Chapter

The Impact of Global Warming and Climate Change on the Development of Agriculture in the Northern Latitudes of the Eurasian Continent

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Abstract

In the northern regions of the Eurasian continent, an increase in the sum of active temperatures up to 1500–2000 °C degrees is observed, which creates more favorable conditions for growing crops. The study reveals the prerequisites for the development of crop production in the northern latitudes and analyzes the yield of crops according to the Doctrine of Food Security. Also considered the yields of the main crops in the northern countries of Europe. In the south of the European part of the Eurasian continent, a decrease in crop yields is expected due to climate change and severe aridity. At the same time, this process will have a more negligible effect in the central regions. Improving the thermal regime in the North of the Far East will also increase the yield of fruit and berry, and vegetable crops. In the northern part of the circumpolar belt, an improvement in the thermal regime with a relatively insignificant change in climate humidity will create conditions for increasing crops' productivity and growing a more comprehensive range of crops, especially in river valleys.

Keywords: Nordic farming, global warming, climate-smart breeding, food security, Eurasian continent, Northern latitudes

1. Introduction

The history of agriculture is inextricably linked to the account of humanity. Different theories of the origin of farming, although divergent in their views, are united in the fact that "the cultural force of alienation" [1] significantly influenced the development of humanity. And the whole domestication of plants went along the way of concentrating on their various organs, which are consumed for human consumption. The story of agriculture is directly related to the cultivation of plants, landscape, and climatic conditions. Concerning technological innovations in plant cultivation, these technologies appeared and improved in cases where humanity, for various reasons, had to grow plants in unfavorable conditions. Less fertile soils, less light, heat, and other vital factors forced people to improve agricultural practices. Some researchers [2] and [3] rightly note that all four ancient civilizations of the Old World were located in the temperate zone of the Northern Hemisphere in a narrow strip along the thirtieth parallel. The alluvial deposits of the flooding Tigris, Euphrates, Nile, Indus and Yellow River allowed highly developed civilizations entirely dependent on river irrigation.

According to one of the hypotheses of the development of agriculture, the increase in population was its consequence, thanks to which man colonized new lands, settling in different corners of the planet, involving in its use an increasing amount of land resources.

The next round of the industrial revolution led to the widespread use of fossil fuels, in all areas of human activity, including, for the most part, the agro-industrial complex. The result has been a disruption of the natural cycle and balance of greenhouse gases on the planet, resulting in a gradual increase in the average annual temperature of the earth (**Figure 1**). On a planetary scale, this will lead to irreversible consequences, and already all countries of the world are concerned about global warming.

In addition to changes in temperature, humans are applying various mineral fertilizers and crop protection products in large quantities to maintain crop yields. Unfortunately, this also has negative consequences, but for soil fertility in traditional crop-growing regions. **Figures 2** and **3** show the dynamics of demand for mineral fertilizers in the world.

Soil degradation results from the pursuit of profit and squeezing all the nutrients out of the earth in all traditionally agricultural regions. And actively stimulating the soil with nutrients using fertilizer application only worsens the situation because the concentration of fertilizers is so high that the ground is deprived of its top quality - fertility - for many years.

These two reasons make it necessary to look for new land to cultivate and organize agricultural production. The way out of this situation, scientists see in the transfer of agricultural land to the North. For example, researchers at Singapore's Rajaratnam School of International Studies (RSIS), Goh Tian and Jonathan Lassa, point out that the greenhouse effect will make Northern Canada, Russia and the

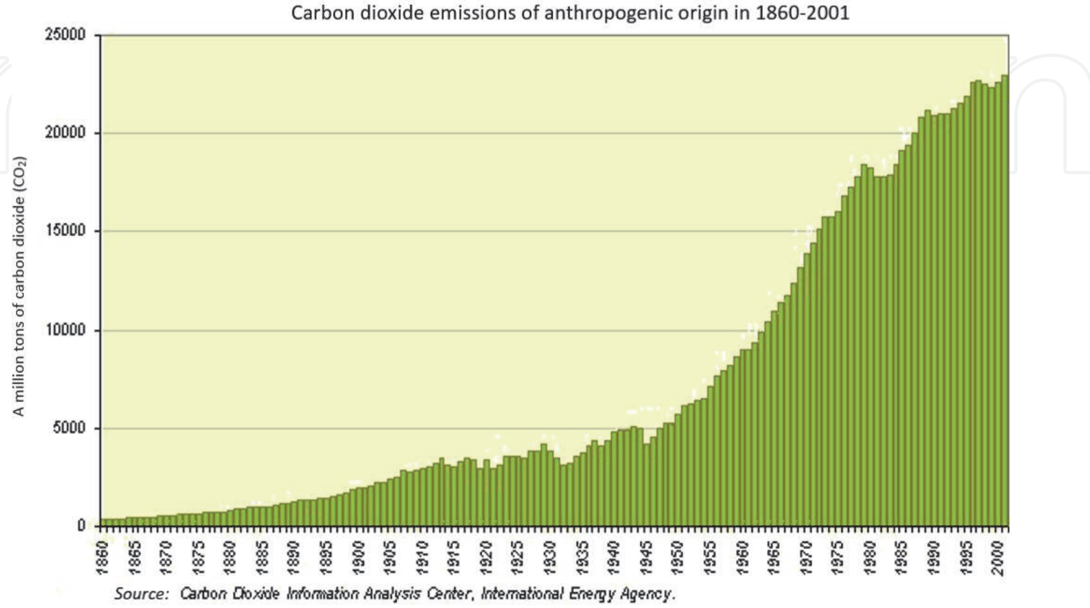

Figure 1.
Change in carbon dioxide emissions from human activities over the past 140 years [http://www.ladoga-lake.ru/pages/artcl-geology-ivashchenko-climat.php].

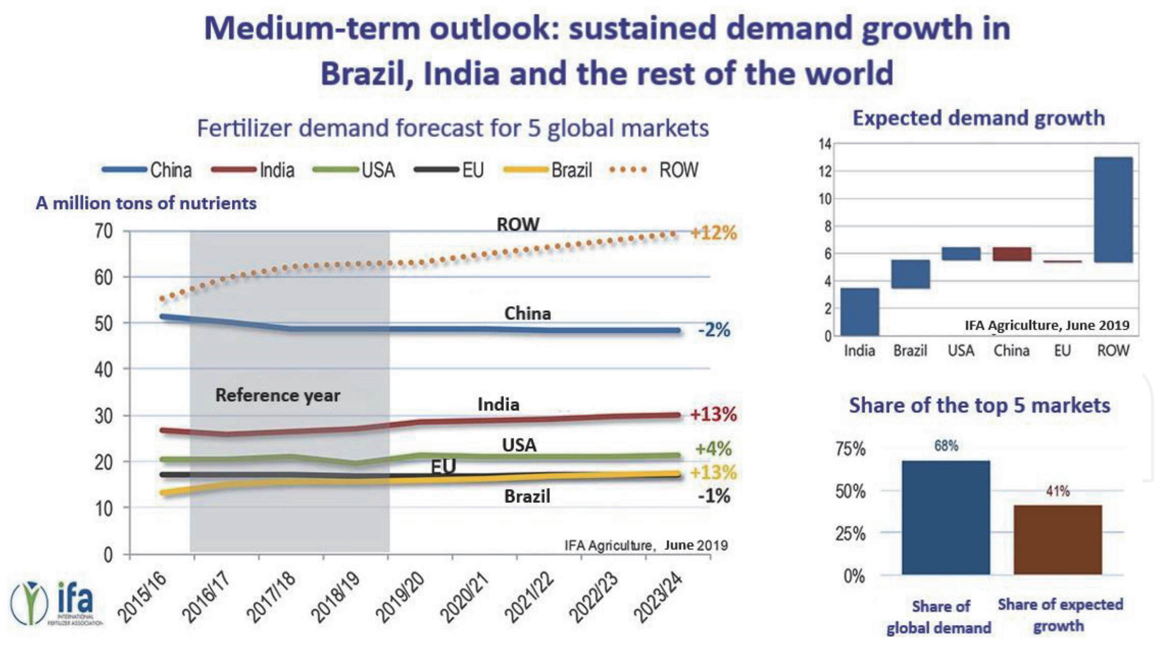

Figure 2.
Fertilizer demand trends in selected countries of the world [https://belchemoil.by/news/tehnologii-i-trendy/trendy-mirovogo-rynka-udobrenij].

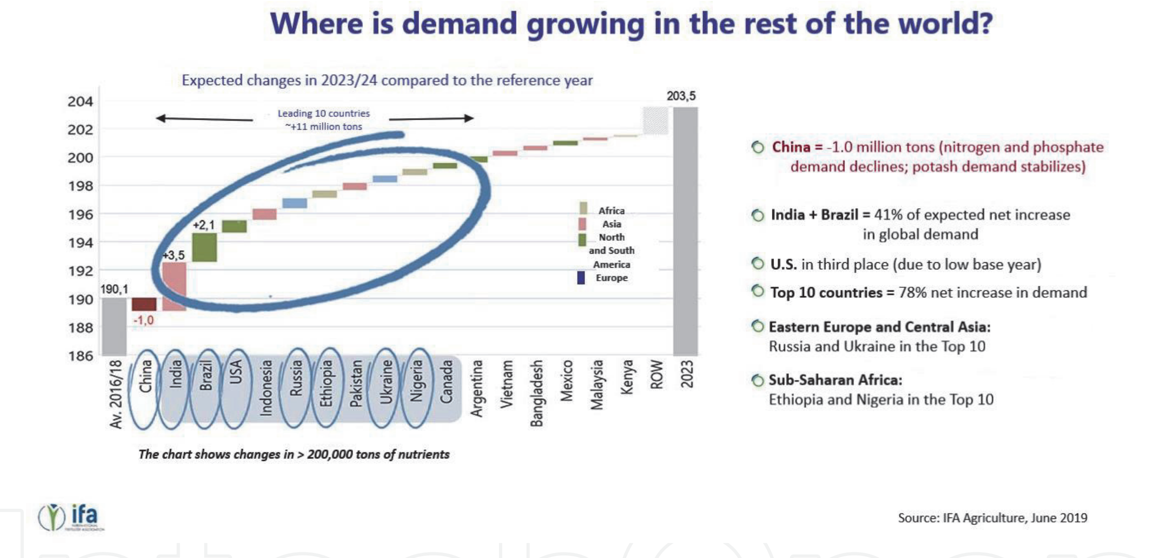

Figure 3.
Expected demand for fertilizers in selected countries of the world [https://belchemoil.by/news/tehnologii-i-trendy/trendy-mirovogo-rynka-udobrenij].

USA, southern Argentina mountainous tropics suitable for farming. "However, favourable conditions for some countries do not guarantee an increase in yields. The winners of climate change will be the countries that can take advantage of the opportunities presented by climate change. Above all, warming will create new regional agricultural centres to replace the old ones and reshape the market for producers - not only between exporters and importers but also between small and large companies" [https://penzanews.ru/analysis/92531-2015].

2. Materials and methods

Climate change has direct implications for the stability of food production systems. The increased frequency and intensity of extreme events, such as droughts and floods, will pose severe threats to the strength of both domestic and global food markets. In addition, the frequency and magnitude of food-deficit emergencies may increase as a result of the complex interaction between political conflict and migration, with increased competition for scarce resources.

One consequence of climate change is the growing scarcity of water resources. Water plays a crucial role in food production, both regionally and globally.

On the one hand, more than 80% of all agricultural land in the world is not irrigated; crop productivity depends on sufficient available moisture in these areas. On the other hand, in areas where this value is limited by climatic conditions, such as the arid and semi-arid regions of the tropics and subtropics and the Mediterranean-type regions in Europe, Australia and South America, agricultural production is very vulnerable to climate change.

On the other hand, global food production depends not only on moisture in precipitation but also on water resources for irrigation. With a warmer climate, the pressure on irrigation systems will increase, which will require additional resources and costs.

Under conditions of global climate change, the risk of competition for water resources increases, especially in regions with inter-boundary rivers and reservoirs, such as Central Asia [4].

In general terms, the adverse effects of global warming on agriculture can be as follows:

- loss of agricultural land fertility through erosion, compaction, desertification, salinization, waterlogging, soil contamination, insufficient mineral content in the soil;
- restructuring of soil biota, reduction of overall land productivity;
- a drop in the yield of cultivated crops due to exposure to high temperatures and dehydration;
- the complete death of plants during wintering;
- deterioration of livestock conditions, thermal stress on animals, leading to reduced productivity;
- lack of water supply, especially in arid areas;
- increased floods and inundations in water-abundant regions;
- the unprecedented spread of traditional crop pests and microorganisms, including in areas where they have not previously been found, the emergence of alien pest species [4].

Rising temperatures are not always uniformly bad; they can lead to increased crop productivity, particularly in the plateaus and high-altitude tropical areas or in northern latitudes where low temperatures limit crop growth.

3. Research results

The research subject is the northern part of the Eurasian continent, which starts from the coast of Norway in the western region and ends with the Kamchatka Peninsula in the eastern part.

The area is limited by the 70th parallel to the North, as further North is the far North where no crops can be grown despite warming. To the south, the 60th parallel.

On the whole Eurasian continent, only a few countries are included in this area: Iceland, Norway, Sweden, Finland and Russia [5, 6]. The main crops cultivated in these countries are shown in **Table 1**.

An important observation of the study is that only livestock production is practised in northern latitudes in all countries other than the Russian Federation. Crop production in northern latitudes is either undeveloped or underdeveloped in these countries. Therefore, further research will focus on the areas of the North of the Russian Federation.

In the context of increasing climate change, Russia, as a country with not only a vast territory but also a variety of different climatic zones, can have a significant impact on global food security, although it, like other regions of the world, will not escape the harmful effects of global warming.

According to many experts, climate change in Russia is already occurring and is often unfavorable for agriculture, the economy and the social sphere.

In studies of climate change across the country, all models without exception show substantial warming of the climate in Russia in the 21st century. Moreover, temperature changes are significantly more significant than the standard deviations throughout the area in question, even during the cold season when intrinsic temperature variability is exceptionally high.

In the scientific literature, various researchers show impressive results in studying the economic impact of climate change on agriculture, especially on the productivity of staple crops (cereals, forage).

Scientists estimated Yield Changes by the IPCC A1F1 Global Development Scenario, which assumes high economic growth with intensive use of fossil fuels. The data obtained were presented by the All-Russian Research Institute of Agricultural Meteorology - RRIAM.

For grain crops in Russia, yields are forecast to fall by up to 17% by 2050. In the Volga and Ural Federal Districts, the decline in grain yields will be catastrophic - by 30% and 38%, respectively. Likewise, the reduction in forage yields will be significant in the Southern and Volga Federal Districts, down 17% and 12%, respectively [5].

Similar conclusions are drawn by international research. In particular, the International Food Policy Research Institute (IFPRI) obtained estimates of yield changes of wheat and some other crops in Russia by 2050, based on which the experts came to several conclusions about the state of agricultural land in the future until 2050

- in the southernmost regions of Russia, a large area may cease to be used for wheat cultivation altogether;
- vast areas of the southwest will face a reduction in yields of more than 25%;
- yield reductions of less than 25% are expected in various areas of southern European Russia, the Southen Urals, Eastern and Western Siberia;
- an increase in climate-dependent wheat yields in the range of 5–25% may be observed in the regions bordering Kazakhstan and in the south of Western Siberia;
- the involvement of new land in agricultural turnover for wheat production is insignificant.

No.	Crops	Finland			Iceland			Norway			Russian Federation			Sweden		
		2017	2018	2019	2017	2018	2019	2017	2018	2019	2017	2018	2019	2017	2018	2019
1	Anise, badian, fennel, coriander	—	—	—	—	—	—	—	—	—	48488	10146	37578	—	—	—
2	Apples	6758	7200	8090	—	—	—	12664	14878	15593	1493600	1859400	1950800	22130	30610	22210
3	Apricots	—	—	—	—	—	—	—	—	—	53300	66300	69600	—	—	—
4	Barley	1460100	1353190	1701960	7400	3900	7900	574100	440900	581000	20628955	16991907	20489088	1635200	1094400	1546500
5	Bast fibers, other	—	—	—	—	—	—	—	—	—	50076	50061	50073	—	—	—
6	Beans, dry	87	90	60	—	—	—	1032	1131	1308	4368	5432	5715	—	230	260
7	Berries nes	303	130	130	—	—	—	122	84	156	3200	4000	4200	20	20	20
8	Blueberries		130	200	—	—	—	30	26	44	2700	3300	3500	70	80	90
9	Broad beans, horse beans, dry		24160	30170	—	—	—	—	—	—	7419	7600	8044	109400	34400	59500
10	Buckwheat	—	—	—	—	—	—	—	—	—	1524879	931713	785702	—	—	—
11	Cabbages and other brassicas	26213	23300	25400	290	160	276	37911	31613	32364	2687090	2495839	2623230	18290	19470	20470
12	Carrots and turnips	63823	66720	77340	750	520	900	51889	43290	49282	1438420	1408348	1558866	109080	92540	106730
13	Castor oil seed	—	—	—	—	—	—	—	—	—	117	81	319	—	—	—
15	Cauliflowers and broccoli	4288	3290	4050	55	47	77	11525	12157	11707	18744	23530	23237	10300	9330	8230
16	Cereals nes	3243		1020	—	—	—	—	—	—	13257	12807	12538	—	—	—
17	Cherries	—	—	—	—	—	—	623	956	689	37300	46400	48700	—	—	—
18	Cherries, sour	—	—	—	—	—	—	—	—	—	186500	232200	243600	100	90	90
19	Chickpeas	—	—	—	—	—	—	—	—	—	418646	620400	506166	—	—	—
20	Cucumbers and gherkins	50763	55330	56130	1800	1927	1924	16484	17462	18475	1504965	1604346	1626360	38100	35790	37900
21	Currants	1888	1420	1870	—	—	—	695	676	631	319800	398000	417600	360	290	290
22	Flax fiber and tow	—	—	—	—	—	—	—	—	—	38795	36715	38464	—	—	—

No.	Crops	Finland			Iceland			Norway			Russian Federation			Sweden		
		2017	2018	2019	2017	2018	2019	2017	2018	2019	2017	2018	2019	2017	2018	2019
23	Fruit, fresh nes	—	—	—	—	—	—	—	—	—	700	900	1000	—	—	—
24	Garlic	75	10	70	—	—	—	—	—	—	206074	211981	202120		40	50
25	Gooseberries	—	—	—	—	—	—	—	—	—	53300	66300	69600	—	—	—
26	Grain, mixed	28900	38890	46210	—	—	—	—	—	—	—	—	—	41100	22200	42300
27	Grapes	—	—	—	—	—	—	—	—	—	580077	627739	677997		60	70
28	Hemp tow waste	—	—	—	—	—	—	—	—	—	1240	1212	1187	—	—	—
29	Hempseed	—	—	—	—	—	—	—	—	—	1078	2117	2893	—	—	—
30	Hops	—	—	—	—	—	—	—	—	—	174	144	205	—	—	—
31	Leeks, other alliaceous vegetables	628	520	730	—	—	—	2717	3335	2702	—	—	—	4170	3180	3510
32	Lentils	—	—	—	—	—	—	—	—	—	197858	194726	116618			
33	Lettuce and chicory	14099	14350	13620	—	—	—	28541	27511	26576	—	—	—	30760	28410	32140
34	Linseed		500	400	—	—	—	—	—	—	611283	557888	658644	7800	4000	4300
35	Lupins	—	—	—	—	—	—	—	—	—	161684	136352	166271	—	—	—
36	Maize	—	—	—	—	—	—	156	142	101	13208095	11419020	14282352	—	4600	11300
37	Millet	—	—	—	—	—	—	—	—	—	316137	217200	439771	—		
38	Mushrooms and truffles	1320	1320	1330	580	580	560	—	—	—	16088	30686	47951	—	1200	1540
39	Mustard seed	—	—	—	—	—	—	—	—	—	98398	123507	164857	—	—	—
40	Nuts nes	—	—	—	—	—	—	—	—	—	17832	20044	19686	—	—	—
41	Oats	1013900	831520	1187480	—	—	—	282700	156600	233700	5456237	4719324	4424433	676400	363500	671200
42	Oilseeds nes	—	—	—	—	—	—	—	—	—	63438	39110	39806	—	—	—
43	Onions, dry	26252	23300	31440	—	—	—	27195	19034	29008	1794417	1642106	1670129	62800	52980	54870

No.	Crops	Finland			Iceland			Norway			Russian Federation			Sweden		
		2017	2018	2019	2017	2018	2019	2017	2018	2019	2017	2018	2019	2017	2018	2019
44	Oranges	—	—	—	—	—	—	—	—	—	84	83	75	—	—	—
45	Peaches and nectarines	—	—	—	—	—	—	—	—	—	29300	36500	38300	—	—	—
46	Pears		230	250	—	—	—	249	553	416	53300	66300	69600	2050	1740	1650
47	Peas, dry	9100	20150	34200	—	—	—	3800	3000	4000	3285500	2304432	2369479	82200	48330	68490
48	Peas, green	7096	6290	8860	—	—	—	3548	1941	4141	121768	79892	86599	12050	9580	21030
49	Plums and sloes	—	—	—	—	—	—	1859	1948	2546	133200	165800	174000	250	250	250
50	Potatoes	611900	600300	618900	9000	6020	8200	315500	326400	332200	21707645	22394960	22074874	852500	723000	846900
51	Pulses nes	—	—	—	—	—	—	—	—	—	9095	10573	8770	—	690	1190
52	Pumpkins, squash and gourds	1686	2350	2300	—	—	—	—	—	—	1165150	1191538	1195611	—	3980	4760
53	Quinces	—	—	—	—	—	—	—	—	—	5300	6600	7000	—	—	—
54	Rapeseed	91300	70900	41900	—	—	—	10300	7250	15000	1510324	1988697	2060320	362700	217700	381500
55	Raspberries	1071	950	1310	—	—	—	2994	2599	2408	133200	165800	174000	430	480	480
56	Rice, paddy	—	—	—	—	—	—	—	—	—	986620	1038222	1098660	—	—	—
57	Rice, paddy (milled rice equivalent)	—	—	—	—	—	—	—	—	—	658076	692494	732806	—	—	—
58	Rye	113500	42990	185260	—	—	—	50000	7900	50000	2548719	1916056	1428421	141800	88200	221300
59	Safflower seed	—	—	—	—	—	—	—	—	—	100885	25259	81189	—	—	—
60	Sorghum	—	—	—	—	—	—	—	—	—	103550	49128	98702	—	—	—
61	Soybeans	—	—	—	—	—	—	—	—	—	3621712	4026850	4359956	—	—	—
62	Spinach	1028	150	450	—	—	—	—	—	—				150	290	260
63	Strawberries	13861	15510	17820	—	—	—	8090	7964	9142	159900	199000	208800	15740	15640	16250
64	Sugar beet	430300	355400	501400	—	—	—	—	—	—	51913442	42065957	54350115	1963500	1698400	2028900

No.	Crops	Finland			Iceland			Norway			Russian Federation			Sweden		
		2017	2018	2019	2017	2018	2019	2017	2018	2019	2017	2018	2019	2017	2018	2019
65	Sunflower seed	—	—	—	—	—	—	—	—	—	10480958	12755725	15379287	—	—	—
66	Tea	—	—	—	—	—	—	—	—	—	554	504	298	—	—	—
67	Tobacco, unmanufactured	—	—	—	—	—	—	—	—	—	4	6	9	—	—	—
68	Tomatoes	39386	39320	40450	1334	1213	1183	10574	12801	11311	2668993	2899664	3015010	14450	18230	16900
69	Triticale	—	—	—	—	—	—	—	—	—	500939	400651	355883	156500	66900	178300
70	Vegetables, fresh nes	12431	—	—	—	—	—	6887	9445	7629	2006655	2128047	2104172	40100	1180	1330
71	Vegetables, leguminous nes	—	—	—	—	—	—	—	—	—	375	342	332	—	—	—
72	Vetches	—	—	—	—	—	—	—	—	—	177459	156115	163163	—	—	—
73	Watermelons	—	—	—	—	—	—	—	—	—	1815022	1969954	1785277	—	—	—
74	Wheat	802000	501600	914180	—	—	—	400500	137700	459000	86002542	72136149	74452692	3298600	1620300	3476800

Table 1.
Gross harvest of the main cultivated crops in the Nordic countries of the Eurasian continent, tones [6].

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Fluctuations in the production and supply of grain in the grain market caused by climate change strongly affect grain prices.

The food security of the Russian Federation [5, 7] in the long term largely depends not only on the readiness of agricultural systems to adapt to extreme climatic and weather events but also on the ability to adapt to these changes in the rest of the agro-industrial complex - logistics, agricultural processing and food consumption, as well as the social-economic sphere of the regions and the country as a whole.

In conclusion, the global community recognizes that climate change will make it challenging to produce enough food for the world's growing population and alter water resources' availability, quality, and mode of use. Avoiding over-intrusions into already stressed ecosystems will require countries to double the current rate of agricultural productivity growth while minimizing agricultural-related harm to the environment. This productivity will require the deliberate application of new or pre-existing technologies and practices, the development of crop varieties resistant to climatic shocks, the diversification of rural livelihoods, improved forest and fisheries management, investment in information technology and systems, and the active use of emerging computer technologies such as precision farming, GIS, etc.

International organizations including FAO [6], the International Food Policy Research Institute - IFPRI, the World Bank and others have developed recommendations for adapting world agriculture to global climate change.

Addressing this major challenge requires joint efforts and actions by all countries to effectively implement measures to mitigate climate change effects on agriculture and adapt the world food system.

The level of food security of the Northern regions of Russia depends on the local production of agricultural products and their regular import from favorable areas. And, in this regard, we have considered food security based on the gross harvest of the above indicators in the regions of the North [8].

The table shows that it is practically impossible to grow wheat (winter and spring) in the northern latitudes. Winter wheat is produced only in two subjects of the Federation out of 12 regions that we selected for the study (**Table 2**). According to the data, during the reporting period, winter wheat cultivation in the Tyumen region decreased by 38.04 thousand centners (or 24.9%), while in spring wheat, it decreased by 1037.2 thousand centners (or 11.6%). On the contrary, there has been a 15.6% increase in wheat yields in Russia's North.

The status of the Doctrine [7] indicator "potatoes" is more favorable than that of wheat. Potatoes are grown in 11 out of 12 regions. In the Krasnoyarsk region as a whole, potato self-sufficiency (6.182.97 thousand quintals) is high per capita (0.6 kilograms per day), i.e., exceeds 2.5 times the dietary standards. Still, in 2 autonomous Districts (Taimyr (Dolgano-Nenetskiy) and Evenk), potatoes are not grown due to difficult climate conditions and specific arctic [8]. Potatoes in these districts are not a staple food, unlike in Russia as a whole. In the other constituent entities of the Federation, potatoes are grown, albeit in small quantities. For example, in 3 regions (Yamalo-Nenetskiy Autonomous District, Magadan region, Chukotskiy Autonomous District), self-sufficiency in "potatoes" is low and equals less than 0.1% of the total in Russia. The Tyumen region (without districts), just as in wheat, shows a decrease in the gross output of potatoes by 1,031.79 thousand quintals. There is also an insignificant reduction in the gross harvest in 3 regions - the Republic of Sakha (Yakutia), the Magadan region and Chukotskiy Autonomous District. Three federal subjects (Khanty-Mansiysk Autonomous Area, Yamalo-Nenetskiy Autonomous Area, Kamchatka region) show increased potato cultivation. Still, only one part, Yugra, shows a significant growth rate of 140.84 thousand quintals.

No.	Regions of the Russian Federation	Wheat (thousand quintals)				Rate of increase/ decrease, in % in 2020 to 2017
		2017 year	The 2018 year	2019 year	The 2020 year	
Winter wheat						
1	Tyumen region (without districts)	152.66	115.52	127.64	114.62	↓ 24.9%
2	Krasnoyarsk region*	67.91	122.09	82.58	136.78	↑ 101.4%
Spring wheat						
3	Arkhangelsk region	22.6	17.8	15.7	16.1	↓ 28.7%
4	Tyumen region (without districts)	9 018.74	7 414.64	8 656.4	7 981.54	↓ 11.6%
5	Krasnoyarsk region*	12 560.18	11 352.66	13 274.28	16 983.47	↑ 35%
6	Republic of Sakha (Yakutia)	12.31	15.81	17.21	11.44	↓ 7%
7	Kamchatka region	0.07	0.07	—	—	—
8	**IN TOTAL**	**21 834.47**	**19 038.59**	**22 173.81**	**25 243.95**	↑ **15.6%**

**The entire Krasnoyarsk region, as no wheat is grown in the Taimyr (Dolgano-Nenetskiy Autonomous District) and Evenk Autonomous Districts.*

Table 2.
Gross harvest of wheat (winter and spring) in farms of all categories in the northern regions of the Russian Federation for the period 2017–2020 [5].

During the study period, potato yields increased from 24.5% in the Murmansk region to 104.1% in the Komi Republic. Therefore, self-sufficiency in the potato indicator in these regions is high.

The third Doctrine [7] indicator is “vegetables and gourds”. These crops are more thermophilic than potatoes and are practically not intended for growing in the permafrost zone. Therefore, their cultivation rate is meager in this macro-region. The histogram (**Figure 1**) shows this clearly.

Despite the climatic conditions, the regions of Russia’s northern latitudes are looking for opportunities to grow vegetables and gourds food crops. But the yield of the crops grown is low enough for the body to obtain all the vitamins it needs.

Melon crops are not grown in all regions of the northern latitudes due to the incompatibility of these crops’ physiological and morphological characteristics and the difficult climatic conditions of the North. Thus, in 2020, according to federal statistics and the histogram, only three areas found it possible to supply themselves with minimal amounts of melon food crops, such as the Krasnoyarsk region (the entire region), the Republic of Sakha (Yakutia) and the Tyumen region (without districts) with a gross harvest of 3.56 thousand quintals, 3.04 thousand quintals and 0.17 thousand quintals respectively.

As for outdoor and indoor vegetables, small volumes of gross harvest are present in the regions of Northern Russia. But the values are so low that the histogram (**Figure 2**) does not show them. As a result, only two areas give a small visualization (Krasnoyarsk region at 1.543.02 thousand quintals and Tyumen region at 1.267.82 thousand quintals in 2020) (**Figure 5**).

The average harvest of outdoor and indoor vegetables in 2020 is recorded in three regions. For example, the Republic of Sakha (Yakutia) shows 263.63 thousand quintals, the Kamchatka region - 135.77 thousand quintals, and Khanty-Mansiysk Autonomous District - 267.64 thousand quintals.

And the lowest indicators for the cultivation of outdoor and indoor vegetables in 2020 are represented by three subjects of the Federation (Magadan region (44.05 thousand quintals), Chukotskiy region (2.7 thousand quintals) and Yamalo-Nenetskiy Autonomous District (1.36 thousand quintals).

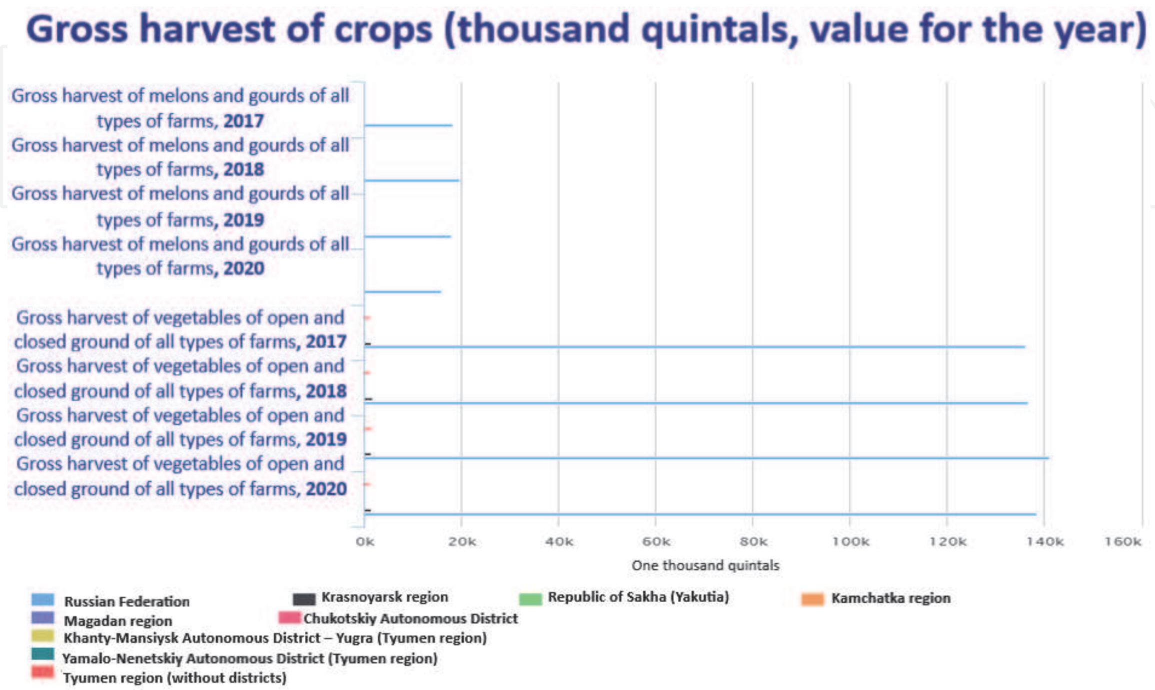

Figure 4.
*Gross harvest of vegetables and gourds in farms of all categories in the northern regions of the Russian Federation 2017–2020 [5]. *The entire Krasnoyarsk region, as in the Taimyr (Dolgano-Nenetskiy Autonomous District) and Evenk Autonomous Districts, no vegetables and melons are grown.*

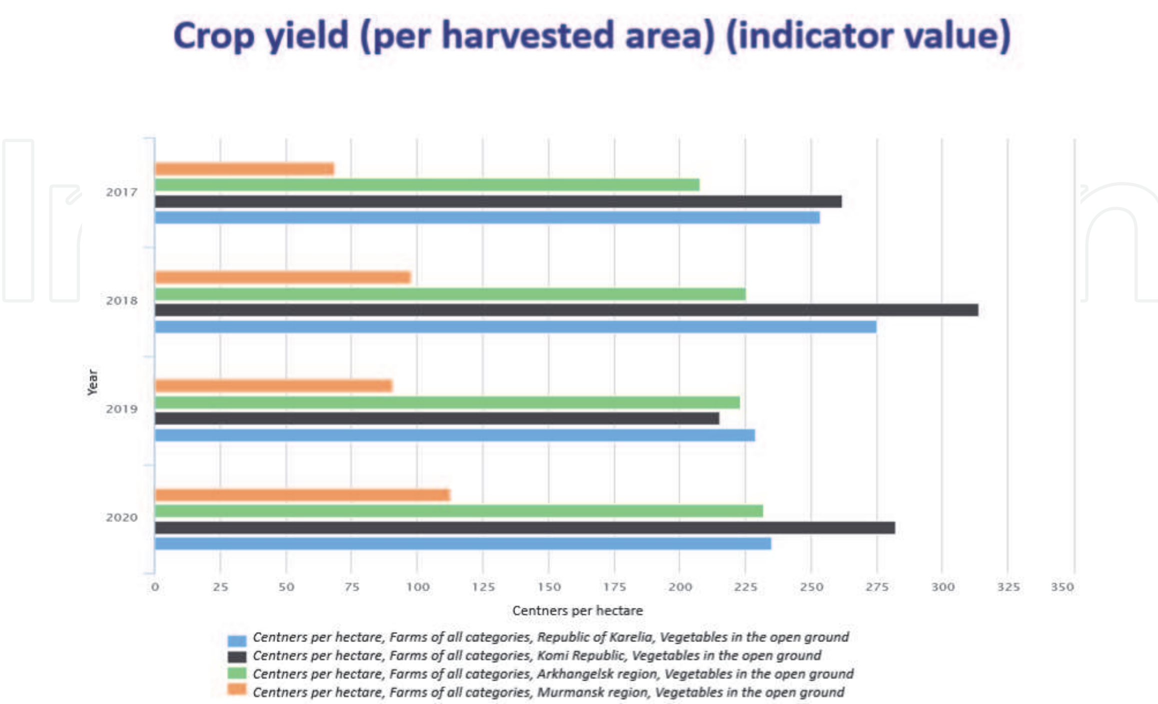

Figure 5.
*Gross harvest of outdoor vegetables in farms of all categories in the northern regions of the Russian Federation 2017–2020 [5]. *The entire Krasnoyarsk region, as in the Taimyr (Dolgano-Nenetskiy) and Evenk Autonomous Districts, no vegetables and melons are grown.*

The regions of the European North of Russia do not grow melons. But open field vegetables are grown in farms of all categories. The leader in growing vegetables among the European North of Russia regions is the Komi Republic in 2018 and 2020. The lowest yields are obtained in the Murmansk region due to the relatively small territory, climatic conditions and, of course, the specialization of the area itself. This region is an outpost of Russia in the North Seas.

Thus, we can conclude from this very Doctrine [7] indicator that man cannot change weather conditions in northern latitudes. Still, human engineering and technology of recent years show that it is possible to grow vegetable and food gourds even in extreme conditions. Besides, the facts recorded by meteorologists on global warming and climate change in northern latitudes over the past decades show that the sum of active temperatures (SAT) is observed more frequently than 35–50 years ago.

For example, in the Murmansk region over the last 35 years (**Figure 3**), there has been a significant upward trend in July temperatures from 15.2 °C in 1985 to 17.9 °C

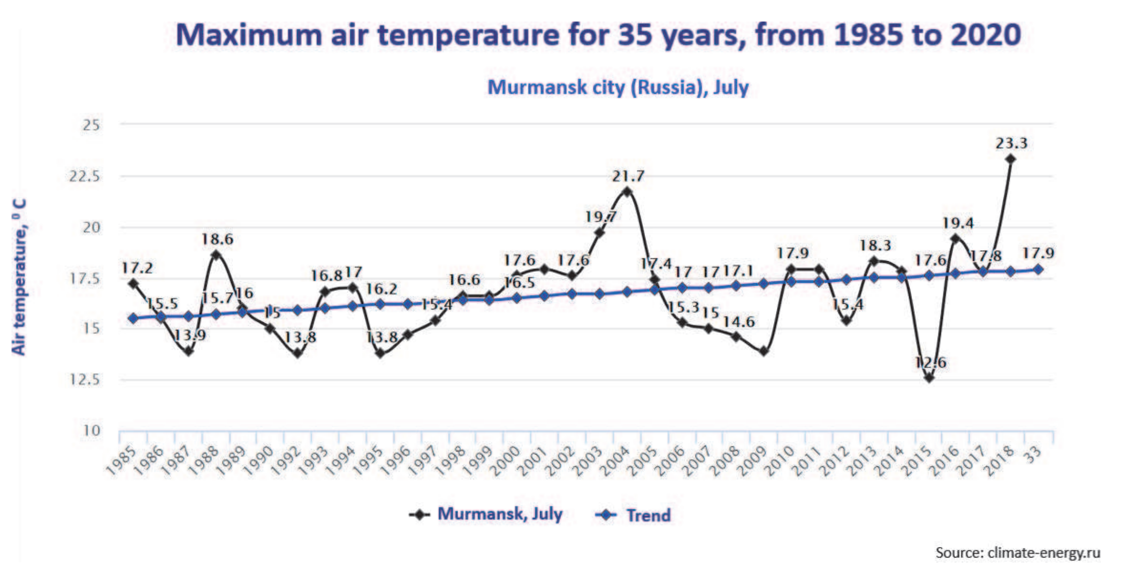

Figure 6.
Maximum air temperatures in Murmansk in July from 1985 to 2020.

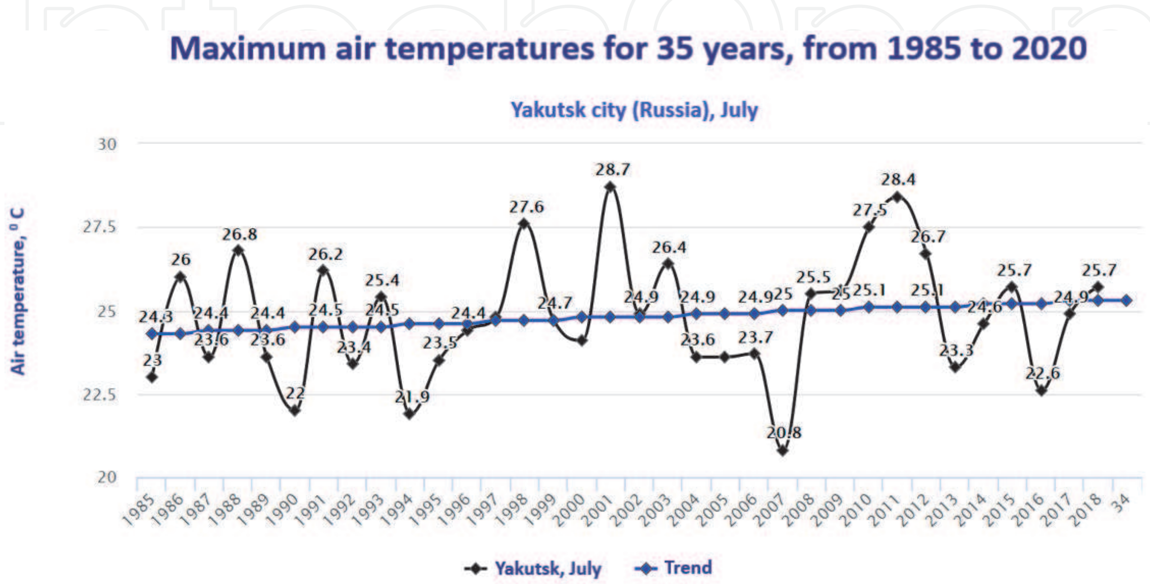

Figure 7.
Maximum air temperatures in Yakutsk in July from 1985 to 2020.

in 2020, which of course, shortly could affect the cultivation of even more vegetable and food crops to increase food security (**Figure 6**).

Scientists observe the same trend in the Republic of Sakha (Yakutia) over 35 years (**Figure 4**). In July, the temperature increased from 24.3 °C in 1985 to 25.5 °C in 2020, indicating an increase in the Russian North's range (**Figure 7**).

The next Doctrine [7] indicator, "fruit and berries", also depends on the sum of the active temperatures in the northern latitudes of the macro-region. **Table 3** proves this. The availability of fruit and berry plantations, including strawberries, strawberries, raspberries, currants, gooseberries, and other berries, does exist. Still, the gross yield is insignificant to supply the population of this macro-region.

These tables indicate the possibility of developing crop production in the regions of the North of Russia. However, food availability by the Doctrine indicator "Fruits" is high only in two areas (Tyumen and Krasnoyarsk regions) relative to other regions of the North. And, even these values of 69.36 thousand quintals and 64.27 thousand quintals do not cover the needs of these regions in fruit. For example, according to Order No. 614 of 09.08.2016 of the Ministry of Health of the Russian Federation, the norm for consumption of fruit and berries is 100 kg/year per capita. In the Krasnoyarsk region, fruit supplies are similar to those in the Tyumen Region. The per capita fruit deficit is 77.51 kg/per year per capita, without considering the increased consumption of fruits and vegetables for residents of the Far North by 15%. In other words, the current state of the gross fruit harvest is insufficient for the

No.	Regions of the Russian Federation	Potatoes (thousand quintals)				Rate of increase/ decrease, in % in 2020 to 2017
		2017 year	2018 year	2019 year	2020 year	
1	Republic of Karelia	133.2	156.2	163.7	167	↑ 25.3%
2	Komi Republic	88.7	143.7	120.5	181.1	↑ 104.1%
3	Arkhangelsk region	93.6	141.7	135.4	136	↑ 45.2%
4	Murmansk region	99.3	107.7	117.2	123.7	↑ 24.5%
5	Tyumen region (without districts)	4 248.69	4 352.6	4 101.38	3 216.9	↓ 24.2%
6	Khanty-Mansiysk Autonomous District – Yugra (Tyumen region)	682.83	667.04	596.27	823.67	↑ 20.6%
7	Yamalo-Nenetskiy Autonomous District (Tyumen region)	7.65	8.47	8.01	7.66	↑ 0.13%
8	Krasnoyarsk region*	—	—	—	—	—
9	Republic of Sakha (Yakutia)	756.1	829.35	814.82	711.78	↓ 5.86%
10	Kamchatka region	364.86	3558	400.88	396.71	↑ 8.72%
11	Magadan region	88.64	83.29	58.12	77.14	↓ 12.9%
12	Chukotskiy Autonomous District	1.26	1.24	1.27	1.04	↓ 17.4%
13	**IN TOTAL**	**6 564.83**	**6 847.09**	**6 517.55**	**5 842.7**	↓ **10.9%**

**Only the Taimyr (Dolgano-Nenetskiy Autonomous District) and Evenk Autonomous Districts.*

Table 3.
Gross potato harvest in farms of all categories in the northern regions of the Russian Federation for the period 2017–2020 [5].

self-sufficiency of the population of this region, let alone other territories of the Russian North.

As for fruit supply in Krasnoyarsk Region, the situation is similar to that in Tyumen Region. The per capita fruit deficit is 77.51 kg per year, and this does not include the 15% increased norms of fruit and vegetable consumption for residents of the Far North (**Table 4**).

No.	**Regions of the Russian Federation**	**Fruit and berries (thousand quintals)**				**Rate of increase/ decrease, in % in 2020 to 2017**
		2017 year	**2018 year**	**2019 year**	**2020 year**	
Fruit and berry plantations (strawberries, strawberries, raspberries, currants, gooseberries and other berries)						
1	Republic of Karelia	83.6	96.4	112.4	137.6	↑ 64.5%
2	Komi Republic	96.7	97.2	133.3	183.8	↑ 90.0%
3	Arkhangelsk region	122.0	130.6	143.1	148.3	↑ 21.5%
4	Murmansk region	20.7	24.2	25.4	40.9	↑ 97.5
5	Tyumen region (without districts)	345.36	368.37	293.95	253.05	↓ 26.7%
6	Khanty-Mansiysk Autonomous District - Yugra	41.38	47.28	68.84	71.96	↑ 73.9%
7	Yamato-Nenets Autonomous District	—	—	0.02	0.06	—
8	Krasnoyarsk region*	336.93	394.92	455.11	441.63	↑ 31.1%
9	Republic of Sakha (Yakutia)	0.97	0.94	2.57	6.35	↑ 554.6%
10	Kamchatka region	5.7	7.68	15.26	15.8	↑ 82.4%
11	Magadan region	2.57	2.52	2.85	2.22	↓ 13.6%
12	Chukotskiy Autonomous District	—	—	—	0.01	—
Seedlings (apple, pear, quince, etc.)						
1	Republic of Karelia	33.3	55.6	75.5	79.7	↑ 139.3%
2	Komi Republic	7.6	29.6	19.3	19.3	↑ 153.9%
3	Arkhangelsk region	41.5	40.6	43	39.9	↓ 3.85%
4	Tyumen region (without districts)	65.14	62.68	80.55	69.36	↓ 2.7%
5	Khanty-Mansiysk Autonomous District - Yugra	—	—	3.13	1.53	—
6	Krasnoyarsk region*	354	46.43	56.95	64.27	↑ 81.5%
7	Kamchatka region	—	—	—	0.09	—
8	**IN TOTAL**	**1 238.85**	**1 405.02**	**1 531.23**	**1 575.83**	↑ 27.2%

**The entire Krasnoyarsk region, as in the Taimyr (Dolgano-Nenetskiy) and Evenki Autonomous Districts, no vegetables or melons are grown.*

Table 4.
Gross harvest of fruit and berries in farms of all categories in the northern regions of the Russian Federation for the period 2017–2020 [5].

For the Doctrine [7] indicator "berries", the situation, according to the table, is more optimistic, as there is no deficit in this position. Still, there is an oversupply of these crops per capita per year. For example, Khanty-Mansiysk Autonomous District - Yugra shows 42 kg/year per capita against the consumption norm of 7 kg/year per capita (not including the increase of consumption norm by 15% inhabitants of the Far North). Three other regions exceed the consumption norms: Tyumen region (without districts), Krasnoyarsk region (the entire region) and Kamchatka region.

We found that the gross berry harvest in four regions of the North of Russia (Yamalo-Nenetskiy Autonomous District, the Republic of Sakha (Yakutia), Magadan region, Chukotskiy Autonomous District) is lower than the average Russian consumption rate.

The growth rate for 2017–2020 in the regions of the European North for fruit and berry plantations and berries shows a steady increase in yield as these regions have significant stocks of non-timber products, which are in demand both domestically and internationally. Therefore, this area of crop production needs to be developed and maintained. Furthermore, because of the change in air temperature by 2.7 °C in these regions, it can be said that the growing season increases in days and, accordingly, some crops can adapt to the weather and climatic conditions of the North.

4. Discussion

There is considerable uncertainty in quantifying how climate change is expected to play out in the future and its impact on ecosystems, economic activity, and social processes in different countries and regions.

Studies on the impact of climate change on the economies of world regions and individual countries (including agriculture) have been carried out by various international organizations and national research centres. For example, the World Bank's Economics of adaptation to climate change synthesis report (2010) estimates that the costs of adapting to 2-degree global warming between 2020 and 2050 are in the range of $70 billion to $100 billion a year, depending on future climate change scenarios.

The same report notes that in addition to the financial costs of adapting the world's regions to climate change, the prices of mitigating the negative impacts on developing economies will rise, totaling US$265 billion to US$565 billion [4]. As a result, the cost of mitigating the effects of climate change would increase to a total of US$265 billion to US$565 billion [4].

It should be noted that even under constant climate conditions, as shown in the model studies, prices for the most critical crops will rise. By 2050, it is predicted that the cost of wheat could increase by 39%, rice by 62%, maize by 63% and soybean by 72%. Climate change will result in additional price increases: an average increase of 32–37% for rice, 52–55% for maize and 12–14% for soybeans, with the highest growth expected for wheat, ranging from 94 to 111% [4].

Adapting the food system to global climate change will require complex social, economic and biophysical adjustments to food production, processing and consumption. Such changes will be most difficult for the poorest and most vulnerable regions and populations. Furthermore, climate change modeling shows that the most severe impacts are likely to occur in the tropical drylands. Many of the poorest countries are located in these regions, so nations least able to adapt will be most affected.

Nevertheless, the food system is embedded in global processes and linked to other systems, which has both advantages and disadvantages. For example, economic shocks in one geographic region may spread rapidly to others. Still, shocks due to sharp reductions in the food supply in one area may be offset by output from the other areas. The global food system also affects the efficiency of food production by allowing parts with advanced production systems to export to lagging regions [4].

A global problem of the scale of climate change requires coordinated efforts at the international level. However, its solution depends on the actions taken by each country in its territory. Primarily, it is a question of reducing greenhouse gas (GHG) emissions into the atmosphere.

5. Conclusion

Based on the research, there is a strong dependency on crop production in the Northern regions of Russia, and the level of "food security" is relatively low. A significant reason for this, of course, is the climate. But even so, this factor is beginning to "melt away" over time in favor of growing more thermophilic crops. Thus, opening even more opportunities for the state and population to develop rural areas and agriculture in this macro-region.

We suggest using the maximum possible agro-technologies for crop production under global warming conditions, such as snow retention, reduction of unproductive evaporation, and expansion of drought-tolerant crops (primarily corn, sunflower, millet), and growth of winter crops (wheat).

We also suggest a need to develop climate-friendly crop breeding, which will cope with abiotic stress conditions as much as possible and adapt to climate change.

Today, the primary vector in solving the food problem and the development of rural areas is the development of productive forces of agriculture with a bias towards innovative and nature-based technologies [6], in providing the population with domestic functional foods, except for exotic foods and the formation of the necessary social infrastructure for the people of the Russian North.

As for the 2030 Doctrine, the overall food self-sufficiency indicators in Russia are more than ambitious, given the background of the food problem. And these difficulties and barriers can be seen in the North of Russia and everywhere, especially in the North Federal District and the Far East of Russia.

However, crop production can and should be developed despite the archaic climatic conditions, especially in the river valleys. This study shows that the "sprouts" of crop production already exist in the regions of the North of Russia. It is necessary to build a growing season for crops in northern latitudes, using agronomic techniques, plant breeding, and genetic methods to gain access to safe, functional food for a healthy lifestyle throughout the season [9]. And, of course, public-administrative and private-investment levers and support are indispensable.

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