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Research Article

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The Impact of Variables on the Yield of Cereal and Leguminous Crops

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ABSTRACT.

Objective. Currently, using forecasting is among the most prospective and challenging areas of research. The study of the relationship between factors affecting crop productivity and the yield of cereal and leguminous crops allows researchers to make proposals for enhancing crop potential.

Methods. The study examines one of the ways to forecast the yield of cereal and leguminous crops based on neural network training. Neural networks facilitate training based on the results of previous years, while making it possible to use the trained network for forecasting purposes in compliance with the poorly formalized legislation, when no specific function or law can describe the results.

Results. The study presents five tables showing changes in crop productivity by region that depend on variations in parameters. The results of the research revealed promising directions of agricultural development in the districts under investigation.

Conclusion. Crop forecasting resulted in a number of conclusions related to the studied areas and in a list of recommendations to improve crop productivity in areas where it is feasible technologically.

Keywords: cereal, neural network, forecasting, food, crop productivity.

INTRODUCTION

Food security is based on the idea that it exists when all people always have physical, social and economic access to adequate quantities of safe and nutritional food supplies in order to satisfy their dietary needs and food preferences for an active and healthy life. Food security is based on the following four principles: availability, access, utilization and stability. Another integral part of food security is the nutritional value of food [1].

Food security in the Russian Federation is a condition in national economics related to Russia's food sovereignty and every Russian citizen's physical and economic access to food that meets Russian legislative requirements on technical regulation in amounts not less than rational norms of food intake necessary for an active and healthy lifestyle [2].

The notion of food security came into common use internationally when extreme weather conditions had badly affected global agrarian production in the early 1970s. A twofold reduction of world cereal stocks caused food shortage, a global increase in food prices and higher inflation, which severely affected food provision on a global scale. At the plenary meeting of the United Nations General Assembly of 17 December 1973, it was decided to hold the first World Food Conference under the auspices of the UN. Governments who attended the 1974 World Food Conference adopted the Universal Declaration on the Eradication of Hunger and Malnutrition, which considered food security in terms of food availability.

The following definition was proposed during the above-mentioned conference: “Availability at all times of adequate world food supplies of basic food stuffs to sustain a steady expansion of food consumption and to offset fluctuations in production and prices” [3].

Food security is directly related to cereal and leguminous crops due to their cheap production per one kcal, with which these crops are capable of providing people to ensure their livelihoods.

The Food and Agriculture Organization of the United Nations used the following seven-point methodological framework to deal with food security issues [4]:

1. The ratio between world cereal stocks and world consumption is used to determine the level of food insecurity and guarantees in case of emergencies. The normal level is 17%, which means that cereal stocks must correspond to the amounts necessary for 60-day consumption.
2. The ratio between exporters’ supplies and the total cereal requirement.
3. Carryover storage of cereal (total amount and by species) for consumption and forage in the exporting countries as a percentage of domestic consumption
4. Trends in cereal production (annual increase over the past decade/the past year)
5. Changes in cereal production in cereal importing developing countries
6. Trends in cereal production in cereal importing developing countries
7. Average annual export prices by type of cereal

“Carryover cereal stocks refer to winter cereal stocks set up by natural and legal persons in various regions of the Russian Federation, where winter cereals are harvested during optimal periods of crop input or between or during the short period between harvest and crop input.

Carryover cereal stocks are used in the year following the seed harvesting year…” [5].

According to statistical data for 2016, the followings Russian oblasts are the leading cereal and legume producers in each federal district [6]:

1. Voronezh Oblast (Central Federal District, CFD)
2. Kaliningrad Oblast (Northwestern Federal District, NFD)
3. Krasnodar Krai (Southern Federal District, SFD)
4. Stavropol Krai (North Caucasian Federal District, NCFD)
5. Saratov Oblast (Volga Federal District, VFD)
6. Chelyabinsk Oblast (Ural Federal District, UFD)
7. Altai Krai (Siberian Federal District, SiFD)
8. Amur Oblast (Far Eastern Federal District, FEFD)

	2010	2011	2012	2013	2014	2015	2016	Position in the RF
Voronezh Oblast (CFD)	854.2	3047.5	3111.3	3814.6	4472.7	4253.7	4817.3	5
Kaliningrad Oblast (NFD)	186.3	156.5	222.1	331.9	429.2	554.8	399.9	43
Krasnodar Krai (SFD)	9942.6	11454.6	8839.2	12037.6	12870.8	13710.6	13979.0	1
Stavropol Krai (NCFD)	6869.6	8186.0	4839.5	6962.0	8555.8	8928.5	10249.9	3
Saratov Oblast (VFD)	1032.3	2065.8	2203.1	3192.0	3682.6	2212.9	4258.6	8
Chelyabinsk Oblast (UFD)	691.8	2218.9	688.7	1031.4	1139.5	1697.9	1947.7	20
Altai Krai (SiFD)	4240.8	3919.5	2516.8	4926.1	3294.9	3940.4	4829.7	4

Amur Oblast (FEFD)	130.4	338.2	271.4	172.3	417.7	351.0	474.7	41

Table 1. Gross cereal production in Russia's federal districts in 2016 [6]

METHODS

When analyzing food security, most researchers compare the quantity of products, carryover stocks included, with the quantity of products consumed in this or that region [7-15]. This method, however, is inappropriate for crop forecasting due to many factors affecting the overall results and to the absence of appropriate legislation.

An analysis of factors affecting crop productivity in the above-mentioned districts is necessary to determine prospective directions of agricultural development in these districts, which can improve efficiency in the agricultural sector. Due to the lack of official legislation and to the large amount of date, the most effective analytical tool may be a neural network.

A neural network or artificial neural networks (ANNs) are computing systems of interconnected and interacting processors or artificial neurons. As a rule, such processors are relatively user-friendly, especially compared to processors used in personal computers. Inside a network, each processor deals only with occasionally received signals and with signal that it transmits to other processors. Nonetheless, these processors are connected to a rather big, controllable system, which makes them capable of tackling challenging tasks, given that neural networks can be trained during operation [16].

The potential of neural networks in today's world are limited only by human capabilities. On a practical level, the most noteworthy aspects of neural networks are the following [17]:

1. Flexible structure for the rapid establishment of computational circuits that meet the requirements of the modelled subject area
2. Availability of algorithms that any computer can use to train a neural network. This is what makes neural networks ideal for various complicated tasks, such as forecasting, classification and diagnostic testing.
3. Ability to automatically filter uninformative, excessive and noise signals.
4. Ability to process a large amount of informal data.
5. Neural networks can handle tasks that specialists cannot handle or handle insufficiently well, assuming such a specialist exists at all. A trained network can further be represented as a straightforward algorithm, which would provide solutions, for instance, as a set of rules ('if…then…'). Furthermore, people can acquire new knowledge by studying this algorithm.

The range of tasks handled by neural networks is very broad, because the choice of neural network algorithms and technologies is so too.

Any use of a neural network starts with its training based on a large number of examples with well-known outcomes. Therefore, the first step is to establish its structure.

The following fourteen parameters have been selected as illustrative of input data:

x1 – average annual temperature (°C) [18]

x2 – lowest monthly temperature per year (°C)

x3 – highest monthly temperature per year (°C)

x4 – difference between the average minimum and maximum monthly temperature per year (°C)

x5 – application of mineral fertilizers per 1 hectare of crop fields in agricultural organizations, in kilograms per 100% of nutrients [6].

x6 – application of organic fertilizers per 1 hectare of crop fields in agricultural organizations, in tons [6].

x7 – average annual rainfall, in mm [18].

x8 – average low rainfall by month, in mm.

x9 – average high rainfall by month, in mm.

x10 – air pollutant emissions from stationary sources, in thousands tons [6].

x11 – discharges of polluted waste water into surface water bodies, in million cubic meters [6].

x12 – fixed investments: agriculture, hunting and forestry, excluding small business entities, in million rubles [6].
x13 – number of agricultural, hunting and forestry enterprises and organizations at the year-end [6].
x14 – amount of losses suffered by agricultural, hunting and forestry organizations at the year-end, in million rubles [6].
d1 – yield of cereal and leguminous crops (in weight after processing), in all types of commercial farm units, in hundred kilograms per hectare harvested [6].

The Neurosimulator 2, presented in the elective course by L. Yasnitsky and F. Cherepanov, was chosen as a software/hardware system for forecasting cereal productivity [19, 20].
A series of test trainings revealed that a neural network with three hidden layers composed of 10, 6 and 3 neurons respectively recorded the least number of errors in training. Using the neural network for forecasting purposes will always show the same result, namely, the yield of cereal and leguminous crops in hundred kilograms per hectare.

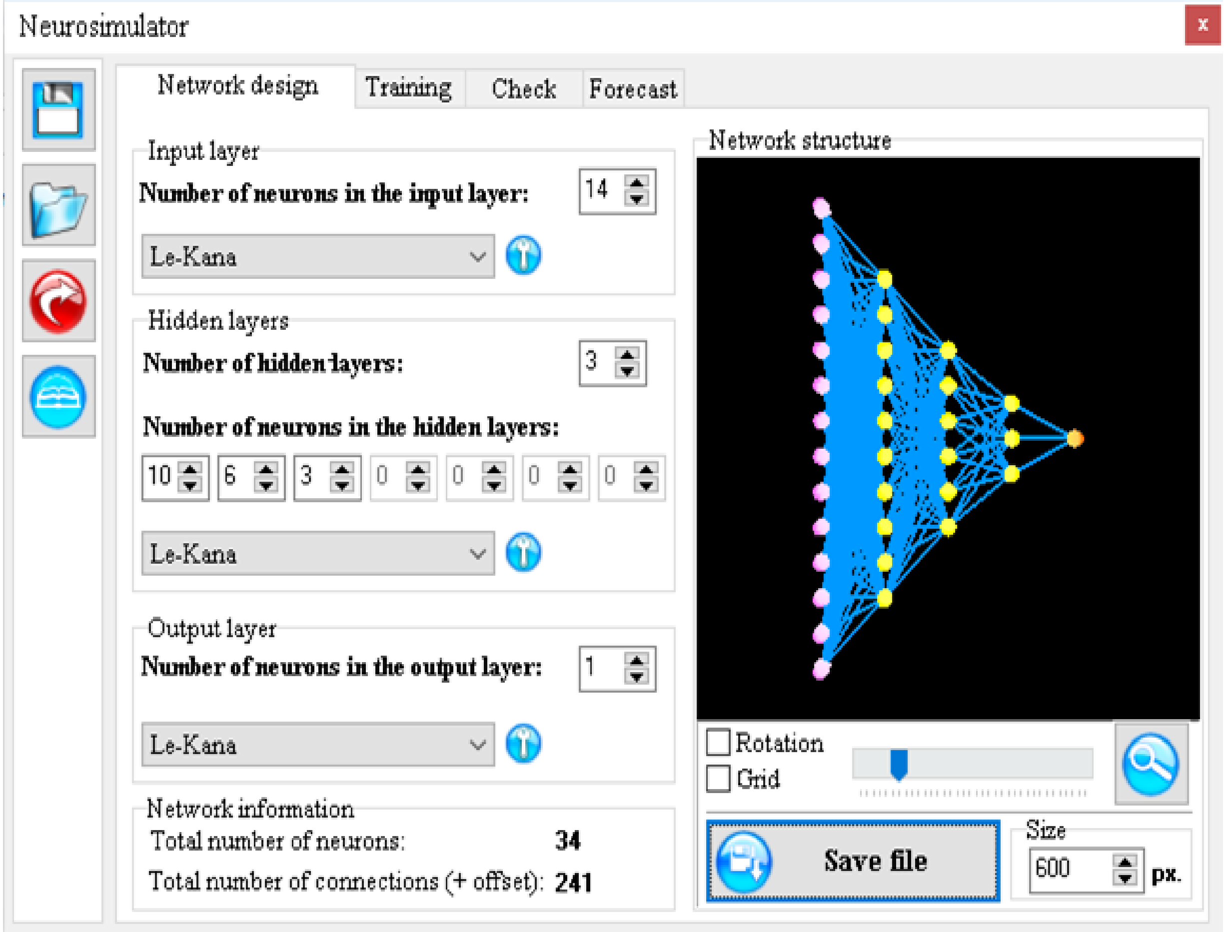

Figure 1. Neural network settings

The neural network's training showed some of the data to be erroneous up to 1795%. Accordingly, it was decided to exclude from training examples the data producing erroneous results, which included data on Amur Krai, Chelyabinsk and Kaliningrad Oblasts.
Data on all oblasts for 2010 were also entirely removed. The final verification of the neural network's training results revealed the maximum error to be 0.05%.

Year	Oblast	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11	x12	x13	x14	x15	x16	d1
2016	Voronezh Oblast	10.85	-8	22.6	30.6	75.8	3.1	68.14	33.4	163.6	73	122	32230.2	1748	1421	371.4	181.5	4817.3
	Kaliningrad Oblast	10.44	-4	18.8	22.8	106.9	3.6	56.61	23.5	128.9	21	111	3374.7	1316	104	922	1839	399.9
	Krasnodar Krai	15.92	0.2	27.2	27	127.1	0.8	64.54	25.6	176.1	242	901	5755.1	4790	2220	1775.3	2114.2	13979
	Stavropol Krai	12.73	-3.2	24.3	27.5	87.7	3.9	56.48	15.9	108.2	88	125	32230.2	5521	803	254.1	82.4	10249.9
	Saratov Oblast	11.15	-9.4	24.7	34.1	8.5	0.2	49.71	8.3	100.1	110	13	4364.6	1789	491	300.2	81.2	4258.6
	Chelyabinsk Oblast	7.35	-17.8	22.5	40.3	6	0.7	40.27	16.1	57.6	597	693	4146.4	1816	831	116.5	95.8	1947.7
	Altai Krai	6.74	-18.1	20.7	38.8	11.7	0.3	40.73	9.5	116.7	213	868	4976.1	2338	1108	184.1	59.2	4829.7
	Amur Oblast	5.61	-19.3	22.2	41.5	21.1	0.1	52.76	1.5	121.9	135	818	2966.7	713	298	100.4	37.4	474.7
2015	Voronezh Oblast	8.72	-4.7	21	25.7	71.3	2.8	43.91	4.2	72.2	69	117	17180.2	1788	1421	414	151.4	4253.7
	Kaliningrad Oblast	9.2	1.2	19.5	18.3	102	4	59.16	13.7	132.8	20	107	1852.6	1292	104	932	2008.3	554.8
	Krasnodar Krai	13.8	2.1	26.3	24.2	118.2	0.9	66.45	8.5	144.7	191	858	20196.7	5051	2220	1515.4	2541.4	13710.6
	Stavropol Krai	10.64	-1.7	23.4	25.1	82.5	3.5	44.04	14.6	102.7	85	123	12576.6	11582	803	298.4	82.8	8928.5
	Saratov Oblast	8.3	-8.6	23.8	32.4	6.1	0.2	38.56	3.3	118.9	118	13	3314.6	1875	491	307	89.3	2212.9
	Chelyabinsk Oblast	4.15	-13	21.7	34.7	5.1	0.5	34.3	6.6	84.4	627	725	6521.8	1964	831	153	97.1	1697.9
	Altai Krai	4.15	-12.7	20.3	33	6.8	0.2	39.18	16.2	63.6	204	908	4094.7	2424	1108	145.2	49.7	3940.4
	Amur Oblast	3.05	-17.9	22.5	40.4	18.9	0.1	32.8	1.3	84.9	127	811	2913.7	740	298	93.1	42.4	351
2014	Voronezh Oblast	7.96	-8.6	22.3	30.9	67.1	2.6	34.95	2	99.8	68	122	15312.2	2029	1421	419.8	183.5	4472.7
	Kaliningrad Oblast	9	-3.8	20.9	24.7	118.4	3.2	53.99	11.3	114	19	103	3048.3	1295	104	1137.8	2871.8	429.2
	Krasnodar Krai	13.3	0.9	27.1	26.2	116.5	1.2	54.9	0	129.4	189	833	20123.6	5153	2220	2319.8	2766	12870.8
	Stavropol Krai	9.98	-3.1	24.7	27.8	79.9	3.2	51.9	15.5	135	79	132	11999.6	11614	803	353.1	148.4	8555.8
	Saratov Oblast	7.1	-8.9	23	31.9	5.2	0.2	31.36	3.9	73.5	120	17	3666.8	1922	491	326.5	105.6	3682.6
	Chelyabinsk Oblast	3.38	-16.2	19.7	35.9	4.7	0.5	33.29	8.8	122.8	653	679	11896.1	2029	831	165.3	161.5	1139.5
	Altai Krai	2.35	-18.9	20.1	39	5	0.2	44.89	11.4	107.6	203	827	5363.5	2646	1108	147.6	57.2	3294.9

	Amur Oblast	2.32	-23	22	45	21.3	0.02	32.56	0.5	106.4	132	812	1505.8	738	298	9.8	39.6	417.7
2013	Voronezh Oblast	8.35	-5.5	21.2	26.7	64	2.4	49.225	12.1	129.5	76	129	15725.5	2116	2831	575.3	365.5	3814.6
	Kaliningrad Oblast	8.22	-4.5	18.2	22.7	129.3	2.9	66.16	16.2	152.5	21	102	1927.1	3129	960	566	7787.4	331.9
	Krasnodar Krai	13.76	0.8	25.3	24.5	108.8	1.1	58.1	17.1	106.6	205	839	16146.4	5399	3148	3950.7	3889.3	12037.6
	Stavropol Krai	10.61	-2.4	22.3	24.7	73.5	2.6	54.36	5.9	134.1	75	133	9512.1	13338	431	634.2	584.9	6962
	Saratov Oblast	7.98	-8.3	21.4	29.7	4.8	0.2	45.36	8.7	141	99	84	4120.4	2063	834	1572.1	485.9	3192
	Chelyabinsk Oblast	4.3	-15.6	20.2	35.8	3.9	0.3	40.45	10.4	166.6	667	713	9922.4	2170	875	4110.7	1656.3	1031.4
	Altai Krai	3.5	-14.1	19.2	33.3	4.2	0.3	41.73	13.9	99.4	201	770	5483.1	2756	325	191.8	238.7	4926.1
	Amur Oblast	1.6	-24.2	21.8	46	28.4	0	68.61	8.2	231.4	125	785	2894.7	752	386	158.2	283.4	172.3
2012	Voronezh Oblast	7.7	-12.1	22.1	34.2	61.4	2.5	69.1	21.1	185.5	79	131	20358.8	2205	2831	410	247	3111.3
	Kaliningrad Oblast	7.7	-6	18.6	24.6	134.1	3.2	86.53	17.5	196.5	25	103	1524.1	3228	233	504	2426	222.1
	Krasnodar Krai	13.34	-5.1	25.8	30.9	109.1	1	47.8	3.5	83.4	216	892	5260.5	10929	3148	1671	2394	8839.2
	Stavropol Krai	10.13	-9	22.6	31.6	77	3.1	39.31	8.4	95.6	69	131	8799	13439	431	232	116	4839.5
	Saratov Oblast	7.74	-14.5	23.9	38.4	4	0.2	43.67	6.3	94.8	128	112	4032.7	2213	834	262	156	2203.1
	Chelyabinsk Oblast	3.94	-19.1	23.5	42.6	4.3	0.4	23.45	2.7	51.8	678	744	6436	2212	875	97.5	121	688.7
	Altai Krai	1.77	-24.3	22.1	46.4	3.8	0.2	33.3	0.2	97.1	216	860	5301.6	2877	325	123	23.6	2516.8
	Amur Oblast	1.23	-25.2	22.6	47.8	23.4	0	53.65	0	211.5	127	752	1620.7	777	386	20.1	26.5	271.4
2011	Voronezh Oblast	7.06	-11.8	23.7	35.5	66.9	1.7	38.4	14	97.3	72	135	10582	2431	515	228.9	174	3047.5
	Kaliningrad Oblast	8.45	-5.4	18.5	23.9	145.4	2.9	70.9	4.3	214.3	25	91	1243.9	3328	234	384.4	2225.8	156.5
	Krasnodar Krai	11.82	-1.3	27.1	28.4	106.6	1.7	66.38	3.1	137.7	161	920	18706	11523	3516	1184.4	2631.1	11454.6
	Stavropol Krai	8.73	-5.8	24.5	30.3	76.7	2.9	46.65	13.6	106.9	68	138	8429.2	13579	803	249.4	110.1	8186
	Saratov Oblast	3.45	-4.3	-2.6	1.7	3.9	0.3	40.85	31.1	50.6	109	18	2789.3	2507	347	107.4	176	2065.8
	Chelyabinsk Oblast	2.1	-19.9	20.6	40.5	7.1	0.2	36.9	4.5	108	694	836	5843.3	2373	491	38.2	125.3	2218.9
	Altai Krai	2.12	-24.1	20.2	44.3	3.8	0.2	26.25	4	42.4	204	860	7850.1	3191	146	99.5	42.1	3919.5

	Amur Oblast	2.52	-20.6	23.9	44.5	20.1	0	37.79	0	143.5	134	755	2047.6	873	249	0.7	27	338.2
2010	Voronezh Oblast	8.69	-14.8	26.4	41.2	75.1	2.1	49.24	29.1	114.6	77	134	5604.9	2596	2831	84.5	157.3	854.2
	Kaliningrad Oblast	6.91	-8.1	21.2	29.3	133.1	3.7	66.25	26.2	124.2	29	88	758	3346	233	268.5	1972.8	186.3
	Krasnodar Krai	14.35	0.1	27.7	27.6	99.5	0.9	63.81	17.6	106.6	139	863	15701.2	12230	3148	929.6	2066.4	9942.6
	Stavropol Krai	11.68	-3.7	25.7	29.4	68.3	2.9	46.95	4.5	93.7	66	144	6861.8	14143	431	98.3	97.2	6869.6
	Saratov Oblast				0	4.9	0.3				95	24	2310.8	2971	834	63.6	171	1032.3
	Chelyabinsk Oblast	3.55	-21.1	22	43.1	7.1	0.3	26.38	2.8	95	749	845	4719.4	2574	875	53.7	155.8	691.8
	Altai Krai	2.06	-25.8	18	43.8	2.9	0.2	36.4	6	119.7	207	859	5115.1	3654	325	62.4	152.8	4240.8
	Amur Oblast	1.7	-20.9	23.3	44.2	18.8	0	55.85	4.4	265.2	119	719	1004.4	951	386	0.8	26.6	130.4

Table 2. Summary of the neural network's training results

RESULTS

The study used data by oblast for 2016 for forecasting purposes. The following example will enable a better understanding of the data provided in Tables 3 to 7. For instance, the average annual temperature in Krasnodar Krai (x1) is 15.92 degrees Celsius. If average annual temperature decreases by 10% or 20%, the yield of cereal and leguminous crops will decline by 2.65% or 7.56% respectively. If average annual temperature increases by 10% or 20%, the yield of cereal and leguminous crops will grow by 1.35% or 2.04% respectively. The remaining results are presented on a similar basis.

Varying parameters	Neural network forecast													
	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11	x12	x13	x14
-20%	-7.56%	0.06%	-8.32%	2.73%	0.36%	2.13%	4.34%	-0.62%	0.80%	-15.72%	4.00%	-0.80%	-10.03%	-30.75%
-10%	-2.65%	0.03%	-2.97%	1.71%	0.36%	1.08%	2.89%	-0.30%	0.00%	-5.79%	2.33%	-0.37%	-3.32%	-20.22%
+10%	1.35%	-0.03%	1.59%	-2.83%	-0.73%	-1.07%	-6.95%	0.31%	-1.89%	2.85%	-3.32%	0.31%	1.42%	3.43%
+20%	2.04%	-0.06%	2.67%	-7.08%	-1.82%	-2.10%	-18.15%	0.64%	-4.69%	4.60%	-7.48%	0.57%	1.94%	4.17%

Table 3. Neural network forecasts for Krasnodar Krai with varying parameters

Varying parameters	Neural network forecast													
	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11	x12	x13	x14
-20%	-0.99%	0.47%	0.17%	7.03%	-3.45%	1.35%	-2.98%	-1.10%	-1.56%	-0.06%	-0.30%	-3.88%	-6.59%	-2.05%
-10%	-0.37%	0.24%	0.18%	3.81%	-1.59%	0.98%	-1.24%	-0.52%	-0.64%	0.01%	-0.15%	-1.77%	-3.03%	-0.99%
+10%	0.18%	-0.24%	-0.36%	-4.44%	1.34%	-1.43%	0.83%	0.46%	0.38%	-0.09%	0.14%	1.49%	2.50%	0.92%
+20%	0.21%	-0.49%	-0.88%	-9.50%	2.45%	-3.19%	1.32%	0.86%	0.53%	-0.26%	0.27%	2.73%	4.51%	1.77%

Table 4. Neural network forecasts for Stavropol Krai with varying parameters

Varying parameters	Neural network forecast													
	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11	x12	x13	x14
-20%	-48.25%	2.51%	-10.14%	3.71%	-9.47%	-5.55%	-3.72%	-2.09%	6.81%	-6.00%	-2.14%	3.45%	-0.51%	2.16%
-10%	-28.36%	1.34%	-5.03%	2.10%	-4.55%	-2.63%	-1.82%	-1.02%	3.67%	-3.02%	-1.06%	2.39%	-0.24%	1.12%
+10%	34.15%	-1.38%	5.42%	-2.51%	4.23%	2.39%	1.61%	0.99%	-3.96%	3.08%	1.07%	-3.46%	0.25%	-1.15%
+20%	69.03%	-2.95%	11.55%	-5.41%	8.13%	4.53%	2.83%	1.91%	-8.06%	6.18%	2.11%	-7.76%	0.47%	-2.35%

Table 5. Neural network forecasts for Voronezh Oblast with varying parameters

Varying parameters	Neural network forecast													
	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11	x12	x13	x14
-20%	-16.64%	8.30%	-8.29%	-29.79%	-6.07%	0.59%	12.08%	-2.61%	39.48%	33.08%	-1.03%	-4.78%	0.87%	1.92%

-10%	-8.59%	4.29%	-2.35%	-12.90%	-3.05%	0.30%	8.77%	-1.56%	18.88%	19.66%	-0.52%	-2.45%	0.49%	0.94%
+10%	9.33%	-4.51%	-1.57%	6.75%	3.09%	-0.30%	-11.85%	1.92%	-16.03%	-19.97%	0.52%	2.57%	-0.58%	-0.93%
+20%	19.40%	-9.20%	-6.43%	7.93%	6.21%	-0.61%	-24.24%	3.97%	-28.58%	-36.87%	1.04%	5.25%	-1.27%	-1.88%

Table 6. Neural network forecasts for Saratov Oblast with varying parameters

Varying parameters	Neural network forecast													
	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11	x12	x13	x14
-20%	-14.29%	-17.65%	37.50%	11.81%	-6.00%	1.55%	-29.32%	11.78%	65.42%	-19.65%	-41.07%	-7.32%	2.40%	3.40%
-10%	-7.48%	-9.95%	16.66%	4.09%	-3.11%	0.75%	-20.98%	5.36%	27.58%	-13.59%	-25.80%	-3.92%	1.14%	1.28%
0	-0.01%	0.00%	-0.03%	-0.03%	-0.03%	-0.03%	-0.03%	-0.03%	-0.03%	-0.03%	-0.03%	-0.03%	-0.03%	-0.03%
+10%	8.18%	11.77%	-11.71%	-0.63%	3.24%	-0.78%	37.86%	-4.34%	-14.97%	18.64%	43.54%	4.36%	-1.16%	-0.38%
+20%	17.11%	24.32%	-19.38%	1.89%	6.66%	-1.52%	82.89%	-7.68%	-20.34%	37.47%	86.86%	9.23%	-2.34%	0.37%

Table 7. Neural network forecasts for Altai Krai with varying parameters

DISCUSSION

1. KrasnodarKrai. Of greatest interest in x14 (amount of losses suffered by agricultural, hunting and forestry organizations at the year-end, in million rubles). If the amount of losses suffered by these organizations decreases by 10% and 20%, the yield of cereal crops decreases by 20.22% and 30.75% respectively. At first glance, these results point to a training error and imply that the results obtained cannot be trusted. Such strange indicators can be accounted for by the fact that training of the neural network focused on good and bad crop years. Many sources report that, in good crop years, organizations suffer increased losses due to a sharp drop in agricultural output prices [21-24].

This does not appear to be the case in other oblasts due to Krasnodar Krai's emphasis on agriculture, as evidenced by x10 (air pollutant emissions from stationary sources, in thousands tons). Krasnodar Krai's economy is directly related to the agricultural sector, and the more crop productivity decreases, the more air pollutant emissions from farm enterprises increase.

The same goes for x13 (number of agricultural, hunting and forestry enterprises and organizations at the year-end): if the number of these enterprises decreases by 20%, there is a 10.03% decrease in crop productivity. In conclusion, Krasnodar Krai is predominantly agricultural and cereal producers need government support to protect their interests on the market, especially in good crop years.

2. Stavropol Krai. Varying parameters barely affected this region's stability. The biggest changes take place in x4 (difference between the average minimum and maximum monthly temperature per year, °C). Local crop productivity decreases by 9.5% if the difference between the average minimum and maximum monthly temperature increases by 20%. This suggests that Stavropol Krai has optimal temperature conditions for cereal cultivation, which are even better than those in Krasnodar Krai.

Much of Stavropol Krai occupies the Stavropol Upland and, further to the east, the Terek-Kuma Lowland, also known as the Nogai Steppe. The Stavropol Upland is bounded by the Kuma-Manych Depression in the north, and the region of the Caucasian Mineral Waters is located in the Caucasian Foothills with igneous mountains or laccoliths rising to up to 1401 m (Mount Beshtau). The highest point of Stavropol Krai is 1603 m above sea level. The climate is moderate continental, with average temperatures in January and July being −5 °C (up to −10 °C in the mountains) and +22 to +25 °C (up to +14 °C in the mountains) respectively. Annual precipitation on the plain ranges from 300 to 500 mm and is above 600 m in the foothills. The length of the growing season is 180 to 185 days [25].

The natural and climatic conditions of Stavropol Krai are ideal for cereal cultivation, but the terrain makes it difficult to grow arable crops.

3. Voronezh Oblast. This region has the least appropriate temperature conditions for cereal cultivation, as evidenced by x1 (average annual temperature, C). In case of a 20% increase of average temperature, the region's crop productivity will reach a record high of 69.03%. Such a high rate is due to other factors that are beneficial for crop yield, but the severity of the climate is a challenge to achieving high rates. Voronezh Oblast has a moderate continental climate, with average temperatures in January and July being −10 °C and +20 °C respectively. Average annual temperature ranges from +5.0 °C in the north to +7 °C in the south of the region. Precipitation varies from 600 mm in the northwest to 450 mm in the southeast [26].

As of now, using varieties of wheat suited to the region's temperatures seems to be the only possible solution for increasing crop productivity.

4. Saratov Oblast. This region is similar to Voronezh Oblast in terms of climate. Excessive precipitation in various months badly affects crop productivity, making it necessary to ensure water removal during the wet season and watering during the dry season. The average number of rainy days per month ranges from 12 to 15.

As far as environmental pollution is concerned, the present-day ecological status of Saratov Oblast is critical, and environmental pollution will continue upwards in step with increased production [27].

Over 400,000 tons of pollutants of varying degrees of hazard are released into air annually. A dramatic increase in the chemical, fuel and petrochemical industries underlie negative impacts on the environment [28].

5. Altai Krai. Currently, Altai Krai has the least amount of precipitation in the regions under consideration. If the average annual precipitation in Altai Krai increases by 20%, crop productivity is likely to grow by 82.89%. Furthermore, a 20% increase in discharges of polluted waste water into surface water bodies (in million cubic meters) will lead to a 20% increase in crop productivity, given that Altai Krai has a considerably developed chemical industry which uses agricultural raw materials.

Chemical, petrochemical, machine building and thermal power plants are among the main polluters of water bodies in Altai Krai.

Among other burning environmental issues are shallowing and pollution of small rivers [29].

CONCLUSION

The development of the agro-industrial sector in Russia should go hand-in-hand with the use of technologies capable of forecasting the results of innovation [30-32].

Their use will avoid poor and unwise investments in areas that will not bring about the desired result in the future. The present study presented promising areas for developing the agro-industrial sector in Russia with emphasis on cereal and leguminous cultivation.

The results of the research can be used to develop programs aimed at increasing crop productivity in the considered regions.

RECOMMENDATIONS

The present study may be relevant to organizations involved in agricultural production, cereal and leguminous cultivation as well as to public authorities and entities working to develop the agro-industrial sector in the regions reviewed.

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