Scientific approaches solving problems of modern steppe land use on the base of modernization of the landscape-adaptive systems of agriculture

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Abstract. Bioclimatic resources were detected in the paper. Reserves increasing crops' productivity were estimated to develop and scientifically explain approaches to solve current agricultural use of steppe lands in the post-virgin land region of the Ural and West Siberia. Agrotechnical reasonability of the practiced structure of crops was analyzed. The principal directions to modernize landscape-adaptive agriculture systems were detected based on anthropogenic pressing reduction and soil protection from further degradation. The data source was official statistical indicators (EMISS) placed in open access, expedition research, calculation, and the author's conclusion. Standard methods of the statistical analysis were used in the data processing. It was ascertained that under practiced agriculture approaches in the Ural and West Siberia post-virgin land regions, a low realization of bioclimatic potential (BCP) of crop capacity (31-37\%) was noticed. A line of spatial peculiarities characterized BCP. The useful key factor of crop capacity stabilization and better BCP realization was the modernization of zonal landscape-adaptive systems of agriculture and optimization of an arable lands structure, replenishment of crops diversity, especially having soil-preserving and soil-recovering effect (annual and perennial grasses, feed crops for green mass, leguminous plants, etc.). In modern natural and anthropogenic changes, it was significant to a departure from monocultures, renew scientifically explained crop rotations, keep technological discipline, and support the whole technical process.

1. Introduction

The solution of socio-economic and ecological problems of priority development of RF regions in the near-term outlook is connected with a concept of stable development considering, as principal priorities, a possibility of adequate response on considerable challenges through optimization of interaction between nature, human, and technologies [1].

In the southern regions of Russia, issues of economic, ecological, food, and on the whole, national securities are closely connected with problems of rational use of the natural-resource potential of the steppe [2]. Steppe has suffered almost total anthropogenic transformation led to a loss of the core of zonal typicalness and urgent agroecological problems [3]. In this case, the currency of development and scientific explanation of approaches to using sufficient resources and reduce a load on natural ecosystems became more significant on the background of current climatic changes. In correspondence with a steppe nature management strategy developed by the Institute of Steppe UB RAS (Orenburg), the structure of existing land use is required immediate optimization. It is connected with a necessity to withdraw degraded lands from agriculture.
The intensification of agriculture on high-productive soils will reduce cultivated lands, excluding food risks under this approach. Simultaneously, the intensification will direct to increase productivity at the expense of improvement of methods to realize more effective bio-resource potential of crops. Bioclimatic resources were detected, and reserves of productivity growth of cornfields were estimated to develop and scientifically explain approaches to solving the problems under agricultural use of steppe lands in the post-virgin land regions of the Ural and West Siberia. Agrotechnical reasonability of the practiced structure of crops was analyzed. It was known the principal directions of modernization of landscape-adaptive systems of agriculture on the way of lowering of anthropogenic pressing and soil protection from further degradation.

The following tasks were formulated to realize the set goal:

- to study spatial and temporal variability of crop productivity, to reveal a character and fullness of realization of bioclimatic potential and a link of separate regions based on this indicator;
- to observe the dynamics of cultivated lands, crops' structures, diversity of crop varieties, and correlation of soil-preserving and soil-exhausting crops in agriculture of separate regions;
- to expose correlation differences of winter wheat productivity from a portion of participation of single varieties of field crops in the tillage structure to explain the results and formulate a conclusion.

2. Materials and Methods

The objects of the study were economic productivity, the total cultivated lands and areas under separate species of crops in Orenburgskaya, Chelyabinskaya, Kurganskaya, Omskaya, Novosibirskaya oblasts, and Altai Kray in the dynamics for 2010-2020. The source of the data was official statistic indicators placed in the open access by the United Inter-Agency Information Statistical System of Russia (EMISS) [4], results of expedition researches, calculation, and the author’s conclusion. General methods of statistical analysis were used in the processing of digital data.

3. Results and Discussion

In the course of the conducted studies, it was ascertained that a considerable variability characterized crop productivity in the post-virgin land regions of the Ural and West Siberia as in temporal so spatial relation. It was noted that the most typical peculiarities inherent in any post-virgin land region of the Ural and West Siberia characterized the agriculture of Orenburgskaya, Kurganskaya, Omskaya oblasts, and in Altai Kray.

Thus, in Orenburgskaya oblast, under the least (among the mentioned regions) average crop productivity 1.05 t/ha, its dynamic varied from 0.63 t/ha (2010) to 1.58 t/ha (2017) with the maximal coefficient of variation (25.0%) for 2010-2020. The most stable crop productivity with the variation coefficient (15.1%) was on fields in Omskaya oblast. Under the average value of 1.5 t/ha, it changed from 0.95 t/ha in 2012 to 1.74 t/ha in 2011. The crop productivity dynamics in the Kurganskaya oblast, according to the range of variation (0.83 t/ha), was close to similar values of Orenburgskaya oblast (0.95 t/ha). In Altai Kray, this indicator (0.75 t/ha) was close to the values of Omskaya oblast.

It should be noted that some dependency emerged between crop productivity (in dynamics) of the examined regions. Thus, crop productivity in Kurganskaya oblast (with the coefficient of correlation \( r = 0.73 \)) had the closest link with the similar value of Omskaya oblast. Dependence between crop productivity in Omskaya oblast and Altai Kray, Orenburgskaya, and Kurganskaya oblasts were so close with the correlation coefficient \( r = 0.62-0.59 \), respectively. In Orenburgskaya and Omskaya oblasts, this indicator was nearer to the average \( r = 0.47 \).

An analysis of economic productivity and its comparison with potential productivity (based on bioclimatic potential (BCP)) represented a low BCP realization level in the studied regions. At the same time, it characterized some peculiarities (table 1).

Thus, in Kurganskaya oblast, under the most significant economic crop productivity (1.51 t/ha), it was the lowest realization of bioclimatic potential – 31.3%. Simultaneously, in Omskaya, Orenburgskaya oblasts, and Altai Kray characterized by less crop productivity, BCP realization was higher at 1.7-3.4-5.9 percentage points (later p.p).
Table 1. Realization of BCP in crop productivity in the post-virgin land regions of the Ural and West Siberia, annual values for 2010-2020.

| Region               | Potential crop productivity, according to BCP, t/ha | Economic crop productivity, t/ha | Realization of BCP in crop productivity, % |
|----------------------|-----------------------------------------------------|---------------------------------|-------------------------------------------|
| Orenburgskaya oblast | 3.02                                                | 1.05                            | 34.7                                      |
| Kurganskaya oblast   | 4.82                                                | 1.51                            | 31.3                                      |
| Omskaya oblast       | 4.54                                                | 1.50                            | 33.0                                      |
| Altai Kray           | 3.38                                                | 1.26                            | 37.2                                      |

In the course of searching of reasons for the low realization of bioclimatic potential in steppe agroecosystems, progressive soil degradation, and other challenges for safe steppe land use, it was ascertained that in current conditions of management, market relations and the large number of corrections introduced in agriculture by the global economic crisis, considerable changes in "regulations" of steppe land use have happened. In our opinion, it was they which became the principal reason for unreasonable ineffective and ecologically insecure use of agro landscapes. The priority of exceptionally financial interests of agricultural commodity producers was accompanied by groundless violation of scientific foundations of ecologically directed nature management, spared soil-preserving agriculture, conservation of the integrity of the environment, and biological diversity [5, 6]. Due to the mentioned changes, a considerable lowering of crop diversity on fields, reduction of cultivated lands under agro technically valuable cultures, and simplification of crop rotation have been noticed only during the last ten years.

Swift expansion of soil-exhausting "commercial" crops to fields has been lasting almost everywhere. The fundamental rules of agriculture have been defied, the use of unsteady lands not suitable for tillage, and merciless exploitation of natural soil fertility accompanied by soil degradation has been going on (figure 1).

Figure 1. Low productive agricultural lands on heavily washed common chernozem soil in the Orenburg Cis-Urals region, June 2019.

The analysis of literature sources confirms the topicality of the problem in other regions RF, and in the world agriculture on the whole [7].
Expedition research conducted on agricultural lands of Russia’s steppe regions in 2018-2020 revealed an unsystematic trend to decrease cultivated lands, more dependent on agricultural lands input into industrial production, road facilities, or land allocation for building. Withdrawal of low productive degraded lands from agriculture is often noticed only in remote areas that difficult to access by transport located on the periphery of RF municipal districts or adjacent states. Lands located nearby settlements are cultivated.

Among the post-virgin land regions of the Ural and West Siberia, the most visible reduction of arable lands was in the Republic of Bashkortostan, where their number decreased at 273.4 thousand ha for the mentioned period that corresponded to the withdrawal of 27.3 thousand ha of areas every year. In Omskaya oblast, where periodical flood impoundment of cultivated lands has been noticed for the last years, their growth at 91.2 thousand has been registered by the present time (table 2).

Table 2. The dynamics of cultivated areas in the post-virgin land regions of the Ural and West Siberia, 2010-2020.

| Indicators                      | Cultivated areas, according to the regions (oblasts), thous. ha |
|--------------------------------|---------------------------------------------------------------|
|                                | The total cultivated lands | Wheat | Forage crops |
|                                | Bashkortostan | Omskaya | Novosibirskaya | Omskaya | Altai Kray | Tyumenskaya |
| 2010                           | 3142.3        | 2787.7   | 1173.6         | 1448.5  | 1053.4     | 320.5      |
| 2011                           | 3103.4        | 2844.6   | 1214.0         | 1460.6  | 1130.3     | 299.5      |
| 2012                           | 3052.9        | 2881.2   | 1099.4         | 1432.1  | 1123.7     | 299.2      |
| 2013                           | 3115.5        | 2975.4   | 1023.5         | 1561.3  | 1111.5     | 295.9      |
| 2014                           | 3094.9        | 3008.1   | 1031.5         | 1629.7  | 959.9      | 302.5      |
| 2015                           | 3051.9        | 3008.5   | 1060.7         | 1631.6  | 988.5      | 296.5      |
| 2016                           | 3069.3        | 3007.5   | 1099.0         | 1653.7  | 878.0      | 294.0      |
| 2017                           | 3004.1        | 3004.6   | 1075.2         | 1562.9  | 848.2      | 305.2      |
| 2018                           | 2952.8        | 2932.9   | 927.0          | 1399.7  | 828.7      | 323.3      |
| 2019                           | 2979.3        | 2864.1   | 959.9          | 1399.8  | 756.3      | 315.7      |
| 2020                           | 2868.9        | 2878.9   | 1005.2         | 1477.2  | 708.6      | 301.5      |
| Coefficient of variation, %    | 3.1           | 2.7      | 8.0            | 6.3     | 16.0       | 3.3        |
| Average values Lowering (-)    | 3030.4        | 2926.7   | 1060.7         | 1514.2  | 944.3      | 304.9      |
| increase (+), thousand ha in a year | - 27.3       | + 9.1    | - 16.8         | + 2.9   | - 34.5     | - 1.9      |

In other regions, a square of cultivated areas remains relatively stable. The most stable (on years) cultivated area with a variation of 1.1% was noticed in the Kurganskaya oblast. An average of about 1358.2 thousand ha has been allocated for crops every year.

In the examined regions, the most widely-spread field cultures are grain crops traditionally occupying a considerable proportion in the structure of cultivated areas, and wheat occupies the largest squares. It should be noted that cultivated areas under wheat are characterized by dynamism, according to years. The most lowering of cultivated areas under wheat at 168.4 thousand ha was registered in Novosibirskaya oblast at the end of the analyzed period. Their growth at 28.7 thousand ha was in Omskaya oblast. Other regions are characterized by more stability; their variation of the cultivated area under wheat does not exceed 2.7-3.0%.

On this background, a considering reduction of cultivated areas under other crops being an inalienable part of scientifically-grounded crop rotations, form severe risks of further soil degradation and decline of the completeness of BCP realization. The situation with forage crops reducing...
everywhere, but especially intensively in Chelyabinskaya and Altai Kray – in 19.9-34.5 thousand ha annually provokes the unique anxiety.

The detailed analysis of the cultivated area structure showed more than 60% of cultivated areas, but in some regions, for example, in Chelyabinskaya and Kurganskaya oblasts, to 70-80% of sites, were allocated for crops (table 3).

Table 3. The structure of crop cultures in the post-virgin land regions of the Ural and West Siberia, in average for 2010-2020.

| Region          | ***Crops, in total | **Spring wheat | *Winter crops | *Annual grass | *Leguminous plants | *Corn silage |
|-----------------|--------------------|----------------|---------------|---------------|---------------------|-------------|
| Orenburgskaya   | 2681.6             | 1372.2         | 505.8         | 176.0         | 76.5                | 61.3        |
| oblast          | 64.1               | 51.2           | 36.8          | 12.8          | 5.5                 | 4.5         |
| Chelyabinskaya  | 1378.1             | 927.8          | 12.3          | 126.6         | 18.6                | 26.6        |
| oblast          | 70.8               | 67.3           | 1.3           | 13.6          | 2.0                 | 2.9         |
| Kurganskaya     | 1085.5             | 872.6          | 19.8          | 79.2          | 21.3                | 3.9         |
| oblast          | 80.0               | 80.3           | 1.1           | 9.1           | 2.4                 | 0.4         |
| Omskaya         | 1973.7             | 1510.1         | 11.9          | 315.6         | 78.7                | 39.1        |
| oblast          | 67.3               | 76.5           | 0.8           | 20.9          | 5.2                 | 2.6         |
| Novosibirskaya  | 1501.5             | 1035.0         | 45.7          | 271.5         | 47.1                | 42.4        |
| oblast          | 64.1               | 68.9           | 4.4           | 26.2          | 4.5                 | 2.8         |
| Altai Kray      | 3385.2             | 2026.2         | 134.5         | 311.0         | 140.4               | 73.7        |
|                 | 63.4               | 59.8           | 6.6           | 15.3          | 6.9                 | 3.6         |

*** - the numerator – thousand ha, the denominator – a portion in the total cultivated area, %
** - the numerator – thousand ha, the denominator – a portion of cultivated area under crops, %
* - the numerator – thousand ha, the denominator – a portion of cultivated area under spring wheat, %.

It was ascertained that spring wheat, the most frequently defining the total crop productivity, in Orenburgskaya oblast occupies more than a half of cultivated areas. In Alatı Kray, Chelyabinskaya, and Novosibirskaya oblasts, it settles to 60-70% of all arable lands, and in Omskaya and Kurganskaya oblasts – to 80% of cultivated areas under crops.

It should be noted that the preferable predecessor of spring wheat having soil-preserving and the productive effect is winter crops, which occupy the most extensive areas in Orenburgskaya oblast. There during 2010-2020, on average, 505.8 thousand ha of cultivated lands were allocated for winter crops which amounted 36.8% of lands under the spring wheat. In Novosibirskaya oblast and Altai Kray, winter crops occupied 45.7-134.5 thousand ha (4.4-6.6%), and in Chelyabinskaya, Kurganskaya, and Omskaya oblasts, only 11.9-12.3 thousand ha (0.8-1.3%) were allocated for them. Cultivated areas under annual grasses (271.5-315.6 thousand ha) representing 15.3-20.9% of the spring wheat areas were noticed only in Omskaya, Novosibirskaya oblasts, Altai Kray. They are cultivated in considerably fewer areas representing 79.2-176.0 thousand ha or 9.1-12.8% of the lands under spring wheat in other regions. Chelyabinskaya and Kurganskaya oblasts produced leguminous plants (18.6-21.3 thousand ha) less than the other regions – only 2.0-2.4% of the areas under spring wheat. Corn for silage occupied low areas within the analyzed regions, especially in Kurganskaya oblast, where it took up an average of 3.9 thousand ha (0.4%). Perennial grasses have low specific weight – about 3.1-8.0% of the total cultivated area in Kurganskaya, Orenburgskaya, Omskaya, Chelyabinskaya, and Altai Kray.

An analysis of the current structure of crops in the post-virgin land regions of the Ural and West Siberia showed that the cultivation of soil-preserving cultures listed above on incommensurably fewer areas than spaces under spring wheat was a reason for their steady reduction that contradicted agricultural laws.
Simultaneously, areas under soul-exhausting cultures, especially sunflower, have increased. As a result, a ratio of areas under field cultures laying on the base of soil-preserving scientific-explained crop rotations and soil-exhausting “commercial” cultures being a basis of the state food security of spring wheat has changed considerably only for the last 15 years (2006-2020) (figure 2).

![Figure 2](image)

**Figure 2.** A ratio of cultivated areas of separate field cultures and wheat in the model post-virgin land regions of the Ural and West Siberia in the dynamics of five-year periods (I,II,III), 2006-2020.

It should be noted that the situation formed in agriculture of the post-virgin land regions of the Urals and West Siberia was typical for the whole field crop cultivation of Russia. Thus, from 2006 to 2010, cultivated areas of perennial and annual grasses worldwide within the Russian Federation have been 45.9% and 17.4% from the fields under spring wheat, and sunflower – 23.9%.

A ratio of cultivated areas under perennial and annual grasses has descended step-by-step for 2011-2015. It was 34.0% and 13.8%, relative to the planted areas under wheat, and the percentage of sunflower has increased to 29.1%.

Among model post-virgin land regions of the Ural and West Siberia, Orenburgskaya oblast was characterized by the most lowering of cultivated areas under perennial and annual grasses relatively arable lands under wheat – at 5.1 p.p and 1.8 p.p, respectively. This region showed the most active expansion of fields with sunflower. From 2006 to 2020, sunflower areas have increased from 28.8% to 53.3% (almost at two times) relative to cultivated areas under spring wheat. In Altai Kray, a change of the cultivated areas under the mentioned cultures had almost such character. In our opinion, it became a considerable obstacle for better realization of bioclimatic potential in productivity of field cultures and the principal barrier to control soil degradation.

Correlated-regression analysis of cultivated areas under different field cultures, their proportion in the structure of crops, and the productivity of spring wheat entirely confirmed our estimates (table 4).

A stable trend of lowering spring wheat productivity under the increase of sunflower fields was revealed in Orenburgskaya, Novosibirskaya oblasts, and Altai Kray. The mentioned parameters are connected the closest, with the coefficient of correlation 0.41, in Novosibirskaya oblast, where used planting acreage of crops was the most limiting factor realizing the yield potential of spring wheat (r = -0.58). A similar reverse average relation of spring wheat productivity and the total planting area under crops was noticed in the agriculture of Chelyabinskaya, Omskaya, and Kurganskaya oblasts.

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Table 4. Correlation of spring wheat productivity and the cultivated area (a portion of participation in the crops structure) of separate field cultures, an average data for 2010-2020.

| Region          | Cultures         | Direct correlation | Revers correlation | Coefficient of correlation (r) | Coefficient of correlation (r) |
|-----------------|------------------|--------------------|--------------------|--------------------------------|--------------------------------|
| Orenburgskaya oblast | annual grasses  | 0.32               | sunflower          | 0.32                           | -0.32                          |
|                 | forage           | 0.36               |                    |                                |                                |
| Chelyabinskaya oblast | annual grasses | 0.47               | crops, on the whole | 0.47                           | -0.34                          |
| Kurganskaya oblast | annual grasses  | 0.63               | crops, on the whole | 0.63                           | -0.44                          |
|                 | forage           | 0.47               |                    |                                |                                |
|                 | winter crops     | 0.36               |                    |                                |                                |
|                 | sunflower        | 0.21               |                    |                                |                                |
| Omskaya oblast  | winter crops     | 0.58               | leguminous plants  | 0.58                           | -0.34                          |
|                 | leguminous plants| 0.55               |                    |                                |                                |
| Novosibirskaya oblast | leguminous plants | 0.52               | crops, on the whole | 0.52                           | -0.58                          |
|                 | winter crops     | 0.36               | sunflower          | 0.36                           | -0.41                          |
| Altai Kray      | winter crops     | 0.60               | sunflower          | 0.60                           | -0.31                          |
|                 | leguminous plants| 0.60               |                    |                                |                                |

Directly correlated dependence of spring wheat productivity on a ratio of annual grasses in the structure of cultivated lands (r = 0.32-0.63) was seen in Orenburgskaya, Kurganskaya, and Chelyabinskaya oblasts, forage planting acreage (r = 0.36-0.47) in Orenburgskaya and Kurganskaya oblasts.

Direct average correlated dependence (r = 0.36-0.60) of spring wheat productivity on a portion of winter crops and leguminous plants in the structure of planting acreage was revealed in Kurganskaya, Omskaya, Novosibirskaya oblasts, and in Altai Kray.

In Kurganskaya oblast, where cultivated areas under crops reached 80%, from which 4/5 of square allotted to spring wheat, even expansion of sunflower areas as arable crop, had a positive trend increasing spring wheat productivity.

4. Conclusion

In the post-virgin land regions of Ural and West Siberia, under the practiced technologies in agriculture, the low level of BCP realization characterized by defining spatial peculiarities was noticed. Under the most economic grain productivity (1.51 t/ha) in Kurganskaya oblast, BCP realization (31.3%) was lower at 1.7-3.4-5.9 percentage points than under the lower productivity in Omskaya, Orenburgskaya oblasts, and Altai Kray. In the condition of current climatic and anthropogenic changes, the post-virgin land regions of Ural (Orenburgskaya and Kurganskaya oblasts) are characterized by the enormous swing of the variability of crop productivity in comparison with the areas of West Siberia (Omskaya oblast and Altai Kray).

The most visible reduction of cultivated areas has happened in the Republic of Bashkortostan (at 273.4 thousand ha), and the most growth – in Omskaya oblast (at 91.2 thousand ha). The rest regions show relatively stable squares of cultivated areas.

Saturation of cultivated areas to 60% or more by grain and an increase of planting acreage under "commercial" cultures on the background of a considerable reduction of agro-technically significant cultures exacerbate risks of further soil degradation lowering completeness of BCP realization in any studied region.

In light of the current situation, modernization of zonal landscape-adaptive agriculture systems could be an effective lever to stabilize crop productivity and realize BCP more completely. The
modernization should be directed to optimize the cultivated areas' structure, supply species diversity of field cultures, especially having soil-preserving and soil-recovering effect (perennial and annual grasses, forage plants for green mass, leguminous plants, etc.). In Kurganskaya oblast, where corn saturation reaches 80.0%, of which 4/5 is allocated for spring wheat, even the growth of cultivated areas under sunflower, as arable crop, has a positive trend increasing spring wheat productivity. Scientifically-grounded expansion of frost- and drought-resistant varieties of winter crops can increase spring wheat productivity in Omskaya, Novosibirskaya oblasts, and Altai Kray.

Maintenance of technological discipline, a departure from monocultures, renewal of scientifically-grounded crop rotations, and competent agronomic support of the entire technical process are significant under current natural and anthropogenic transformations.

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