization of humus, phosphorus and potassium in the fields due to the recycling of plant residues and the greater digestibility of fertilizers.

In addition, in terms of aggravating natural water shortage, with 43.3% of the water consumed in the southern regions being supplied for irrigation, watering and agricultural water supply, water-saving solutions become critical. They also act as flagship areas of sustainable development of the AFS in the South of the Russian Federation, since, according to estimates [21], the correlation coefficient between precipitation and grain yield makes 0.80, which is confirmed by the amplitude of fluctuations in grain production in the Volgograd Region, which has amounted to 322% of the average annual collection over the last 35 years, or in the Republic of Ingushetia, where the losses of farmers from the shortage of soil moisture amounted to 261.2 million rubles in 2017.

Thus, in agriculture, drip irrigation is important, which is not only cost-effective, providing an increase in the yield of vegetables - 50%, melons and gourds - 80%, fruit - 125% in comparison with micro-sprinkling irrigation [22], and saving labor costs per unit of vegetable area - 60-65%, 5/10 days earlier ripening, over 200% profitability when growing vegetables, potatoes, fruits, soybeans, melons and gourds (in the Astrakhan Region conditions) in comparison with sprinkling irritation. But it also meets environmental requirements in terms of improving soil aeration, saving by 40-45% of irrigation water, halving the use of fertilizers and, as a result, the threat of chemical pollution of the environment [21].

Otherwise, the existing irrigation methods and significant water losses, as in the Stavropol Territory, against the background of a water shortage worsening because of aridization, will make it impossible to increase the irrigated areas [23].

Undoubtedly, the implementation of climate-adapted economic decisions requires effective and relevant management decision-making, primarily at the domestic level.

It is advisable to consider the introduction of technologies adapted to climate change in the AFS of the South of the Russian Federation as a national domestic priority that ensures the country's food security in the current period and especially in the long term. From this perspective, the sectoral State Program of the Russian Federation should support *Adaptation of Agriculture of the Constituent Entities of the South of the Russian Federation to Climate Change* pilot section based on regionally differentiated agricultural activities annually selected on a competitive basis, the development and, probably, co-financing of which will be the responsibility of the constituent entities of the South of the Russian Federation.

Meanwhile, the efficiency of climate technologies demonstrated by the world practice, implies incentives for such initiatives by farms at the local level [3], mainly through financing. At the same time, direct financing is necessary not only for climatically adapted economic experience, but also for measures that make it possible to solve the problems of water scarcity and land erosion aggravated by aridization and associated in the Southern regions of the country with the reproduction of soil fertility, introduction of water-saving technologies, organic farming, etc. What is more, under conditions of critical dependence of the AFS of the South of the Russian Federation on climatic fluctuations, the climate insurance should not be ignored [24, 25].

4 Conclusion

Thus, for the AFS of the South of the Russian Federation, climatic changes over the period from 1976 to 2012, statistically verified by the Federal Service of Russia on Hydrometeorology and Monitoring of the Environment, are characterized, on the one hand, by an increase in the heat supply of crops, duration of the growing season, moisture supply in the intercrop, on the other hand, by a decrease in moisture supply in the summer period, spring reserves of soil moisture, an increase in episodes of mass reproduction and spread of gregarious forms of locusts, quarantine pests. In the period up to 2030-2050, a change in moisture is predicted according to the mixed arid-humid type with an increase in aridization in the direction of an increase in the frequency of droughts, including soil ones, increased harmfulness on crops of certain types of agricultural pests and pathogens.

The results of surveys of farmers in the Stavropol Territory showed concern about climate change, and 85.4% of them associate climate change with an increase in losses of agricultural products, 78.0% – with a decrease in crop yields, 68.3% – with the threat of mass reproduction of pests and diseases. Awareness of sustainable development was shown by 83.3% of agricultural producers from the extremely arid territories of the Stavropol Territory, which is many times more than the share (33.3%) of their colleagues from the area of satisfactory moisture. in the course of SDG 2030 ranking in the system of business priorities of the companies represented in the survey, SDG 13 (Climate Action) was ranked 14th out of 17 places, and 56.1% of respondents stated the importance of this problem as well as the lack of corporate practice to solve it.

Climatic adaptation of the AFS in the South of Russia should assume the implementation of a fundamentally new paradigm of sustainable development, the economic basis of which will be Climate-Smart Agriculture providing agricultural production with high resilience and immunity to stresses and shocks caused by climate change.

Priority measures for the climatic adaptation of the agrifood system of the South of the Russian Federation should be associated with an increase in the area of winter cereals, early and late-ripening varieties, underwinter sowing of vegetable, green, fruit and berry plantings, vineyards; heat-loving high-intensity crops; introduction of water-saving and water-retaining technologies, expansion of areas for drip and drip-root irrigation; strengthening of phytosanitary monitoring of crops and control of climate-dependent pests, development of a quarantine list for all regions of the South; increasing the adaptive potential of crops to climate change through agrotechnical methods; introduction of climate adaptive schemes for the use of laylands; engineering of highly productive and resistant to unfavorable climate change agrophytocenoses and agroecosystems.

Measures to stimulate climatic adaptation of the AFS in the South of the Russian Federation should involve the development and support of *Adaptation of Agriculture of the Constituent Entities of the South of the Russian Federation to Climate Change* pilot section by the sectoral State Program of the Russian Federation by means of an annual competition of regional agro-climatic projects based on budget co-financing; financing farms for the implementation of climatically adapted and related agricultural activities, climate insurance.

6 Acknowledgments

The reported study was funded by RFBR, project number 20-010-00375 (project “Formation methodology and development of organizational and economic mechanism for achieving sustainable development goals in the national agrifood system”)

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