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VOL.51, NO.3, SUMMER 2020

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EDITORIAL

The coronavirus that began spreading infection at the end of last year, After that infections continued to spread in many countries, and now with more than 10 million infected people worldwide and continues to expand further more. It's a pandemic !

The earth is connected by traffic and the development of information closer to each other, and new economy and life are born in the society. But this time the coronavirus divided the link to the economy and also the connection of people. For that reason, it has caused an immense economic crisis. Not only general economy but it is also having a huge influence on agricultural economy.

The United States currently has many infected people, but from now on Africa is most worried about the expansion of virus on the continent. Medical infrastructure is not sufficient in many countries. Moreover, there are many poor layers. There are also excessive slums, and the coronavirus is going to spread out to these areas. The most necessary thing for humans to live is food and also rich environment.

It is the agriculture that creates them. Agricultural producers need to strengthen their agricultural production bases to survive this pandemic. Today the population on the planet continues to grow, nearly 30 years later in 2050, it is about to exceed 10 billion. Against that background, it is a big issue as to how to secure food.

The most important issue is to increase land productivity. On that point, timely operations are required and that also requires accurate and precise operations; therefore, further development of agricultural machinery is crucial.

Those concerned about agricultural should make serious efforts to realize a good human connection on this earth overcoming this difficulty. Human beings are members in the life system of this earth living along with many lives. The coronavirus is one of them.

The largest biological existence on the earth are humans, thus the number of parasitic microorganisms that settle down in humans' body must also be increasing more and more. How does a human being live in the big life system of the earth, how humans will live to harmonize with the life system on the earth?

The new science and technology to harmonize the life system is required. Many kinds of diseases and harmful insects damage many farm products and it is also a big issue as how to control these problems. This corona confusion demands people for their reconsideration of many things and we look for a provision of new research.

Yoshisuke Kishida
Chief Editor
July, 2020

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AGRICULTURAL MECHANIZATION IN ASIA, AFRICA AND LATIN AMERICA

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SPECIAL ISSUE:
VIM 90th Anniversary

The Federal Scientific Agro-engineering Center VIM: History of Foundation and Development

by

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Abstract

The Federal Scientific Agro-engineering Center VIM is the leading research organization of the Russian Federation in the field of agro-engineering science, agricultural mechanization, introducing the latest intelligent technologies and robotic technical equipment of a new generation into agricultural production.

In autumn 2020 the scientific community will celebrate the 90th anniversary of the VIM foundation. The history of the institute is inextricably linked to the history of Russia.

The rapid development of agriculture and industry in the Soviet Union in the late 1920s led to the creation of the scientific foundations of agriculture. In this regard, the first scientific institutes were created to deal with issues of mechanization and electrification, the creation of new types of machines for agriculture.

Keywords: agricultural mechanization, tractor, engine, combine harvester, machines and equipment, technical service.

Introduction

January 26, 1930 the Decree of the Ministry of Agriculture of the USSR "On the creation of the All-Union Institute of Agricultural Mechanization (VIM)" was issued.

This Decree set the following tasks for the institute:

- Urgently prepare drawings of the most important agricultural machines for production at Russian factories;
- Develop technical and technological requirements for complexes of machines and equipment for the production of field crops;
- Develop a plan for agricultural production mechanization for all regions of the Russian Federation;
- Develop the theory basics of the main groups of agricultural machinery;
- Develop a training program for engineering personnel for mechanization of the country's agriculture [1, 2].

An important contribution to the establishment of the institute in 1932-1935 was made by academician Vasily Goryachkin (**Fig. 1**), who was the chairman of the scientific council of the institute. At V.P. Goryachkin's suggestion VIM got a leading role in the creation and use of agricultural machinery [3].

During these years, the famous "Goryachkin's triad" was developed, according to which any technological process was analyzed in three aspects of a single system:

- Physico-mechanical properties of the processed material (for example, soil or plants);
- The agricultural machine working body; and
- An energy source (tractor, engine) [4].

Fig. 1 Vasily P. Goryachkin, Academician

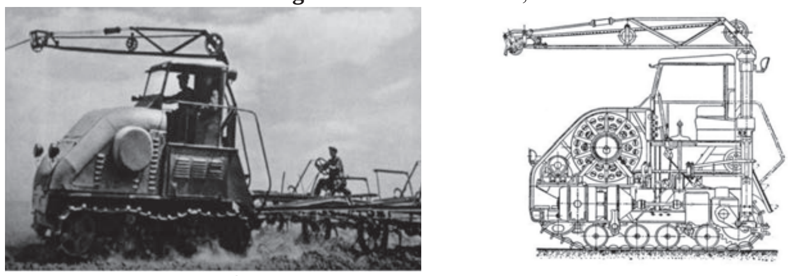
Materials and Methods

The first major problem that was solved by scientists and designers of VIM was the creation of a domestic universal tractor STZ-VIM (**Fig. 2**). From 1934 to 1941 the Kirov and Vladimir Tractor Plants produced more than 200 thousand of these tractors [5, 6].

In the 1930-1940s, the Institute developed the basic machine technologies for the production of grain, potatoes, vegetables, flax, cotton, tea, and subtropical crops. The first domestic complex machines were developed, including agricultural machinery of strategic importance for the economy: a combine harvester (1932, **Fig. 3**), a cotton harvester (1934), a beet harvester (1935), a rice harvester (1935), a potato harvester (1936), wind engines (1937) [7].

In addition to mechanization, VIM scientists were involved in the development of agricultural electrification. In 1930, a heavy tractor with an electric drive with a capacity of 120 kW was created (**Fig. 4**). Electric energy was supplied by wires. About a thousand such tractors were manufactured. Electric tractors were successfully used in tillage and sowing operations, worked with trailed combines for harvesting grain crops and potatoes [7].

Fig. 4 First electric tractor, 1930



(a) General view (b) Circuit diagram

In the 1940s active research was carried out to replace petroleum fuels with alternative fuels. As a result, a tractor with a gas generator engine working on solid fuel (wood logs, wood shavings, straw briquettes, etc.) was created. More than five thousand tractors with an engine power of 45 kW were manufactured (**Fig. 5**). The use of gas generating tractors was very convenient in small agricultural enterprises, made it possible to use local cheap fuel, not to depend on centralized supplies of oil fuel.

By 1946 the country's agriculture was fully provided with domestic equipment. During the 1950s and 1960s VIM developed research in the areas of mechanization, electrification of agriculture, maintenance and repair of agricultural machinery. From the first years of VIM establishment, scientists created and introduced into production new designs of agricultural machines, original devices for studying the physio-mechanical properties of agricultural materials, experimental plants for studying technological processes and working bodies of agricultural machines [7].

In 1952-1953 VIM scientists created a three-row beet harvester. With the beginning of its industrial production in the country, the problem of mechanizing the harvesting of sugar beets was solved. The harvester was awarded the Gold Medal of the World Exhibition in Brussels in 1954 and the Grand Prix of the World Exhibition in Paris in 1964. From 1950 to 1987, about 230 thousand beet harvesters were produced [2].

In 1950-1960 VIM developed a Machine System for the comprehensive mechanization of agricultural production, which included more than 500 types of machines and units for crop production [8].

In subsequent years (1970-1990), the machine system was regularly updated and improved and was the methodological basis for the development and manufacture of agricultural machinery in the country. In 2000-2010, a System of Machines and Technologies was created in relation to market conditions for agriculture and agricultural engineering.

In January 1971 VIM was awarded the State Prize for the development and implementation of new agricultural machinery and advanced agricultural technology, and was

Fig. 2 The first Russian universal tractor "STZ - VIM"

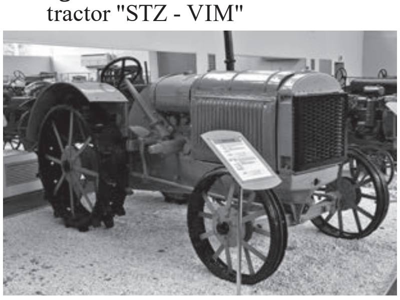
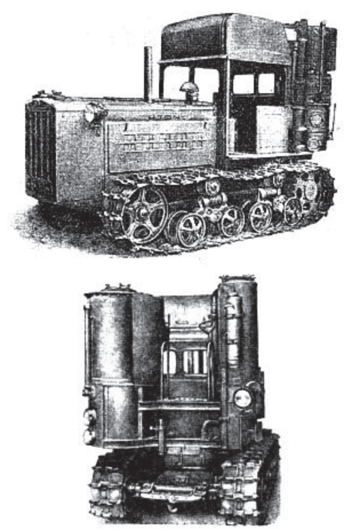


Fig. 3 Tests of a trailed combine harvester, 1932

Fig. 5 Gas-generating tractor, 1940



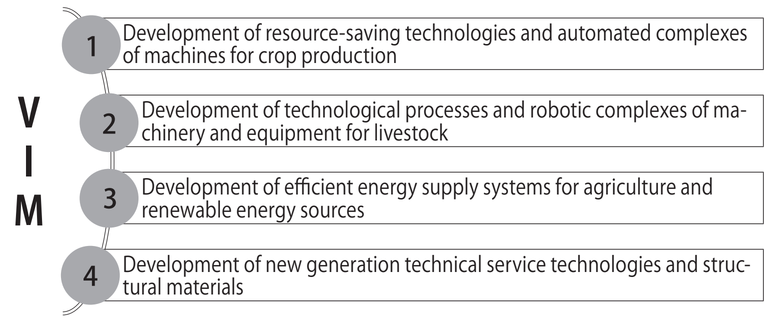


Fig. 6 The main activities of the Center VIM

awarded the Order of the Red Banner of Labor.

Results and Discussion

In the 21st century VIM is actively developing. In 2016, the Government of the country decided to create the Federal Scientific Agro-engineering Center VIM on the basis of the VIM Institute.

Currently the Center VIM includes seven institutes (located in Moscow, St. Petersburg and Ryazan), an experimental plant, a design bureau; more than forty research laboratories and test sites. Thus, VIM today is the largest and leading Russian research and production association for mechanization, electrification and automation of agriculture.

The head of the Federal Scientific Agro-engineering Center VIM is Andrei Izmailov, Academician of the Russian Academy of Sciences, Doctor of technical sciences.

Currently, the Institute conducts research and development in the following relevant general areas:

- Resource-saving technologies and automated complexes of machines for plant growing and animal husbandry;
- Energy supply of agricultural production;
- Technologies for technical service of machines and new materials (**Fig. 6**).

Particular attention is given to the creation of the following groups of agricultural machines:

- Mobile energy facilities;
- Machinery and equipment for breeding and seed production;
- Tillage and sowing machines;
- Machines for vegetable growing and potato growing;
- Machines for gardening;
- Machines and equipment for dairy farming;
- Equipment for the use of renewable energy;
- Equipment for technical service.

New machines and equipment are created using elements of robotics and digital technology.

A model of a universal robotic tractor was created, in the computer of which operation parameters were collected and analyzed: general technical characteristics, reliability indicators, safety indicators, etc. (**Fig. 7**). In addition, the on-board computer monitor displayed parameters on the operation of mounted or trailed machines - tillage, sowing, spraying machines, etc.

A similar project was implemented to automate the operation of the combine harvester. In addition to the technical characteristics, data on the state of the grain mass, its yield, moisture, weediness, stalk height, etc. were entered into the on-board computer of the combine. Tests of the combine with an automatic control system allowed to increase its productivity by 25-30% and significantly increased the quality of work and reduce operator fatigue (**Fig. 8**).

Several perspective projects to create unmanned aerial units for crop production were completed. First of all, unmanned aerial units were used when performing operations that were dangerous to humans

Fig. 7 Automation project for a universal tractor

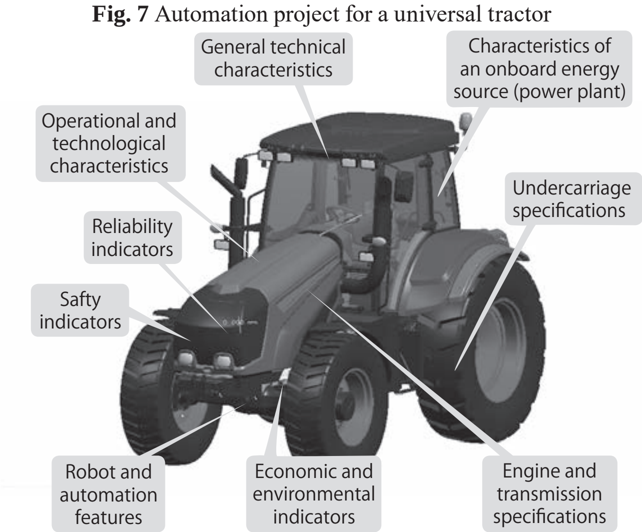
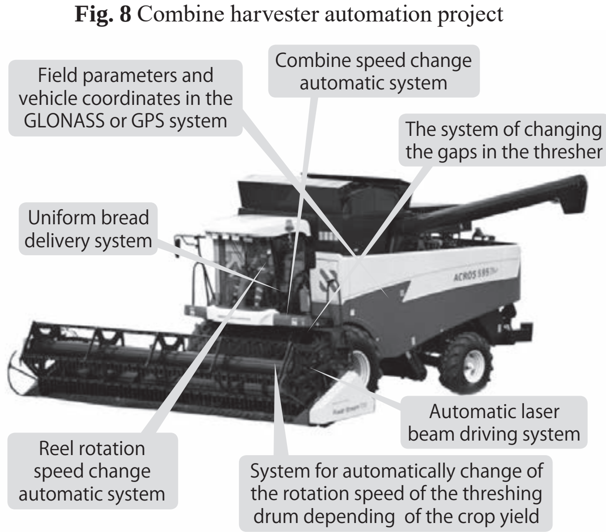


Fig. 8 Combine harvester automation project



[9]. For example, the introduction of chemicals and mineral fertilizers as shown in (**Fig. 9a**). It was also relevant to use unmanned aerial units when performing particularly precise operations, for example, when inter-row cultivation of row crops. In this case, it was possible to improve the quality of processing and reduce operator fatigue (**Fig. 9b**).

Due to the fact that potato production is currently increasing in Russia, a complex of machines for cultivating and harvesting potato seeds is developed at the Center VIM. The complex includes [10]: machines for special tillage, machines for planting seeds (2-row and 4-row), milling cultivators, milling comb formers and milling ridgers, trailed harvesters for harvesting tubers (**Fig. 10**).

Along with an increase in the production of vegetables and potatoes in Russia, plantings of berry crops are sharply increasing: red and black currants, raspberries, blackberries, blueberries, gooseberries, etc. However, mechanization is not enough to cultivate them. Due to the urgency of this problem, the Center VIM developes a high-clearance energy tool and a set of technological adapters for working in berry plants, orchards and nurseries. The power tool has a hydraulic drive, each wheel is equipped with a hydraulic motor. Ground clearance can vary from 1.5 to 2.2 meters [11]. The energy facility is equipped with an automated control system (**Fig. 11**).

For the Russian Federation, as well as for any country, the problem of selection and propagation of seeds of major agricultural crops is extremely important. In this regard, the VIM Center develops and manufactures complexes of machines and equipment for the selection of cereals, cereals, feed and vegetable crops. These are tillage machines for processing selection plots, special seeders, rotary cultivators, combine harvesters and various machines for post-harvest processing of seeds. Together with the company Wintersteiger (Austria), we have organized the Assembly of modern automated combines that are successfully being used by the country's breeding institutes (**Fig. 12**).

In addition to research activities, the VIM Center implements educational programs for masters, graduate students, doctoral students in the following areas: technologies and agricultural machinery; technologies and technical maintenance tool;, power plants based on renewable types of energy; electrical technologies and electrical equipment in agriculture [12].

The Center VIM publishes 3 scientific journals: Agricultural Machines and Technologies, Electrical Technologies and Electrical Equipment in the Agricultural Complex, and Technical Service of Machines.

The main Journal "Agricultural Machines and Technologies" is devoted to urgent problems of developing resource-saving environmentally friendly technologies in crop production, machines and equipment for mechanizing production processes in agriculture.

Команда ВИМ сотрудничает со многими международными организациями в области механизации и электрификации сельского хозяйства.

Conclusions

The VIM team cooperates with many international organizations in the field of agricultural mechanization and electrification. There are International Commission of Agricultural and Biosystems Engineering (CIGR), Euro Asian Association of Agricultural Engineers (EAAAE); Asia-Pacific agricultural machinery testing network (ANTAM), Club of Bologna, American Society of Agricultural and Biological Engineers, Organization for Economic Co-operation and Development (OECD) and others.

VIM's management and team highly appreciate the collaboration with Shin-Norinsha Co., LTD and thank academician Yoshisuke Kishida for his continued help and support.

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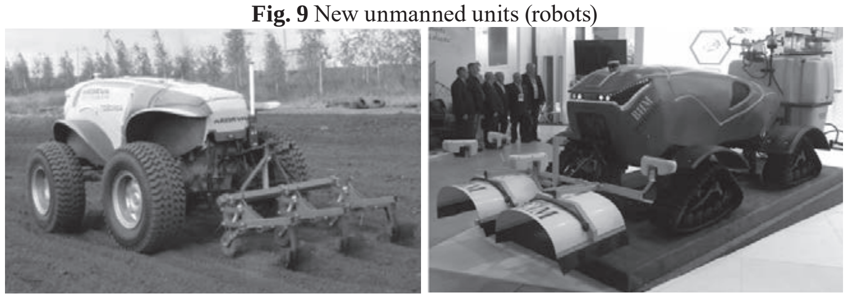
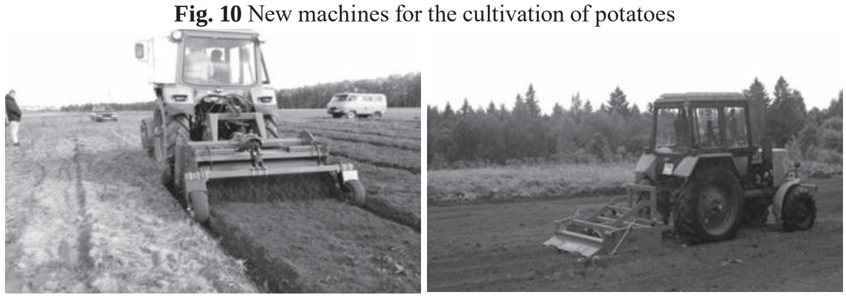
Fig. 9 New unmanned units (robots)



(a) Tillage robot (b) Robot sprayer

Fig. 10 New machines for the cultivation of potatoes



(a) Milling ridger (b) Milling cultivator

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Fig. 11 A high clearance energy machine for the processing of currants

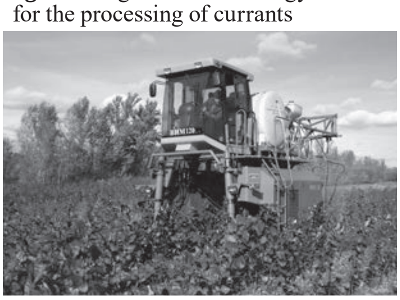

Fig. 12 Selection combine harvester "Wintersteiger-VIM"

Technical Support of Vegetable Growing in Countries of the Eurasian Economic Union

by

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Abstract

Vegetable producers in the member states of the Eurasian Economic Union (EAEU) are forced to import specialized equipment and technologies. High costs in vegetable growing, especially in harvesting as well as the shortage of manual labor lead to a reduction in crop areas, improper implementation of production technologies and, consequently, a decrease in yields. Based on an analysis of the technical support of vegetable growing in the EAEU member states, the authors have determined the need for modern high-tech machines for vegetable growing taking into consideration the total area under vegetable crops. It accounts for 986 thousand hectares, 691 thousand hectares of which are located in Russia, followed by Kazakhstan with an area of 146 thousand hectares, Belarus - 66 thousand hectares, Kyrgyzstan - 52 thousand hectares, and Armenia - 31 thousand hectares. In the course of statistical studies, the current ability of agricultural machinery industry to produce the required number of machines for vegetable growing was assessed. On the domestic market of the EAEU Member States, there is a significant demand for imported agricultural machinery, which is delivered mainly from the European Union. For the revival of agricultural machinery industry and the development of a market for agricultural machinery and implements, the EAEU has identified the main mechanisms for updating the agricultural machinery fleet, related mainly to attracting credit resources of commercial banks and leasing companies.

Keywords: vegetable growing, vegetable seeders, transplanting machines, vegetable-harvesting equipment, Eurasian Economic Union

Introduction

The total area under vegetable crops in the member states of the Eurasian Economic Union (EAEU) amounts to 986 thousand hectares, of which 691 thousand hectares are located in Russia, followed by descending order Kazakhstan with an area of 146 thousand ha, Belarus - 66 thousand ha, Kyrgyzstan - 52 thousand ha, and Armenia - 31 thousand ha.

In 2017, vegetable production increased in all countries (except Armenia, where there was a decrease of 4%) and amounted to: in Russia - 16.3 million tons, Kazakhstan - 3.8 million tons, Belarus - 1.9 million tons, Kyrgyzstan - 1.1 million tons, and Armenia - 1.0 million tons.

For the production of vegetable crops, sets of special and universal machines are used (Amol B. Rohokale, et. al., 2014).

Universal vehicles include general-purpose vehicles, power supply vehicles of various traction classes, special vehicles - planting equipment, cultivators, irrigation machines, and chemical protection machines.

The intensity of farming in modern production conditions is impossible without high-level supply of intellectualization means in machine-technological systems.

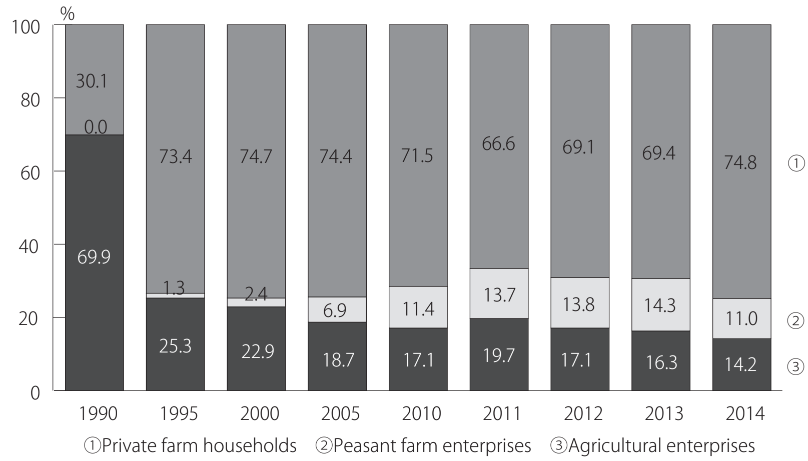
It is possible to obtain high-quality competitive products only by using high-performance machines that combine technological operations, the design of which includes automated process control systems, soil fertility accounting, and ensuring the ecological cleanliness of agro-landscapes (James L. Brewster, 2008).

In farm production use is made of a large range of technical equipment often serving the same purpose.

Moreover, the same crops are produced in different agricultural zones, significantly differing from each other in soil-climatic, reclamation and other conditions, which must be taken into account when choosing technical means.

The purpose of the present research is to determine the current state of technological and technical support for vegetable growing of the EAEU member states.

Fig. 1 Change in the structure of vegetable producers by business patterns (http://www.gks.ru)



Based on the research purpose, the following tasks were set:

1. To assess the degree of technical dependence of vegetable producers on foreign manufacturers of agricultural machinery;
2. To assess the current state of agricultural machinery industry in terms of production of the required number of machines for vegetable growing.

Materials and Methods

Statistical studies served as the basis for developing a model and conceptual principles for the modernization of technological and technical support for vegetable growing operations.

To solve the set tasks, the authors used methodology of system analysis and synthesis, mathematical statistics, numerical methods for solving analytical dependencies.

The reliability of the obtained data is provided by the methods of statistical analysis of research results, the use of licensed mathematical software packages for PCs: Microsoft Excel and STATISTICA-10.0.

Results and Discussion

The world's leader in the cultivation of fresh vegetables (except potatoes) per capita is China - 406 kg. It is followed by the Netherlands and Greece - each producing 302 kg, Spain - 265 kg, Ukraine - 231 kg, Italy - 218 kg, Belarus - 208 kg, Kazakhstan - 202 kg, Romania - 195 kg, Russia - 114 kg, USA - 110 kg, Canada - 65 kg, Switzerland - 55 kg, Denmark - 54 kg, Germany - 44 kg, Great Britain - 41 kg, and Sweden - 35 kg.

In terms of per capita consumption of vegetables, Greece leads at 257 kg, South Korea - 250 kg, Turkey - 238 kg, Jordan - 216 kg, China - 212 kg, USA - 200 kg, Israel - 197 kg, Ukraine - 163 kg, Russia - 79 kg (at a normative rate of 128 kg).

According to the forecast of indicative data for the development of the farming industry of the EAEU member states by main types of agricultural and food products for 2017-2018, a decrease in specific indicators of the availability of basic types of agricultural equipment was expected by 2018, as compared to 2015, despite the planned increase in the number of combine harvesters and generally maintaining the existing number of tractors (99.9%).

An increase in the crop area in the EAEU member states by 2.7% to 111.8 million ha and the expected increase in the production of the main types of crop products against the background of a decrease in the availability of agricultural equipment contribute to an increase in the load per unit of equipment and pose risks of reducing the mechanization level of rural farms.

On the domestic market of the member states there is a significant demand for foreign agricultural machinery, which is delivered mainly from the European Union (**Table 1**). Its share in total imports accounts for 65.9%. Significant importers to the EAEU also include the United States (15.2%), China (7.5%) and Canada (4.6%).

In 2017, the production of tractors in the EAEU amounted to 41.9 thousand units, which is 2.9% more than in 2016. At the same time, tractor imports decreased to 8.4 thousand units (by 30%), and exports grew to 16.4 thousand (by 16%). The market capacity (excluding mutual trade) amounted to 44.1 thousand units (a decrease of 4.3% over the previous year).

In Russia, according to the Federal State Statistics Service, three

Table 1 Import of agricultural machinery to the EAEU Member States from the European Union, units. (Aksenov, A. G., Sibirev, A. V., Emelyanov, P. A., 2016)

Agricultural machinery	Republic of Armenia	Republic of Belarus	Republic of Kazakhstan	Kyrgyz Republic	Russian Federation	Total
Planters and transplanters	4	624	5	18	772	1,423
Precision seeders	8	6	27	4	640	685
Machines for harvesting root crops and onions	1	14	4	–	66	85

types of producers grow vegetables with the following share in gross output (2014): agricultural enterprises - 14.2%; private farm households - 74.8%; peasant farm enterprises - 11% of total production (Artyushin, Elizarov, Lobachevsky, 2012).

In 1990, the share of agricultural enterprises in the gross harvest of vegetables amounted to 69.9%, the rest accounted for private farm households (**Fig. 1**).

By 1995, the share of agricultural enterprises decreased in more than two times, and so far it has been decreasing as well, while the share of private farm households has remained at the same level for more than 20 years - about 74%. This is due to the fact that production in private farm households is primarily aimed at meeting their own needs, and the crop area, as a rule, does not exceed 0.5 hectares, so the purchase of expensive equipment is not always economically feasible (Sorokin and Ponomarev, 2010).

From 1990 to 2015, the number of vegetable seeders decreased in seven times, that of vegetable harvesters in thirteen times, and that of irrigation machines and plants in fifteen times (**Table 2**).

There are several reasons for the sharp fall. First, the number of agricultural enterprises decreased in four times. Namely, these enterprises featured the greatest availability of machines for vegetable growing. Personal subsidiary farms have no specialized machinery (Aksenov, Sibirev, Emelyanov, 2016).

Second, machinery began to be imported to the Russian market, which are two or more times higher than the replaced equipment in terms of performance and reliability (Litvinov, Ludilov, 2011).

Table 3 shows how much the number of machines has decreased per 1000 ha and the load per a machine has increased.

The use of vegetable-growing equipment is very intensive and it exceeds all the existing standards (**Table 3**). So, for vegetable seeders, the standard annual workload is 40 hectares, and in fact it amounts to more than 150 hectares, a similar situation is observed with other machines (Emelyanov, Aksenov, 2009). The above analysis of the state of machine and tractor fleet in Russia applies to farms directly involved in the production of vegetables, however, to meet the needs of vegetable farms with elite seeds, a set of machines and equipment for their cultivation is required.

For sowing the elite seeds of carrot, onion, cabbage, and beetroot, use is made of precision vegetable seeders, the total need for which amounting to 230 units.

Seed farms require more than 200 planting (transplanting) machines, 440 harvesting machines and 450 machines for post-harvest processing of vegetable crops.

Table 4 shows data on the needs of Russia in elite seeds of vegetable crops and machines for their production.

Harvesting is one of the most labor-intensive technological operations. Its share in total labor costs and wages is: for tomato - 51.9 and 49.9%, respectively; for cucumber - 60.4 and 57.4%; for carrot - 81.4 and 77.1%; for table beetroot - 63.7 and 60.9%.

To satisfy the need of vegetable seed producers in harvesting machines, with their standard annual workload amounting to 28.5 ha, about 400 units are required.

On the Russian market there are machines for the separate collection of onion, potato, carrot, cabbage and beetroot from several manufacturing companies.

These are machines for cutting tops, digging vegetables, and loading products into vehicles. They are produced by Asa-Lift (Denmark), Samon (Holland), Simon (France) and others.

To ensure high field germination

Table 2 Machinery fleet for growing vegetables in specialized farm enterprises, thousand units (Aksenov, A. G., Sibirev, A. V., Emelyanov, P. A., 2016)

Agricultural machinery	1990	1995	2000	2005	2010	2013	2014	2015
Vegetable seeders	7.37	4.95	3.41	2.10	1.47	1.35	1.26	1.21
Transplanters	1.10	0.74	0.51	0.32	0.22	0.20	0.19	0.18
Combine harvesters	14.70	9.36	4.50	2.00	1.32	1.27	1.23	1.18
Sprinkling and irrigation machines and implements	79.40	46.3	19.20	8.60	5.40	5.30	5.20	5.20

Table 3 Technical equipment of agricultural enterprises with machines for vegetable growing (Aksenov, A. G., Sibirev, A. V., Emelyanov, P. A., 2016)

Indicators	1990	1995	2000	2005	2010	2013	2014	2015
Vegetable seeders:								
number of machines per 1000 ha, units	18.1	19.2	15.6	12.6	8.2	6.5	6.6	6.4
crop area per a machine, ha	55.1	52.1	64.2	79.5	122.5	153.8	152.0	157.2
Vegetable harvesters:								
number of machines per 1000 ha, units	36.2	36.3	20.6	12.0	7.3	6.1	6.4	6.2
crop area per a machine, ha	27.6	27.6	48.6	83.5	136.4	163.5	155.7	161.2

Table 4 The need for elite seeds of vegetable crops and agricultural machines (Aksenov, A. G., Sibirev, A. V., Emelyanov, P. A., 2016)

Indicators	Onion	Carrot	Beetroot	Cabbage
Total amount of seeds, t	1,200	500	1,000	100
Vegetable harvesting machine				
Crop area, ha	2,400	555	500	125
Vegetable Seeder	52	12	11	3
Transplanter	240	56	50	12
Vegetable harvesting machine	171	40	36	9
Vegetable processing machine	171	40	36	9

of seeds, they must be processed properly after harvesting and stored in appropriate conditions. Seed farms need more than 400 machines for primary processing of vegetables. They are supplied to the Russian market by Daunmar, Upmann and other manufacturers.

For high-quality extraction of vegetable seeds from various impurities, seed threshing and rubbing, as well as separation of seeds, additional post-harvest equipment is necessary: seed hummeling machines, seed cleaning machines, separators (gravity, dielectric, photo separators) and others. Such companies as Cimbria (Denmark), Petkus (Germany) are considered to be the leading manufacturers of post-harvest seed processing machines.

In Russia, Federal Scientific Agroengineering Center VIM is engaged in the design, research, and production of machines of this type (Izmailov, Lobachevsky, Kynev, 2008).

One of the features of vegetable growing is the particular sensitivity of plants to maintaining water balance during the period of growth and development, and therefore, crops and plantings must be irrigated (Ludilov, 2011).

In the past decade, drip irrigation technology has been widely implemented using appropriate equipment: pumping stations, pipelines, drip tubes, pipe layers, drip tube extraction machines. In Russia, equipment for drip irrigation and mulching film laying is not produced, but is fully imported from abroad (Bekseev, 1998).

Where drip irrigation is difficult or impractical, drum-type sprinkler machines are used. In some farms, irrigation plants such as DDA, Frigate, and Kuban have still been preserved and are successfully operating.

In the Russian Federation, machines for vegetable growing are produced by Kolnag LLC, Agrotehmash LLC, Millerovoselmash OJSC, Voronezhselmash LLC, Belinskselmash CJSC and a number of other machine-building enterprises.

In particular, Kolnag LLC, in cooperation with Western European partners, produces equipment for the cultivation of vegetable crops from basic and pre-planting tillage to preparing marketable products for storage. Sowing and planting machines of Kolnag LLC are intended both for sowing small-seeded vegetable crops and for planting mother root crops. Machines of this plant are used in the cultivation of onion, carrot, beetroot, and green crops.

Belarus produces tractors for agriculture, fertilizer spreaders, machines for harvesting potato and vegetables, and, of course, combine harvesters.

RUE “Gomselmash”, OJSC “Bobruiskagromash”, OJSC “Lidaagroprommash” produce machines for a wide range of operations - from presowing tillage to postharvest processing of marketable products: cultivators, combing machines, sowing machines, harvesting machines, as post-harvesting machinery sets.

Gomselmash Holding is a diversified manufacturer of agricultural machinery. For vegetable growing, they produce the КГО cultivator-bed cultivator, СТВ-8К, 8КУ, 12,

Fig. 2 Gross harvest and yield of vegetables in farms of all categories of the Rep. of Belarus (http://www.belstat.gov.by)

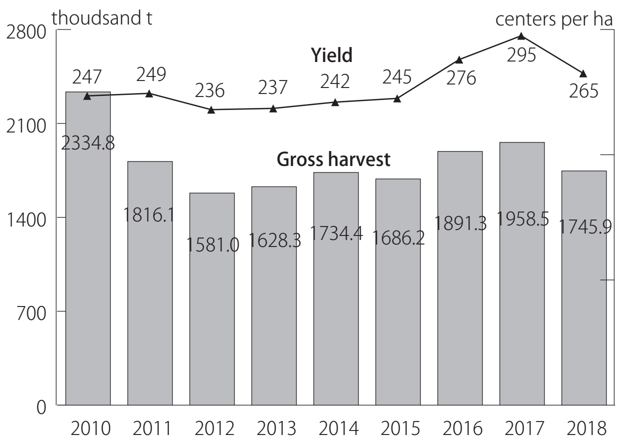
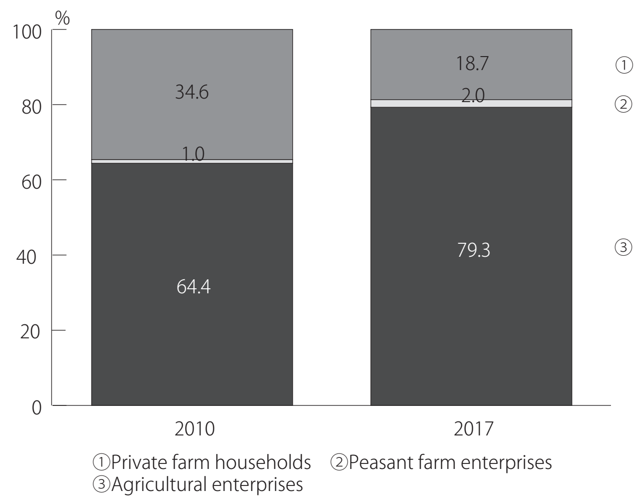


Fig. 3 The production structure of vegetable crops by farm categories in the Rep. of Belarus (http://www.belstat.gov.by)



12У seeders designed for sowing seeds with a diameter of 2.5 mm and row-spacing of 60-75 cm. For the cultivation of vegetable crops, a self-propelled high-level sprayer OBC-4224 was developed, for the transportation of vegetables - trailer 2ПТС-14.

OJSC Bobruiskagromash manufactures machines for applying liquid and solid organic and mineral fertilizers (МЖУ-20, МТУ-18, РУ-7000).

A special line has been developed for post-harvest processing of vegetable crops, including a БПВ-40 receiving hopper, a system of transporting conveyors ТВН-40, a pick-up table ПР-10, and a sorting station ПКСП-25.

According to studies of the National Statistical Committee of the Republic of Belarus, in 2010-2018. crop areas in farms of all categories decreased from 85.7 thousand to 62.4 thousand ha. Despite the fact that the yield of vegetable crops is increasing, the gross harvest of vegetables is still being reduced, which was the result of a reduction in crop areas (**Fig. 2**).

The largest gross harvest of vegetables is obtained by agricultural enterprises, whose share in the overall structure of production is 79.3% (**Fig. 3**).

From 2012 to 2018, the gross harvest of vegetables in the Republic is gradually growing. In 2016, it reached 1891.3 thousand tons.

Manufacturers of agricultural machinery of the Republic of Belarus are actively developing assembly production in the territory of the Member States of the Customs Union and the Common Economic Space.

Gomselmash Production Association also has nine assembly enterprises in Russia and one enterprise (AgromashHolding JSC) in Kazakhstan, which produce mechanized units for soil tillage for vegetable growing: disk tillage unit - АПД-7.2, disk cultivator - ЛДГ-10/15, cultivator combing machine - КГР-5.7.

OJSC Bobruiskagromash has seventeen assembly plants in Russia and two in Kazakhstan.

There is no production of agricultural machinery in the Republic of Armenia, imports are also insignificant (**Table 1**). In 2017, four planting machines, eight seeders and one machine for harvesting root crops and onion were imported to the Republic.

This indicates a weak level of mechanization in the vegetable growing industry, which affects the crop areas, which are the smallest of all EAEU member countries.

In the Kyrgyz Republic, areas under vegetable crops are gradually increasing due to growth in the number of peasant and private farms (**Figs. 4** and **5**). There are only means of partial mechanization used for cultivation and harvesting of vegetable crops. Since 2016, the country has not produced farm machinery, and the imports of machine sets for vegetable growing does not allow for the industry to be maintained at the modern level of mechanization.

In 2017, twenty-two farm machines were imported from the European Union to the Kyrgyz Republic, of which eighteen were planting machines and four - sowing machines.

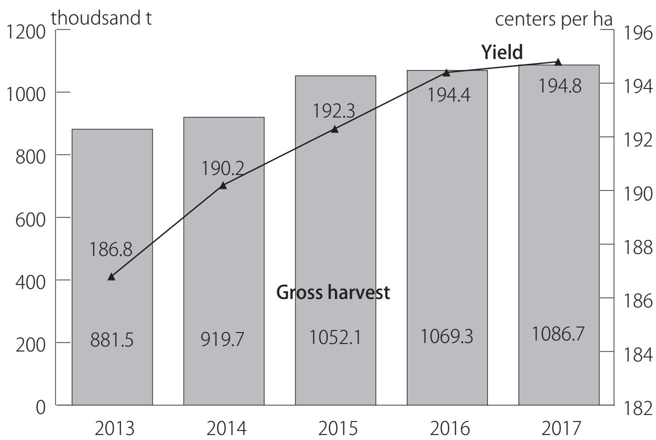
In the Republic of Kazakhstan, manufacturers produce machines for primary and pre-planting soil tillage, seeders, as well as machine sets for harvesting vegetables.

To a large extent, this is due to the presence of assembly production of the leading manufacturers of farm machinery of the EAEU member states: RUE Gomselmash (Republic of Belarus), as well as OJSC Rostselmash (Russian Federation).

In the territory of the Republic of Kazakhstan, OJSC Rostselmash produces offset harrows and cultivators, as well as trailed and self-

Fig. 4 The structure of cultivated areas under vegetable crops by farm categories of the Kyrgyz Rep. (http://www. Stat.kg.ru)

Fig. 5 Gross harvest and yield of vegetable crops for all farm categories of the Kyrgyz Rep. (http://www. Stat.kg.ru)



propelled sprayers for the vegetable growing industry.

According to the results of studies performed by the Statistics Committee of the Ministry of National Economy of the Republic of Kazakhstan, the state fully meets the need for vegetables through its own production in farms of different categories (**Fig. 6**). Gross harvest of vegetables is growing annually (**Fig. 7**).

Significant subsidies and subventions are transferred from the state budget to the farm industry of Kazakhstan, the tax burden is eased, and foreign investors are attracted. But, despite all the measures taken, there are significant problems in the industry. One of them is the unfavorable state of the agricultural machinery fleet: farm machinery wear is about 80%.

The formed dynamics of intensive agricultural production in Kazakhstan indicates an imbalance in the production capacity of agricultural enterprises with the level of technical security of the country's agribusiness.

Conclusions

In the member states of the Eurasian Economic Union, an increase in vegetable production volumes inextricably correlates with the level of technical support for the vegetable growing industry, which confirms the localization degree of agricultural machinery industry in the Russian Federation, as well as in the Republic of Belarus and Kazakhstan, where they produce machine sets for operation ranging from pre-planting tillage to post-harvest processing of marketable products:

- Russian Federation: LLC Kolnag, LLC Agrotehmash, CJSC JV Bryanskselmash, OJSC Millerovoselmash, LLC Voronezhselmash, CJSC Belinskselmash, etc.;
- Republic of Belarus: RUE "Gomselmash", OJSC "Bobruiskagromash", OJSC "Lidaagroprommash";
- Republic of Kazakhstan: assembly production of RUE "Gomselmash" (Republic of Belarus), as well as OJSC "Rostselmash" (Russian Federation).

In the domestic market of the EAEU member states there is a high demand for equipment from the European Union:

- planters and transplanters - more than 1000 units;
- precision seeders - more than 600 units;
- machines for harvesting root crops and onion - more than 80 units.

The demand of EAEU producers for modern high-tech machinery sets used for vegetable crop production is very high today. But most agricultural enterprises in the EAEU are low-profitable and cannot purchase expensive equipment at their own expense. Therefore, one of the main mechanisms for upgrading the agricultural machinery fleet is to attract credit resources from commercial banks and leasing companies.

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Fig. 6 The structure of cultivated areas under vegetable crops by farm categories of the Rep. of Kazakhstan (http://www.Stat.gov.kz)

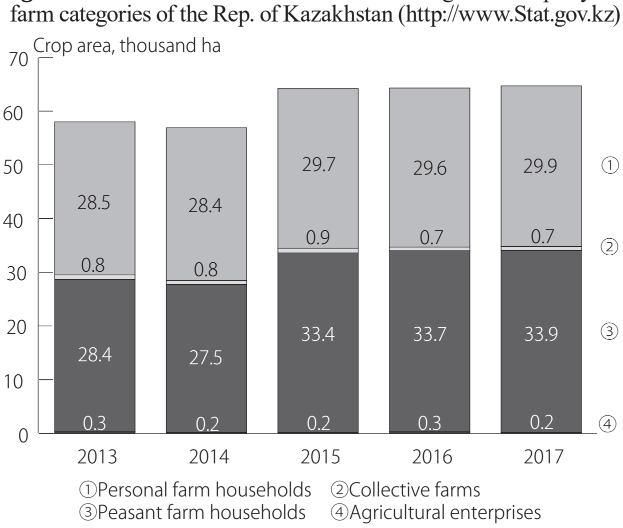
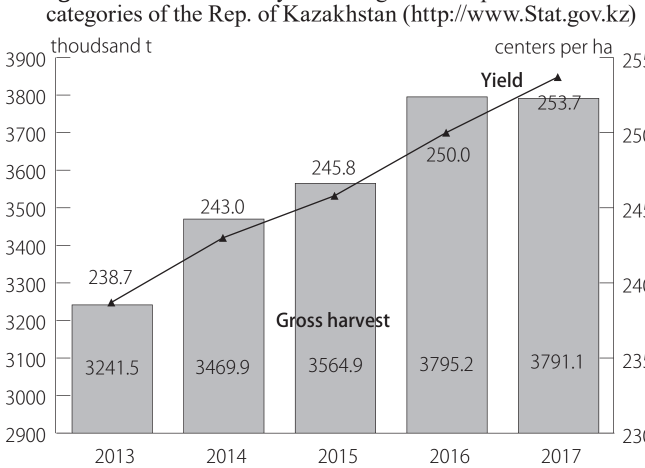


Fig. 7 Gross harvest and yield of vegetable crops for all farm categories of the Rep. of Kazakhstan (http://www.Stat.gov.kz)



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The Prospect of Using Gas Turbine Power Plants in the Agricultural Sector

by

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Abstract

The research discusses issues related to the use of gas turbine engines in mobile vehicles, and the conditions for their effective operation. Russian manufacturers have repeatedly tried to use a gas turbine engine as a drive for cars and tractors. But for various reasons, this is not possible. At the same time, foreign manufacturers are developing the tractors production with gas turbine engines of various traction classes for industrial and agricultural purposes. The research purpose is to identify the advantages of using gas turbine engines on tractors for industrial and agricultural use; to develop kinematic schemes and electromechanical transmissions for tractors with gas turbine engines. The authors studied the experimental studies' results in Russia on the use of gas turbine engines on tractors and cars. They identified their advantages and disadvantages compared to diesel counterparts. It was shown that abroad, tractors with gas turbine engines are successfully operated in industry and agriculture, as their power units are adapted to each other and have significant economic efficiency. The determining factor for such advanced equipment production was the availability of precision engineering, digitally controlled machine tools at manufacturing enterprises, and qualified service personnel. The authors described the parameters of gas turbine engines in comparison with diesel counterparts. They presented a kinematic diagram of an experimental K-701 tractor with a gas turbine engine. They revealed the advantages and disadvantages of its structural design. They showed various types of electric transmissions used on diesel tractors for industrial and agricultural purposes. To increase the efficiency of work on industrial and agricultural tractors of various traction classes, it was recommended to use gas turbine units adapted with an electromechanical transmission.

Keywords: gas turbine engine, gas turbine tractor, electromechanical transmission, kinematic scheme, diesel engine.

Introduction

Modern agricultural self-propelled vehicles have a diesel power unit in the engine-transmission compartment, a mechanical or automatic gearbox and drive and driven axles. This kinematic scheme works well and is time-tested. Such vehicles are widely used in transport, in agriculture, construction, and military equipment production.

Mechanical technical means in agriculture are used to mechanize operations and technological processes in order to increase labor productivity. For each type of work, there are various types of equipment - tractors, combines, self-propelled machines, in which the drive is represented by a diesel engine and mechanical transmission.

Research purpose is to identify the advantages of using gas turbine engines on tractors for industrial and agricultural purposes; to develop kinematic schemes and electromechanical transmissions for tractors with gas turbine engines.

Materials and Methods

The main advantages of gas turbine engines (GTE) over diesel ones has proven its easy start-up at low temperatures (within 1-1.5 minutes without heating at a temperature of minus 35 °C); reduction in the complexity of maintenance by 25-47% and the cost of overhaul by 23-65%; weight reduction of 1.8-2.5 times and dimensions of 1.4-1.6 times. Such engines can operate on various types of fuel without significant alteration of systems, they emit toxic components 3-5 times less, they are characterized by lower levels of vibration and noise, they are well adapted to external loads, their production requires 4-5 times less parts (Kossov, M .A., 1964; Zhdanovsky, N. S. et al., 1986; Popov, N. S. et al., 1980).

One of the significant drawback of GTE - low fuel economy - is practically eliminated; the best examples of autotractor GTE with a capacity of 260-440 kW have a specific fuel consumption of 210-250 g/kW·h. The issue of reducing it to 200 g/kW·h is being successfully resolved. On the agenda is improving engines' operational reliability and durability. In order to improve efficiency, ceramic materials are used, the initial gas temperature is increased to 1,350-1,370 °C, the degree of pressure increase (lx) is increased to 5.5-8.0 and the regeneration rate to 0.9. The GTE engine resource is almost brought up to 60,000 engine hours.

Despite the relative simplicity of the design, small masses, dimensions, and a number of other very important advantages, the tractor's twin-shaft gas turbine engine has not yet been given sufficient attention, since manufacturers of promising cars and tractors have not stopped at choosing a specific type of transmission (electric, hydrostatic, friction and others, including stepless and differential, except mechanical).

Gas turbine units as a vehicles drive are mainly represented in the armed forces of technically developed countries, for example, on the Russian main tank T-80U with a capacity of 1,250 hp. or on the American Abrams M-1 A-1, Abrams M-1 A-2 power of 1,500 hp

In 1950, in the USA, Boeing together with Kenworth installed a 175-horsepower gas turbine in the engine compartment of the main tractor. The installed turbine weight was 91 kg - 13 times less than a diesel engine of similar power. And the volume occupied by the gas turbine engine was 2 times less than the volume of the engine compartment (**Fig. 1**). However, the manufacturer refused to carry out work on replacing the diesel unit with a gas turbine one, explaining this by the necessity for a complete change in the transmission design and the car's units layout, which at that time was not economically feasible.

At the same time, in the Soviet Union, the Kremenchug Automobile Plant tried to install a gas turbine engine on the KrAZ-256 dump truck, but the engine power was too small and the volume did not allow to install this engine under the hood, as the Soviet turbine of the same power was larger than the American one. In addition, it needed a cumbersome reduction gear, as the turbine shaft rotated at a speed of 35 thousand rpm, which was critical for the existing transmission.

After that, by the USSR Ministry of Defense order and with its financing, the plant completed testing of the new KrAZ-260, with an aggregate capacity of 350 hp. The clutch and gearbox were purchased in Hungary and were installed on the experimental KrAZ-E260E (**Fig. 2**). The hood of this car was significantly longer compared to the serial KrAZ-260 (**Fig. 3**).

The developed power unit design opened up significant prospects: the engine weighed half the serial YaMZ, the exhaust was 3-6 times cleaner, and fuel consumption in nominal conditions was 20% lower.

As tests' result, the machine passed 2500 km. Most of the faults were caused by the Hungarian transmission: as stated in the plant history book, "it could not withstand any criticism."

In 1976, the second KrAZ-E260E was created, with a more compact gas turbine unit. At the same time, the power was increased to 360 hp, and the fuel consumption in the steady state was 1.4 times less than that of the diesel counterpart. However, when operating in transient conditions of "acceleration" and "braking" the turbine significantly exceeded the diesel engine fuel consumption. Other quite logical problems were added: the dynamics left much to be desired, the transmission

Fig. 1 Main tractor with a gas turbine engine

Fig. 2 Gas turbine KrAZ-E260E

Fig. 3 Gas turbine engine on KrAZ-260

was constantly breaking. This was due to the fact that the gas turbine engine rotor had a high level of inertia. Spinning up to 20-30 thousand rpm, it could not quickly reduce the speed, even if the fuel supply was completely shut off. Therefore, gear shifting occurred at drive shaft high speeds, which was critical for the transmission. For safe speed switching, it was necessary to wait a few minutes when the speed decreased, but the car could stop by that moment. On this Krazov experiments ended.

Results and Discussion

Today, with hindsight, it becomes clear that for automotive technology it is necessary to develop a class of gas turbine drives that could synchronously work with modern automatic and electromechanical transmissions designed specifically for such engines.

The gas turbine engine has proven itself in industrial plants, where the “acceleration” and “braking” modes are excluded during operation.

Abroad, gas turbine tractors have successfully passed field tests.

Work in this direction is continuing intensively, and the existing designs reflect the most characteristic features of gas turbine tractors.

The American tracked bulldozer R-91, created by Alice Walters, with a GTE 502-US with a power of 177 kW from Boeing, is widely known abroad; DW-15 wheeled tractor of the American company Caterpillar with General Motors GTE of 166 kW, Canadian wheel tractor manufactured by AVCO Canada with a GTE T-6 model of 236 kW, NT-340 agricultural tractor of the American company International Harvester with gas turbine of Titan Solar company the T-62T model with a power of 59 kW, as well as small traction class tractors (**Fig. 4**).

In addition, there is a number of tracked vehicles and tractors with GTE and machines similar in operation to tractors.

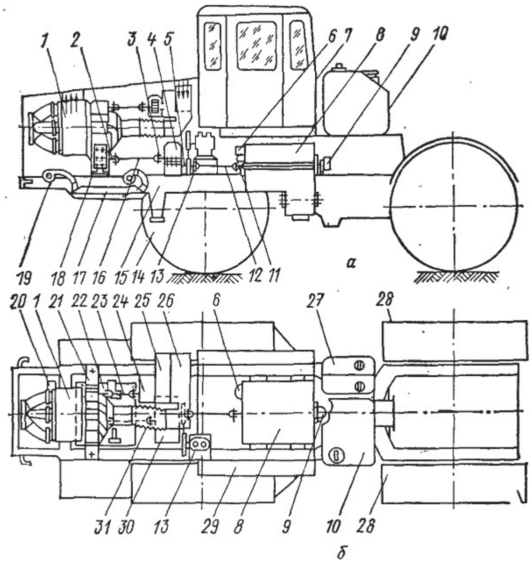
Their power units are adapted to each other and have significant economic efficiency. The determining factor for the production of such advanced equipment is the availability of precision engineering, digitally controlled machine tools at manufacturing enterprises, and qualified service personnel.

In national practice, the results of working with GTE of the Kirovets type tractors are most fully generalized. One of these tractors was created on the basis of K-700 model (**Fig. 5**).

It is of interest to consider a gas turbine tractor (GTT) of the LSHI-LKZ Turbo type, created on the basis of K-700 and K-700A tractors (Ageev, L. E. et al., 1986). It has a twin-shaft gas turbine engine of GTD-350T type (**Fig. 6**) (Shkrabak, V. S. et al., 1983).

The diesel engine is replaced by a gas turbine unit and is located in the tractor front part so that the longitudinal axes coincide in direction. In addition, the engine output shaft (its traction turbine) faces reduction gear and gearbox. In the nominal mode, the output shaft has a speed

Fig. 6 The basic layout of the gas turbine tractor "Kirovets"

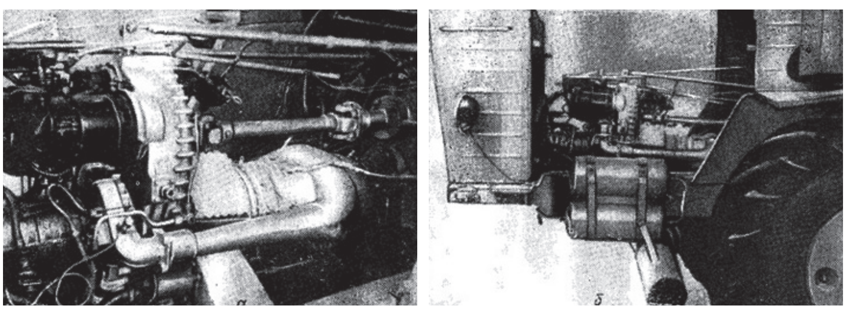


a - side view; b - top view

1 - gas turbine engine; 2- an engine output shaft; 3 - reduction gear drive shaft; 4 - reduction gear; 5 - reduction gear driven shaft; 6, 9 - hydraulic pumps; 7 - a cabin; 8 - gearbox; 10 - a fuel tank; 11 - gearbox drive shaft; 12, 16, 23 - cardan shafts; 13 - tractor pneumatic system compressor; 14 - front wheels; 15 - tractor frame; 17 - a casing; 18 - side panel; 19 - electric fan; 20, 21 - supports; 22 - a distributing shaft; 24 - fan; 25 - a radiator; 26 - air cleaner; 27 - an oil tank; 28 - rear wheels; 29 - wing; 30 - a box of drives; 31 - corrugated sleeve

Fig. 4 Cub Cadet gas turbine tractor Garrett GTP 30-67

Fig. 5 Gas turbine engine of the Kirovets tractor



(a) General view (b) Location

of 6,595 rpm; therefore, to maintain tractor's traction and speed characteristics, the reduction gear has a gear ratio of 3. The ability to move the engine in horizontal and vertical planes allows to ensure alignment of its output shaft with the reduction gear drive shaft; these shafts are connected between each cardan. The reduction gear drive shaft is installed coaxially with the drive shaft of the gearbox and is connected to it by a cardan. The power steering pumps and tractor hydraulic systems are attached to the box body, the drive shafts of which are connected by spur gears to the gear of the input (primary) shaft of the gearbox.

Thus, when the engine is idling, the rotation from the traction turbine rotor is constantly transmitted to: output shaft, reduction gear drive and output shafts, gearbox drive shaft, hydraulic pumps. These units are a constant load on the engine and require fuel costs, which, in authors' opinion, is wrong.

To transfer movement to the tractor wheels, hydraulic pumps supply oil to the clutch boosters. The entire kinematic chain is driven, which in this case is exactly the same as that of the serial K-700A tractor, its gearbox is used in an experimental tractor and is not adapted with a gas turbine unit.

Following the path of least resistance, the plant's specialists retained the serial gearbox, which is not considered the best solution. At a rated output shaft speed of 6,595 rpm, the overall dimensions of the developed for this engine gearbox could be reduced three times.

The gas turbine engine is installed on the front and rear bearings. The oil cooling system fan in the engine oil cooler is driven into rotation from the engine transfer shaft through the cardan. Together with the cyclone type air purification system, it is installed in the engine compartment on a welded frame located between the engine and the cabin. The air pipe of the air purified in the air purifier is connected with the corrugated sleeve to the air inlet to the engine.

The air supply system includes an air intake device with a mesh, a cyclone type air cleaner, an oil cooler blower fan and air ducts (**Fig. 7**).

On gas turbine tractors, it is possible to use various types of transmissions, which determines their traction and dynamic parameters. Particular attention is paid to agricultural tractors transmissions, including gas turbines, due to the unsteady nature of the load, which is often found in agricultural production. The negative impact of this load type on the power plants workflow of gas turbine units is almost neutralized due to the gas-dynamic connection of the traction and compressor turbine rotors. However, it affects negatively the working conditions and the durability of the transmissions. Usually mechanical, hydrodynamic, hydrostatic and electric transmissions are installed.

The authors consider the electromechanical transmission to be the most promising for a powerful and heavy-duty tractor with a gas turbine engine. Such transmissions were developed in the Federal Scientific Agro-engineering Center VIM. They have the ability to work simultaneously with gas turbine engines thanks to the gas-dynamic transmission of torque, which greatly simplifies such machines layout.

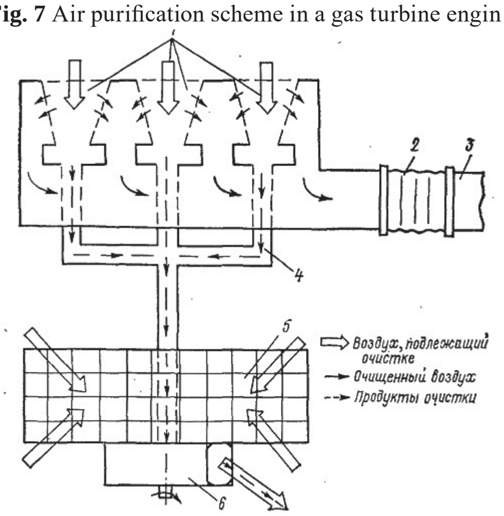
Some types of electric transmissions developed in the second half of the twentieth century, successfully operate on diesel engines such as DET-250, DET-400, DET-400M.

Electric transmissions can operate on direct or alternating current, as well as on combined power sources. DC transmissions have a wide range of speed control and provide the ability to create an "opaque" scheme. However, their use is hindered by comparatively large mass and dimensional indicators, low reliability in the presence of brush contacts, and high manufacturing costs. At the same time, a search is on the way to address these shortcomings.

There are several electromechanical transmissions electrical connections: on asynchronous squirrel-cage motors; the same with power from thyristor converters; with brushless motors in combination with valve switches; with AC-DC collector motors and others.

AC transmissions have good mass and overall dimensions due to the direct connection of the gas turbine engine shaft with the generator shaft (non-contact or synchronous). In the simplest version, multi-speed synchronous squirrel-cage traction motors are used. The required speed control range is provided as a result of changing the traction turbine rotational speed of a twin-shaft gas turbine engine, also by switching the number of induction motors pole pairs. The electric transmission in this embodiment is almost identical in properties to a conventional three-stage "transparent" mechanical transmission. The main disad-

Fig. 7 Air purification scheme in a gas turbine engin



1 - air purifier cyclones; 2 - corrugated hose; 3 - gas turbine compressor; 4 - collector of polluted air; 5 - oil cooler gas turbine engine; 6 - radiator fan

vantage of this option is considered an overload due to the rigidity of the induction motors mechanical characteristics.

In another variant, each of the asynchronous squirrel-cage traction motors is powered by an individual thyristor static frequency converter. According to this scheme, several electric transmissions were performed, for example, at a BelAZ-549V dump truck, an ER-9A electric train, and a number of others. Currently, frequency converters with a DC link and with direct connection of circuits are used. The first ones consist of a controlled or uncontrolled rectifier and an autonomous inverter that converts direct current into alternating current of adjustable frequency and voltage. A standalone inverter can provide the required frequency control range, and hence the speed of induction motors. However, to obtain the desired traction characteristic waveform, to balance the load on the onboard electric motors when turning the machine, a complex automatic control system for SAU2 is required. A relatively small number of thyristors and the absence of capacitors for their forced locking, as well as the ability to receive a current that is close in shape to a sinusoidal output, have become important advantages of converters with direct circuit coupling. However, these converters are used less and less due to the limitation of the upper limit of the operating frequencies (up to half the frequency of the generator) and the consumption of significant reactive power.

In the case of a combination of brushless traction motors with valve switches (motors), the switching of the windings occurs in the same way as for DC machines, depending on the rotor rotation angle. Valve motors have a mechanical characteristic favorable for traction, which greatly simplifies the control system of ACS2 and provides a significantly lower mass than DC motors.

The complexity of the last two systems, the lack of sophistication and the high cost of thyristor converters, switches and control systems remain a common shortcoming that hinders their widespread use.

AC-DC transmission includes a synchronous generator, a block of silicon power valves and DC traction motors. Silicon valves (current up to 320 A at voltages up to 1000 V) make it possible to create compact and reliable rectifier units that are easily installed on mobile machines. It is not difficult to develop a simple and reliable system for the automatic control of independent excitation traction motors ~ SAU2.

To change the speed of asynchronous motors, frequency converters based on field and AGBT transistors are widely used. Such converters are the most compact, reliable and have a higher conversion efficiency.

Conclusions

Analysis of literary sources showed that gas turbine engines for Russian mobile equipment were used only on the main T-80U tanks.

Russian manufacturers have repeatedly made attempts to use a gas turbine engine as a drive for cars and tractors, but for various reasons this could not be done.

Foreign manufacturers are developing the production of tractors with gas turbine engines of various traction classes for industrial and agricultural purposes.

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The State, Promising Directions and Strategies for the Development of the Energy Base of Agriculture

by

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Abstract

In this article, indicators of energy consumption in agriculture have been discussed, starting from the year 1990, and their forecast values for the period up to 2030 with the analysis of the decay in the period from 1991 to 2010 and gradual growth of energy resources consumption started in 2010 and continued to the present days have been analyzed. The outlines of the strategy of rural energy base development and optimization have been considered. Demand, development and implementation conditions of decentralized energy supply systems have been substantiated, and their features, composition and application field have been specified. It has been shown that the major energy resource of standalone energy systems is local and renewable energy sources and of agricultural production wastes. Methods and technologies for conversion of renewable energy sources (RES), biomass and wastes of agricultural production into heat and power have been characterized. Perspectives of decentralized energy supply systems in rural areas and forecast quantitative indicators of their contribution to the energy balance for the period to 2030 have been outlined.

Analyses and Discussion

The strategy of rural energy basis development comprises perspective directions and target indicators of power supply systems and facilities improvement, reduction of energy intensity of agricultural production and growth of its energy efficiency, increasing the level of living standards and labor conditions of rural population, as well as that of projected energy demand and energy carrier structure [1].

Importance of rational and effective energy provision of agricultural enterprises, sites and social services has raised, in recent years, which can be explained by expanding and enhancement of electrification, electrical mechanization and automation of technological processes, as well as by inadequate (dominating) growth of electricity tariffs compared to agricultural product prices that resulted in the increase of energy share in product cost, to a substantial extent.

Both the reliability and quality of energy supply have decreased while the frequency and duration of power and heat outages have grown for various reasons. Therefore, we are behind many developed countries, in a wide range of energy indicators. Though we have vast energy resources including both conventional and local ones their use in agriculture has not yet become well-targeted and effective.

Energy intensity of agricultural production in Russia is 2 to 2.5 times higher compared to advanced countries. Fuel utilization factor (FUF) does not exceed 40% (while in advanced countries FUF > 50%). Reliability of power supply is one order of magnitude lower than that in advanced countries. That is, the average number and duration of mains failures exceeds 90 hours per year (while abroad this parameter equals to only 10 h/year). Energy loss in power grid amounts to 14.5% (8.9 %, in advanced countries) while that in rural heat supply networks exceeds 20%. In rural areas, only 68% of farms, enterprises and residential sector are connected to gas distribution networks. The share of non-conventional and renewable energy sources in rural energy balance does not exceed 1.2% which is one order of magnitude lower compared to advanced countries.

That is why the issues of rural energy basis development, as well as those of energy efficiency, estimation and forecasting energy demand of enterprises, improvement of energy supply reliability and quality, development and implementation of energy-saving technologies and equipment, wide use of centralized systems, local and renewable energy resources, have gained essential importance and relevance, today.

The major indicators of energy efficiency in agricultural production are energy intensity and the share of energy-related costs in total production cost. In terms of these indicators, national agriculture is behind that of advanced countries where energy intensity is substantially lower than in Russia. The share of energy-related expenditures in agricultural products cost has attained 30%, by 2015, and today it exceeds significantly the level of the year 1990 when it was in the range of 10% to 15%.

Relatively low energy efficiency of agricultural production and being behind advanced countries are conditioned by certain external and internal reasons comprising the following ones:

- Harsh (cold) weather conditions,
- Relatively low, compared to advanced countries, production efficiency in agriculture (only in the poultry breeding branch we have nearly attained the level an advanced countries),
- Relatively low technical and organizational level of energy supply systems having the values of fuel utilization factor not higher than 40%,
- Unsuitable implementation rate of groundbreaking systems and modern energy-efficient equipment, as well as that of decentralized energy supply systems and facilities in agriculture including those on the basis of local and renewable energy sources and wastes of agricultural production.

In 1990-s and early 2000-s, decrease of agricultural production was accompanied by considerable reduction of energy consumption. Thus, consumption of fuel-and-energy resources (FER) in agriculture had a two-fold drop, by 2005, in comparison to 1990, while the aggregate rural FER consumption decreased by 45%.

In that period, annual electric power consumption decreased by 40% and fell down to 1500 kWh/person. In production sphere, it was a subject to nearly 3 times drop accompanied by 2 times decrease of electric power supplied per job.

At the same time, electric power consumption in domestic area, personal subsidiary plots (PSP) and social sphere had raised by 30% (from 29 bln. kWh to 38.0 bln. kWh), by 2005, which can be explained by shifting of substantial factual agricultural production from the public sector of economy to the private one (family farms and personal subsidiary plots) [2], as well as by a broader application of electrified equipment and facilities and household appliances. Nevertheless, annual electric power consumption per person in domestic sector and PSP was lower in rural areas than in urban ones, and this was an abnormal situation.

The main reason for energy resources consumption decrease in that period was substantial, nearly two-fold, reduction of production volumes and that of plowed field and area under crops [3]. Since 2005, in view of a certain recovery of agricultural economy and production growth of a number of agricultural items, the indicators of energy and electricity consumption started to grow. Thus, electric power consumption increased by 7%, by 2015 compared to 2005. But it happened mainly owing to the growth of power demand in domestic sector, PSP and family farms. The contribution agricultural enterprises to this growth were not so tangible, deviating slightly from year to year.

In 1990, the aggregate volume of gross agricultural product in all categories of household was 4.35 trillion rubles (72.5 Billion Dollars), in comparable prices. This indicator was decreasing till 2005 and, from that moment, recovery and a certain growth of production took place. In 2015, the aggregate price of agricultural products attained the level of 1990 [2].

In 1990, energy resources consumed for production purposes in all categories of household amounted to 75.0 mln tce while in 2014 it was equal to 47.0 mln tce (**Fig. 1**). Nevertheless, the aggregate energy resources consumption in the production sector had reduced by 35%, in all categories of household, and energy intensity of gross domestic product (GDP) in agriculture had therefore reduced considerably.

Dynamics of energy intensity of GDP in agriculture and that of the share of energy in product cost is shown in **Fig. 2**.

At the same time, the share of energy in agricultural product cost had increased from 12.3% to 30%, by 2015, compared to 1990 which can be explained by sharp growth of price for energy resources in comparison to that of agricultural product (**Fig. 1**).

In **Table 1**, averaged data on energy intensity of production for major agricultural products are given including energy-related costs of feeding-stuffs and their share in the aggregate product cost (2015).

In recent years, indicators of energy intensity of production for a number of agricultural products have been decreasing but the share of .energy-related costs in the aggregate product cost has been growing constantly. Thus, for current price rate for energy-carriers, the cost of consumed energy resources in the total cost for major agricultural products amounts to, on average, 30% (in period of 1985-1990, these indicators were on average 7% to 15%). Relatively high level of energy intensity and costs related to energy provision attests to a rather low efficiency of fuel-and-energy resources use which essentially affects agricultural production costs.

Decrease of energy intensity indicators for agricultural products was a result of a number of factors that include the following ones:

- Essential shift of agricultural production from the social sector of economy to the private one. In 1990, the share of agricultural enterprises was 74% and that of private sector was only 26%, while in 2015, only about the half of agricultural product (48%) was produced by agricultural enterprises and the contribution of peasant farm economies and personal subsidiary plots (PSP) was 52% [2] characterized by a high share of hand labor whose amount has not been taken account of in the above indicators of energy-related costs which certainly resulted in underestimation of these data. The relationship of these indicators, within the period of 1990 to 2015 was also influenced by the change of ratio of prices for energy resources versus those of agricultural product.
- Substantial (disproportioned) growth of energy resources tariffs made all economic entities and private producers economize energy, eliminate mismanagement in the sphere of energy and fuel consumption and, in a number of cases, abandon energy-consuming businesses such as production of grass meal, green housing equipped with boilers fed with solid and liquid fuels,
- Certain growth of agricultural production efficiency that took place, in recent years (for example, the average yearly milk production from cows increased by 46% and by 100%, particularly in agricultural enterprises in the period from 1990 to 2014) made its contribution to the energy intensity reduction
- Technical progress including implementation of new energy-saving and less expensive technologies, processes, equipment and technical facilities made its positive effect on the reduction of energy-related cost.

Of cause, the reduction of energy intensity of gross domestic product (GDP) in agriculture, in recent years was, to a great extent, conditioned by the growth of agricultural production efficiency. At the same time, implementation of new technologies, energy-saving equipment, methods of energy saving and intelligent use applied by producers (particularly in conditions of galloping outrunning growth of prices for energy carriers) made it possible to reduce specific energy-related costs in agriculture by 12% to 15% which made a positive contribution to the increase of productivity.

Generally, reduction of energy intensity in agriculture is defined by the growth of productivity and agricultural production efficiency, development of its energy basis, rational and effective use and saving of all kinds of energy resources.

Based on the analysis of the status of the energy supply system and facilities for rural sites, components of energy intensity in agricultural production and with respect to worldwide experience and latest decisions in the field of energy efficiency, new perspective engineering projects, energy-saving perspective development directions and methods of energy supply systems modernization of rural enterprises, enhancement of energy efficiency of fuel-and-energy resource use have been defined that include the following:

- Transition to new energy-saving and resources-saving technologies,
- Growth of production efficiency

Fig. 1 Agricultural production (GDP), in comparable prices, and energy consumed for these agricultural products with the forecast until 2030

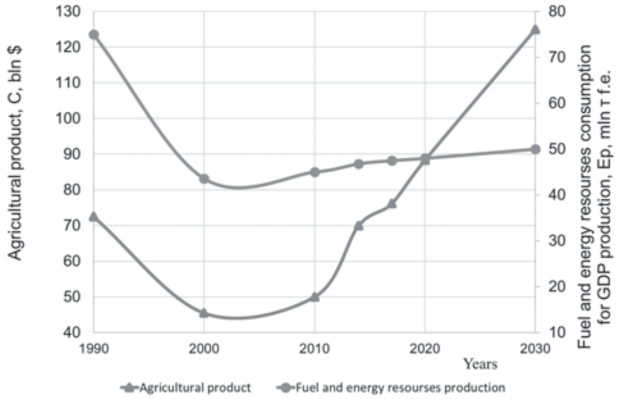
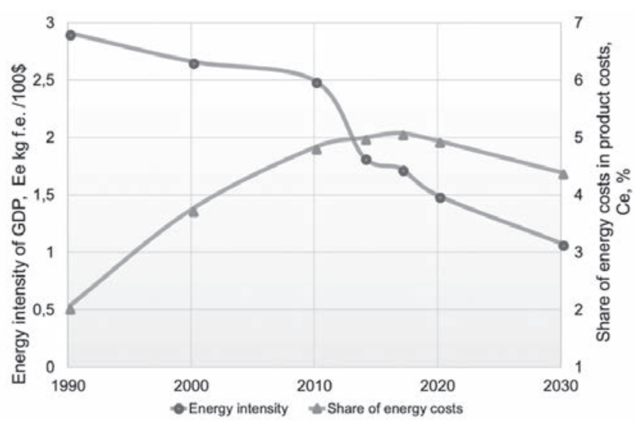


Fig. 2 Energy intensity of GDP and the share of energy in product cost with the forecast until 2030



in agriculture,
- Implementing energy-efficient facilities and equipment,
- Raising the reliability of power supply and electric power quality, reduction of fuel and lubrication materials (POL) consumption and energy loss,
- Production of alternative and renewable fuels, wide use of nonconventional energy resources,
- Raising the efficiency of fuel use (FUF) and that of energy owing to the heat utilization, application of heat pumps, thermal energy accumulation, combined generation of heat and electricity (CPH) and application of local heating, providing an energy cost reduction of about 30% to 40%, in the abovementioned processes,
- Development and implementation of systems and facilities of 'small power' on the basis of the use of local energy resources and wastes which can provide substitution of all conventional energy-dedicated fossils to the extent of 10% to 15% of their total demand,
- Development and implementation of biomass and agricultural waste conversion technologies for gaseous and liquid biofuels production (biodiesel, bioethanol, biogas) providing a substitution of traditional fuels the extent of 10% to 12% of their demand,
- Implementation of new cattle-breeding technologies and wide use of innovative energy-efficient equipment.

Therefore, enhancing the efficiency of fuel-and-energy resources use, as well as those of their energy return on investment, energy consumption optimization, energy loss reduction and wide use of local energy resources and renewables is the most important task of machinery-technological and energy modernization of agricultural production along with the growth of productivity and labor efficiency.

In recent years, both the demand for development and use of decentralized (standalone) power supply of various enterprises and sites, in rural areas, has grown considerably.

These are the major reasons for this:
- Excess of power demand over supply (there is an energy deficit, in a number of rural areas),
- Drastic growth of prices (tariffs) for electric power, heat and fuel supplied by utilities and other suppliers,
- Power supply reliability and quality have fallen and the frequency and duration of outages have grown which causes damage for agricultural producers, particularly in greenhousing, poultry farming, agricultural complexes, farms, storages and processing enterprises,
- Substantial growth of prices for connecting new consumers to grid, as well as those for compliance with technical requirements specified by utilities that are practically unachievable by many customers,
- Demand of many entities (particularly, in cattle-breeding) for combined heat and power (CHP) supply,
- Access to local energy resources in many rural areas including biomass, wastes of cattle-breeding farms, those of plant cultivation, forestry, oil-plants, development of technologies for their conversion into high-grade liquid fuels and gas that can be effectively used in decentralized systems for combined heart and power generation,
- Energy loss in transmission systems in excess of standard indicators,
- Possibility to reduce the cost of energy generated by independent producers and the payback period, sales of energy produced in excess to the rated volumes,
- Ability of energy producing equipment to operate on various fuel types including both manufactured locally and obtained via centralized supply (gas, diesel, biofuel),
- Possibility to reequip already existing boilers to implement mini-CHP of higher efficiency.

An essential part (to 30%) of the Russian territory has no access to centralized power supply. Connecting rural settlements to centralized power grids is associated with the problem of inadequately high investments and electricity rates, lack of funds for building expensive heat distribution networks and power transmission lines. It means that a large number of consumers located in these territories can be, with the maximal practicability, provided with electric power and heat with the help of standalone, 'small power', generating equipment and systems. Today, the problems related to the energy supply of such areas are solved mainly by installing diesel power stations which is not really optimal solution that provides not more than a temporary way out of difficult situation. Therefore, de-

Table 1 Averaged indicators of energy intensity in agricultural production

Product item	Energy-related costs		
	Aggregate energy intensity (kg of coal equivalent)		Share of energy-related costs in the aggregate product cost (%)
	per 100 kg of product	per kRUR	
Milk	21.7	12.0	30.0
Pork	208.0	12.2	32.5
Beef	94.0	6.0	13.0
Eggs (1000 pc.)	36.0	12.0	35.0
Grain crops	13.0	13.5	32.5

velopment and implementing small power systems on the basis of decentralized and combined power supply sources with the use of local energy resources and renewables are gaining an essential importance since these power solutions are more effective for a great number of consumers (particularly, remote ones) and, in certain cases, having no other alternative.

In recent years, new energy consumers have appeared such as farmer economies, PSP, new enterprises in cattle-breeding, plant cultivation and agricultural product processing. For these sites, it is essentially important to choose effective energy supply system already at the stage of project. That is why the task of development of methodology and recommendations related to the choice and sizing efficient energy supply systems and technical facilities designed for rural areas is vital.

Taking these conditions into account, implementing combined systems of decentralized energy supply, the choice of particular system and equipment depends on the demand of a site for certain energy types and quantities, as well as on local conditions and access to its own energy resources, renewables, distance from the centralized energy supply system and it shall be defined by comparative techno-economic estimations for a number of options.

These conditions require development of various types of decentralized systems and equipment including the following criteria:

- Capacity,
- Fuels to be used and access to local energy resources and renewables,
- Schedule of seasonal and daily thermal and electric power load on the site.

Decentralized systems may include various energy equipment such as:

- Diesel power plants (most often applied, so far);
- Mini-CHPs on the basis of cogenerating units producing both electricity and heat,
- Wind-solar power plants,
- Combined power installations (diesel generator + wind-solar power plant).

Unlike many developed countries of Europe, the status of cogenerating sets in power plants has not been specified in Russia creating a barrier on the way to their wide use, today.

Cogenerating plant is an alternative to already existing energy supply systems since, apart from natural gas, it can be fueled by nonconventional fuels, first of all, different kinds of biogas, biodiesel, fuel blends, producer gas and pyrolysis gas, and there are examples of such applications which, in perspective, creates favorable conditions for manifold growth of volumes of this fuels used in agricultural power branch.

In agriculture, mini-CHP can be applied for energy supply of the following objects:

- Cattle-breeding, poultry-farming, pig-breeding complexes,
- Greenhouses,
- Feed factories, sugar-mills,
- Large farms,
- Schools, hospitals, administration buildings and residential areas.

Technical-economic comparison of various heat supply systems shows the effectiveness of decentralized systems application (**Fig. 3**).

In many areas, efficient use of local energy resources in rural power industry, i.e. biomass, timber and other plant-derived wastes, peat, plant-derived oil residues, manure, sewage etc. may cover a considerable part (to 30%) of energy balance of a number of farms and enterprises, to reduce the frequency of power outages by a half, and to decrease their dependence on centralized energy supply creating conditions for decentralized systems implementation, up to complete self-supply.

While solving this problem, an important part has to be assigned to the development and application of technologies and complexes of equipment designed for conversion of biomass, plant-derived and timber wastes into high-grade fluid and solid fuels including bio-conversion of manure into biogas and fertilizer.

One of the positive elements of the problem of energy-dedicated waste utilization is their practically, annual renewability and accessibility in major areas of agricultural production and therefore, the use of wastes in agricultural power industry has a particular importance.

Average annual resources of local fuels comprising plant-derived and timber wastes, manure and poultry excreta amount to over 160 mln tce but their use as fuels was insignificant, so far.

Today, the goal is set to increase substantially the share of local energy resources in the energy balance of rural consumers. Particular role in energy supply of standalone consumers including cattle-breeding enterprises a number of which can be completely transferred to local and renewable energy sources belongs to small and medium power.

That is why the use of local energy resources in form of biomass, agricultural production wastes, manure, etc. converted into high-quality and more processable fuels has great perspectives.

In recent years, new effective technologies and methods have been developed such as plasma-assisted combustion, gasifying, pyrolysis, supercritical water oxidation and so on designed for biomass conversion, including plant-derived wastes and timber, into high-grade and more processable fuels

One of the perspective branches is fabricating blended biofuels from wet manure (wastes of cattle-breeding, swine rearing, poultry excreta) and hydrocarbon fossil fuels (oil sludge, waste oil, fuel oil) in various ratios. Technology of such biofuel production and use includes a number of operations including crushing, components mixing, homogenization and combustion with the help of ultra-disperse catalysts.

Today, a new stage has begun that of development and improvement of biogas technologies with the use of anaerobic and aerobic processes for manure fermentation, fractions separation and utilization of heat of fermented mass. This technology involves modular architecture of biogas equipment complexes that comprise heat pumps, apart from other units.

Implementing new biogas technologies and equipment sets on the basis of cattle-breeding farms makes it possible to produce additional energy carriers in form of biogas and high-grade organic fertilizer providing substantial reduction of anthropogenic load on the environment.

Energy requirement of national agriculture for the use of renewable energy sources (RES), i.e. solar energy, wind power, hydro and geothermal energy, makes its contribution to the solution of energy supply problem in agricultural production, in a number of areas, to the issues of hydrocarbon fuels saving and modernization of existing standalone systems.

Economical potential of RES amounts to about 20% of today's internal energy consumption of the country. However, factually, only not more than 1.5 % of it finds application in rural areas (excluding large HPP and wood fuel). With the account of local resources and energy-dedicated wastes it gives 2.5%. In accordance with the data on RES distribution over the regions of the country, each area has two or three types of applicable RES at the disposal. Therefore, the use of all RES is an expedient and perspective branch of power industry in Russia and, first of all, in agricultural energy branch as an alternative to a part of conventional energy carriers.

Indicators of nonconventional energy resources (RES + local resources) use along with those of their growth prognosis are shown in **Fig. 4**.

Current trends in global power industry development show that volumes of electricity produced by independent generating parties with the use of RES and other resources of 'small power' will increase considerably, by 2020 and even more by 2030. According forecasts, the share of RES in rural areas will attain 7% to 8%, by 2030 which, along with local energy resources, will correspond to 15% of rural energy balance.

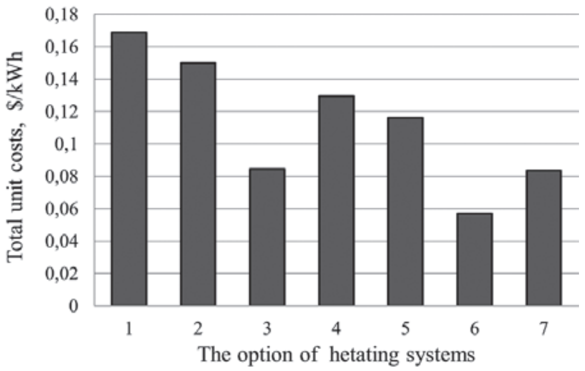
Today, there exist a number of installation types developed to convert various renewables in heat and power that can be effectively applied in agriculture. These are photoelectric power plants of modular structure, wind power stations of 0.1kW to 100kW, micro- and mini-HPP, etc. They are designed for energy supply of separate rural dwelling, small settlements, nonagricultural producers' cooperative artels, garden-plots, PSP, small farms, distant pastures and so on. The most effective way is creating combined power installations or their combination with conventional energy supply systems to ensure uninterrupted power supply and diesel fuel saving (to 50%).

While developing power plants based on RES, the major objective is increasing their efficiency and cost reduction.

Effectiveness of energy supply of rural consumers, costs of energy resources and therefore energy intensity of production are, to a great extent, defined by the choice of energy supply system, energy carrier and energy loss estimation. That is why substantiation and the choice of reasonable energy supply system for a particular site (or its modernization) adapted to the local site conditions and accessibility of energy resources is no doubt an important problem for implementation of energy supply system.

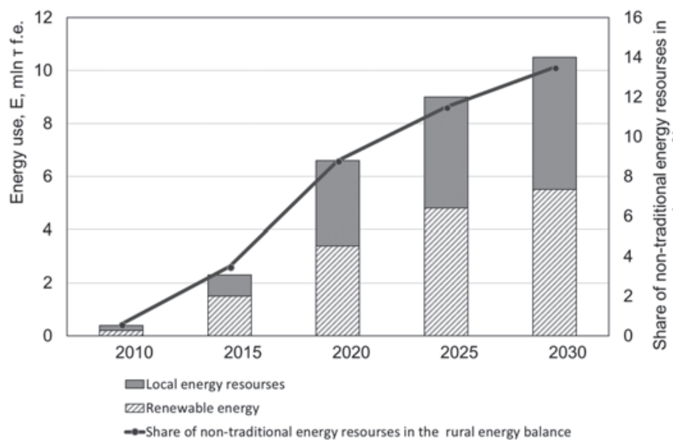
Today, agricultural energy systems of Russia are characterized by high level of wear-out. For example, distribution power lines are wearied-out by more than 30% and energy loss in distribution networks

Fig. 3 Comparison of various heat supply systems of cattle-breeding farm for 200 heads of livestock



Boiler houses operating on: 1 - solid fuel (coal), 2 - liquid fuel, 3 - natural gas; **Decentralized system operating on:** 4 - solid fuel (coal), 5 - liquid fuel, 6 - natural gas, 7 - electricity

Fig. 4 Indicators of the use of nonconventional energy resources (RES, local resources) and perspective of growth



amounts to 15% to 20% and even exceeding 20%, in certain conditions. In centralized heat supply systems, fuel utilization factor on the level of end consumers is as low as 40% to 30%.

A great deal of work on restoration of the distribution networks whose lifetime has expired and on reconstruction of operating lines to cover constantly growing loads has to be done in the nearest future.

Solving the accumulated urgent problems in distribution networks by modernization, reconstruction and implementing new generation networks in compliance with up-to-date requirements for power distribution and supply to customers, as well as those in the sphere of economics and environment protection and with the world technical level is therefore essentially important for energy supply, in rural sector.

Natural gas is convenient and cheapest energy carrier, today.

Nowadays, more than 30% of rural areas, settlements and buildings have access to centralized gas supply. That is why the goal is set to extend and to expand substantially (by 50%) gas supply services along with its wide application both in residential-social sphere and in production (first of all, in heat-demanding processes).

In recent years, a number of new consumer categories have appeared and still continue to appear that include farmer economies, PSP, new enterprises in cattle-breading, agricultural product processing for which the choice of effective energy supply system is vital.

That is why development of recommendations on the choice and specifying effective energy supply systems and technical facilities for typical rural sites is a task of prime importance. This problem has to be solved with the account of their location, values of electric and thermal loads, distance from centralized energy supply networks and access to local energy resources, as well as with regard to the development of up-to-date energy efficient equipment.

This will enable to carry out specifying the most effective options of energy supply system and power equipment for newly erected objects and for upgrading systems and equipment of sites being in operation.

Reasonable choice of most efficient systems of either centralized or autonomous energy supply including upgrades of currently operated systems for particular sites (energy consumers) will make it possible to use energy resources (conventional, nontraditional, local, renewable) rationally, to reduce energy-related costs and therefore energy intensity of agricultural product and its cost of production owing to the reduction of energy-related component in its structure.

Enhancement of rural objects power supply reliability and that of power quality has to be ensured on the basis of reconstruction of centralized power supply networks, reduction of their coverage area, involvement of both network and standalone backup, introduction of modern standard indicators of reliability on the project stage, in operation and maintenance, as well as load symmetry improvement and power loss reduction, enhancement of maintenance services which provides reduction of possible damage to agricultural production caused by emergency and scheduled outages of centralized power supply by 10% to 35% and reduction of electric power loss down to established standard values.

These requirements have to be adhered to on the stages of project engineering, building and reconstruction of energy supply system.

One of the perspective directions of energy supply development for certain consumers is implementation of new power transmission methods including resonance-mode single-line system, energy accumulation systems and activities designed to reduce energy loss.

Implementation of resonance-mode single-line and non-contact type power transmission methods developed in VIESH have a good perspective, particularly, for remote sites, for lighting systems of cattle-breeding and poultry-farming enterprises and mobile installations. In FSAC VIM, system and equipment have been designed realizing resonance-mode single-line power transmission method having capacity of 3 kW and 30 kW designed to power various consumers.

At a number of cattle-breeding enterprises, poultry-farming premises equipment of resonance-mode single-line system has been supplied and is now in operation for powering LED-based lighting system which made it possible to reduce power consumption by 60% and to save 30% of energy owing to the reduction of power loss in distribution networks and commutation.

One of the essential branches of rural energy supply is development and application of standalone local micro-networks, within the distributed power concept.

With the use of distributed power development on the basis of micro-networks using mainly renewable and local energy sources, the problem of energy supply of remote (dispersed) cattle-breeding sites, low-rise buildings and some other consumers in rural areas is being successfully sold.

Micro-network can be designed for operation in various modes including the following:

- Complete integration with centralized power distribution system enabling power exchange in both directions,
- Entirely standalone operation mode,
- The mode of power input from centralized power distribution system to cover the deficit of power produced by standalone energy source.

Specific feature of RES application in networks is their relatively small capacity and changeability of their output parameters (day hours and night hours, for solar PV plant or wind speed, for WPP, etc.). That is why, to stabilize operation in time and to control network parameters of power generating sources, it is essentially important to have automated, in a certain sense, intellectual control and supervision system equipped with sensors and maintaining link with them. Software of such control systems shall perform turn-on and shutdown of power sources, redirection of power flows, monitoring the status of networks that terminate their single-direction operating mode in conditions of joint operation, monitoring power equipment and carrying-out estimations of generated and consumed energy, etc.

Modernization of systems and facilities of rural power industry with regard to capacity deficit, problems of network parameters instability, particularly, in dead-end mains, frequent power outages shall be, first of all, tested and attested on pilot samples. It has to be related to working-out principles of organization and functioning algorithms of ‘smart’ network comprising renewables.

The problem of rational use of energy resources, as well as that of reduction of energy-related costs and energy intensity of agricultural production in cattle-breeding comprises development of energy-efficient systems of power supply of cattle-breeding enterprises, innovational solutions in the sphere of technical facilities and equipment in combination with technological modernization of production and organizational measures.

In the cattle-breading branch, these are up-to-date energy-saving technologies and systems of livestock management including technological processes such as feed preparation and distribution, milking operation, microclimate control, product primary processing and storage, collecting and utilization of wastes (manure, poultry excreta, feedstock residue), lighting, veterinary interventions, etc.

In FSAC VIM a number of import-substituting equipment items has been designed such as milking machines for various methods of cattle management, milk chilling plants, equipment for microclimate control, Computer-Aided Process Control System (CAPCS), feed distribution and feeding system, automated system for milking shutdown and teat cups dismantle, manure transportation system, etc.

The developed equipment has been manufactured, implemented and put into service at a number of farms, in many areas of Russia.

Vast reserves of energy-saving and reduction of energy cost and energy intensity of production are associated with employment of energy-saving power and thermal technologies, electro-technological processes and equipment that have been already developed and those that are currently under development. In the sphere of stationary technologies, these are, for example, thermal processes for climate control, lighting and treatment by irradiation, product processing and storage, grain preprocessing and drying, seeds preprocessing, weed control, disinfection, protected ground vegeculture, feed preparation, etc., as well as mobile plant cultivation processes.

Energy supply decentralization principle, that is when energy plants are integrated into separate premises to supply energy directly to particular technological process, has proved its effectiveness in application to farms and other enterprises. Most often electrified or gasified installations are used for this purpose which makes it possible to avoid long-length power, heat and gas networks thus reducing energy loss, to a great extent. For such systems, energy equipment has been designed and is being developed including infrared and gas heaters, storage and direct-flow water heaters, convector radiators, heat-and-steam generators, waste-heat steam boilers.

In heat supply systems, such technological processes as waste heat utilization and application of heat pumps have high energy efficiency, and their implementation will enable energy savings of about to 40% for heating and microclimate control. Application of these technologies in the process of cattle-breeding farm ventilation, milk chilling, and water heating is particularly effective and has great perspectives.

Besides, heat pumps will find their employment in energy supply systems of protected ground farms, private farmer economies. They are also well applicable for product storage in compliance with specific conditions of particular site.

One more important energy efficient branch is the advancement of lighting systems with the use of resonance-mode power supply systems and systems for irradiation of agricultural plants and animals on the base of new type long-life light sources having high luminous efficiency (compact fluorescent lamps, light-emitting diode lams, metal halide light sources, sodium vapor lamps) providing 2-fold to 5-fold power consumption reduction compared to conventional tungsten lamps and widely used luminous tube lamps.

Growth of agricultural production and labor productiveness is, to a great extent, defined by the progress in science and technology, advancement of technology and technics, complex electrical mechanization, stable reliable and effective energy supply.

Agricultural production growth in various branches stipulated in ‘Development Program of Agriculture for the period of 2013-2020’ will require intensification of all production processes, enhancement of the level of complex electrical mechanization of production and, therefore, the rate of energy supply per production unit. Attaining this goal will require the involvement of additional energy resources. Taking in consideration that specific .energy-related costs and energy intensity of production have to be minimized, technical level of energy supply systems and the efficiency fuel-and-energy resources shall be increased substantially.

To reduce specific energy-related costs in technological processes and assets for energy supply it is necessary, apart from technologies advancement, to select the most cost-saving energy supply systems for particular conditions with regard to implementation of energy-saving measures and opportunities provided by the employment of local and nonconventional energy sources and carrying-out the effective strategy of energy saving.

Development of centralized energy supply systems will involve the advancement and reconstruction of rural energy supply networks on the basis of new concept of their designing, building new power transmission lines and renovation of currently operated ones with the account of the perspective of growing loads, two-fold increase of their reliability and 50% to 2 times reduction of energy loss.

Thermal processes in production sphere and domestic sector will be implemented mainly with the use of decentralized systems of heat and power supply. Such systems fueled with gas and electricity, biofuels and fuel blends are more effective than centralized heat supply from low-temperature boilers featuring substantial energy loss in networks.

One of the important perspective development directions is combined heat and power generation with the use of mini-CHP, re-equipment of old boiler units that produce only thermal energy so that they generate both thermal and electric energy, wide use of heat pumps.

By the year 2020 and further on, local production of heat, electricity and biofuels will grow considerably (by 10% to 15%), in rural areas, by independent producers with the use of facilities and equipment of 'small power', local and renewable energy resources and wastes of agricultural production.

Implementation and employment of new heat and power technologies, energy efficient energy equipment, those being under development and already developed, will become an important component of agricultural production energy intensity reduction.

New technologies under development including power technologies and technological processes, nanotechnology and electro-physical methods designed to produce effect on biological objects, i.e. plants, seeds, animals, birds, agricultural products, air environment, ground, feed and water have good perspectives both in terms of obtaining new properties and features of materials and media and in connection with substantial reduction of energy-related costs, saving fuel-and-energy resources and reduction of energy intensity of agricultural product, first of all, in cattle-breeding. A number of engineering designs of this direction are already in the stage of implementation.

Growth of productivity in agriculture, as well as that of agricultural production volumes, is linked to the increase of the level of complex electrical mechanization and power supply per production unit which results in the growth of energy consumption.

At the same time, growth of agricultural production efficiency and adhering to the energy-saving strategy, advancement and implementation of new energy-saving technologies, energy efficient equipment and facilities and rational use of energy resources will make it possible to reduce specific costs of agricultural production, i.e. to decrease energy intensity of production and to attain the targeted indicators that is 40% and 60% reduction by 2020 and 2030, respectively.

Many perspective scientific-technical solutions in power industry and electrification have to be considered as the contribution to the development of the energy sector and rational use of fuel-and-energy resources in rural areas whose implementation, is to a substantial extent, defined by 'renaissance' of economics and creating conditions and the base of energy-saving strategy.

With regard to perspective forecast indicators of development of the agro-industrial complex and agricultural production, and directions of energy base and energy-saving advancement forecast indicators of energy consumption and power available per worker, have been specified and estimated for each stage for the period to 2030.

The choice of effective energy supply systems for particular agricultural consumers (farms, enterprises, sites) has to be carried out based on energy-related and economic evaluation of various options with the account of specific regional and local conditions, access to local energy resources, status (access to) centralized power supply system and current tariffs, required capacity and schedules of heat and power load (daily and seasonal energy demand schedule).

In order to minimize energy supply related costs it is important to transfer large and medium rural sites to the, day hours dependent, differentiated electric power accounting system. Taking the advantage of restricted hour tariff (50% and more) established in many regions it is expedient to reorganize production schedule and to select power equipment so that it could be possible to decrease power consumed in day hours and to increase that consumed in night hours by corresponding restructuring power loads.

Practical methods designed to evaluate reasonability of transferring particular sites to differentiated tariff of consumed power accounting makes it possible to define consumers for which positive economic effect is expected and what measures have to be carried out related to the production cycle restructuring.

Energy-related evaluation of systems, technologies and equipment for heat supply, as well as the inventory of the developed energy-saving measures are required to define directions of activities and potential opportunities for fuel-and-energy resources saving and substitution of conventional energy sources (gas, coal, oil, electric power) which proves significance of this sphere of activity.

Structural analysis of the rural energy base status, that of energy equipment fleet, as well as the developed recommendations on upgrading energy systems and samples of energy facilities, enable to form the inventory of first-order energy-saving activities comprising the following ones:

* Advancement and upgrading energy supply systems and facilities including main-type network building architecture and application of resonance-mode power transmission system to enhance reliability, stability, economical efficiency, power quality and energy loss reduction in networks by 35% to 40% and energy saving to 10%.
* Rising the efficiency of fuel (FUF) and energy use, first of all, in the most energy-demanding thermal processes of animal and poultry management, microclimate control, lighting, irradiation, disinfection with the use of heat utilization, heat pumps application, heat accumulation techniques, combined heat and power generation, local heating, etc. that ensures energy consumption reduction these processes from 20% to 40%.
* Development and implementation of systems and facilities of 'small power' on the basis of local energy resources, and wastes of agricultural production.
* Development and implementation of technologies for conversion of biomass including agricultural wastes into gaseous and liquid biofuels (biodiesel, bioethanol), conversion of cattle-breading production residue (manure) into high-grade fertilizer and biogas to provide complete or partial substitution of conventional fuels, in farms.
* Application of new power technologies in processes of microclimate control, feed preparation, irradiation, seeds pretreatment and drying, product storage and disinfection of premises, water and feed helps to reduce energy-related costs by 25% to 30%.
* Development and implementation of efficient lighting systems and facilities for production premises on the basis of new energy-saving lanterns with the use of resonance-mode power transmission systems to provide electric power saving for lighting to 70%.
* Wide use of renewables in rural power industry to substitute conventional energy resource (to 15%, by 2030).
* Re-equipment of old boilers and building new thermal-electrical plants that is mini-CHP generating both thermal and electric energy which enables to attain fuel saving to 30%.
* For southern areas, while engineering, construction and servicing low-rise buildings, schools, hotels, health resort objects, etc. it has to be mandatory to use solar water heating systems equipped with water storage installed on the roof and to apply heat pumps.
* Development of IT technologies for agricultural production management and, first of all, that of energy supply system in order to enhance the efficiency and energy resources saving.
* Partial transfer of mobile equipment to electric drive including single-line and contactless power supply and electric energy accumulation which can ensure fuel saving to 20%.
* Use of newly designed active vacuum thermal insulation for walls of buildings, greenhouses and other sites to reduce heating-related costs to 30%.

Specified forecast indicators of demand for energy resources correlate with those of 'Development Program of Agriculture… for the period of 2013-2020', 'Strategy of machinery-technological modernization in agriculture' scales of putting into service arable lands, growth of tractor-machinery fleet, production growth of practically all items of agricultural products.

The growth of agricultural production and that of labor efficiency are, to a great extent, defined by scientific-technical progress, technology and techniques development, complex electrical mechanization and reliable, stable and efficient energy supply.

Enlargement of agricultural production in all of its branches planned in 'Development Program of Agriculture' will require intensification of production processes, raising the level of complex electrical mechanization of production and, therefore power availability per worker and per production unit. To achieve this goal additional energy resources have to be employed. Since it is necessary to ensure reduction of specific energy-related costs and energy intensity of production and, consequently, that of the total product cost the efficiency of energy supply systems, as well as that of fuel-and-energy resources use have to be increased essentially.

In the sphere of centralized energy supply development, the most important task is the advancement and reconstruction of rural energy supply systems and networks on the basis of new concept of their engineering, construction of new power transmission lines and reengineering of existing ones with the account of perspective loads, enhancement of their reliability and energy loss reduction in 1.5 to 2 times.

For energy supply of thermal processes in production and domestic sector, decentralized energy supply systems will gain wider development since these systems operating on gas and electric power, biofuels and fuel blends are more efficient compared to centralized heat supply from low-temperature boilers that feature large energy loss in heat distribution networks.

By 2030 and further on, production of electric power, thermal energy and biofuels will grow considerably (to 10% to 15% of the total demand) produced locally by independent producers with the use of facilities and equipment of 'small power', local and renewable energy resource and wastes of agricultural production.

One of the important components of energy intensity of production reduction will be implementation and putting into service new heat and power technologies, energy efficient power equipment that have been already designed and those that are currently under development. A number of design solutions in this direction are now on the stage of implementation.

Growth of productivity in agriculture and that of agricultural production volumes is associated with increasing the level of complex electrical mechanization of agricultural production, its power supply per production unit which will require the growth of heat and power consumption.

On the other hand, carrying out the energy-saving strategy, advancement and implementation of new energy-saving technologies, energy efficient equipment and technics and rational use of energy resources will make it possible to reduce specific cost of agricultural production, that is to reduce energy intensity of production and attain the scheduled level of its reduction of 40%, by 2020 and 60%, by 2030.

Many perspective scientific-technical solutions in energy industry and rural electrification whose implementation opportunities are, to a great extent, defined by renaissance of economy of enterprises and by creating conditions and the base for carrying-out energy-saving policy shall be also considered as significant achievements of power industry, rational use of fuel-and-energy resources, in agriculture. With the account of perspective forecast indicators of development in the field of agro-industrial complex and agricultural production, as well as the directions of advancement of energy basis and energy-saving with the use of various forecast methods (standard method, trend analysis, forecast analysis) forecast indicators for energy consumption and power availability per worker have been specified, in particular stages for the period up to the year 2030.

According to forecasts, consumption of fuel-and-energy resources is expected to increase by 7% and 17% in 2020 and 2030, respectively, compared to 2015.

Volumes of energy consumed from nonconventional sources including local energy resources have to grow considerably in the entire structure of energy carriers attaining 6 mln t, 13 mln t and 15 mln t of reference fuel, in 2020, 2030 and 2035, respectively.

Figs. 5 and **6** show forecast indicators of rural areas' demand for energy resources and power availability per worker for various stages in the period to 2030.

Summary

Thus development and modernization of rural energy base, energy-saving activities to be implemented

Fig. 5 Indicators of energy consumption and forecast estimations of the demand for fuel-and-energy resources in agriculture, in the period to 2030

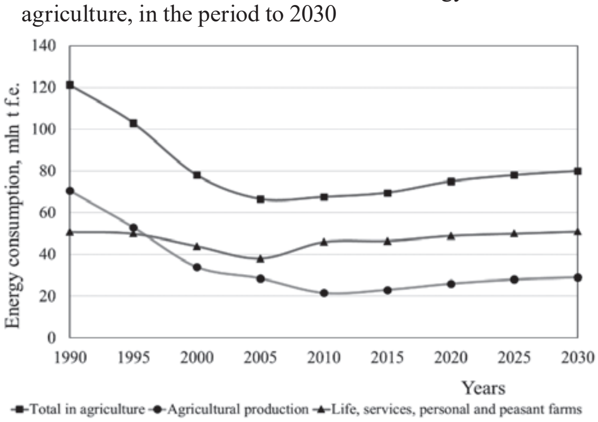
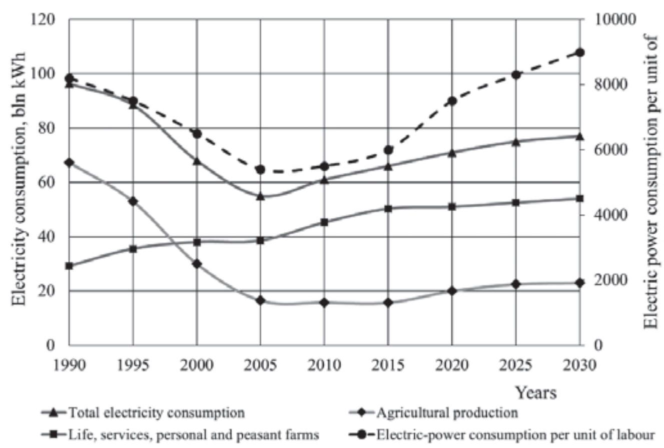


Fig. 6 Indicators of energy consumption and power availability per worker in agriculture, in the period to 2030



in various sites will make it possible to reduce the energy intensity of GDP by 40% as a whole, by 2020, and 15% to 20% of this reduction is expected to be ensured owing to the enhancement of energy efficiency of energy supply systems and facilities.

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Regional Features of Scientific-technical and Technological Modernization of Agro-industrial Sector of Bashkortostan at the Present Stage

by

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Abstract

The article analyzes in dynamics the level of technical equipment of enterprises of the agro-industrial complex of the Republic of Bashkortostan. The regional programs for the support of agricultural machinery of the republic, agricultural producers for the purchase of equipment and machinery, etc., which are being implemented in the republic and have shown high efficiency, are given.

The efficiency of the organization of the overhaul and modernization of the equipment in service on the basis of specialized repair enterprises of the republic has been determined. The feasibility of creating an association of repair-technical enterprises at the regional level to coordinate work on the organization of capital repairs, rehabilitation and modernization of agricultural equipment is shown.

Keywords: technical equipment; machine system; modernization; repair of agricultural machinery; restoration of parts.

Introduction

Natural and climatic conditions, the level of infrastructure development, the historical development of the territory, the number of the rural population mainly determine the characteristics of agricultural production in a particular territory. The scientific-technical and technological modernization of the agro-industrial sector of the Republic of Bashkortostan is caused primarily by the fact that the territory of the republic is located on the border of Europe with Asia **Fig. 1** and is divided into 6 natural-agricultural zones: I - Northern forest-steppe, II - North-eastern forest-steppe, III - Southern forest-steppe, IV - Pre-Ural steppe, V - Over-Ural steppe, VI - Mountain-forest.

The climate is continental with relatively warm summers and long, moderately cold winters, due to the

Fig. 1 Territorial position of the Republic of Bashkortostan in the Russian Federation

annual course of solar radiation, changes in the radiation properties of the underlying surface and features of the circulation processes. The most important feature of the climate of the republic is the presence of two sharply differing periods of warm with positive temperatures and cold with negative temperatures and the formation of a stable snow cover. The vegetation in the latitudinal-zonal section varies from dark coniferous forests in the north to feather grass steppes in the south, in vertical-zone - from meadow-steppe vegetation of the intermountain valleys of the Zilair plateau to the mountain-tundra on the most elevated tops of the mountains of the Southern Urals. The afforestation of the territory varies greatly from 5% in the south of the steppe zone to 90% in the northern part of the mountain-forest zone of the republic, an average of 38%. Data on land use and the main indicators of agricultural production in the Republic of Bashkortostan are shown in **Table 1**.

The existing organizational and production infrastructure of engineering and technical support of enterprises of the agro-industrial complex in the Republic of Bashkortostan is mainly preserved in the traditional form of the mid-70s of the last century. In agricultural enterprises there are a sufficient number of engine yards (832 units), repair shops (615 units), maintenance points (272 units), car garages (475 units), oil storage facilities (560 units) and covered parking lots for agricultural machinery (339 units). In all 54 municipal districts there are services of the chief engineer of directorates (departments) of agriculture. There are two large republican and seven municipal machine-technological stations, one mechanical squad as part of the state unitary enterprise.

Maintenance and repair of equipment, components and assemblies can be carried out on the basis of 35 repair and technical enterprises in the territory of 19 municipal districts. The leading repair and service enterprise in the region is the state unitary enterprise “Bashselkhoztekhnika”, which is the dealer of the main Russian and a number of foreign manufacturers of agricultural equipment. Foreign agricultural machinery manufacturers - Case-New Holland (CNH), John Deere, Claas, AGCO and others, have their own customer services and production bases in the territory of the Republic of Bashkortostan.

The dynamics of the number of main types of agricultural machinery in the Republic of Bashkortostan is presented in **Table 2**.

Until 2011, the annual disposal of the main types of equipment in the agricultural organizations of the republic was 3-5 times higher than the supply of new ones. The number of tractors and self-propelled combine harvesters exceeding the standard operating time reached 90 percent of the fleet with an average age of 18 years or more. Due to the low availability of machinery, the optimal timing of the mechanized work on sowing and harvesting crops was not respected, and crop losses reached 20-25% [1, 2, 3]. Up to 40% of the main mechanized work on the cultivation and harvesting of crops was carried out by the republican

Table 1 Land and production of agricultural products in the Republic of Bashkortostan

Types of land	1990	2000	2010	2017
Total land area, thousand hectares	14,294			
including farmland	7,300			
of them arable	4,860	4,345	3,670	3,600
Grain production, thousand tons	3,770.2	2,519.8	780.9	3,782.7
Milk production, thousand tons	1,855.0	1,539.9	2,078.1	1,718.4
Meat production, thousand tons	498,0	355.0	467.1	410.2
Sugar beet, thousand tons	1,570.5	1,143.7	376.5	1,593.5

Table 2 Dynamics of the presence of the main types of agricultural machinery

Type of machinery	01.01. 1990	01.01. 2001	01.01. 2005	01.01. 2010	01.01. 2015	15.07. 2018
Tractors	41,771	37,278	28,035	19,155	15,732	14,892
Forage harvesting combine	3,852	3,153	2,083	1,187	855	760
Combine Harvesters	17,521	10,687	6,514	4,224	3,649	3,659
Beet harvesters	1,320	1,183	889	380	190	137
Sowing machines	23,797	14,766	12,207	10,530	9,017	8,981
Plows	14,294	11,053	8,544	6,020	4,921	4,718
Cultivators	21,228	14,700	11,737	8,142	6,441	6,125

machine-technological stations. The level of technical equipment of the agro-industrial sector in the region from 1998 to 2011 was supported by the purchase of mainly imported equipment exclusively at the expense of the republican budget allocations through the creation of republican machine-technological stations.

Purpose of the Study

Determination of effective measures of regional state support aimed at increasing the level of technical equipment of enterprises of the agro-industrial complex.

Research Methodology

The regulatory document for the technical modernization of agricultural production was developed by the Ministry of Agriculture of the Republic of Bashkortostan together with the Bashkir State Agrarian University and the Scientific and Practical Center of the National Academy of Sciences of Belarus on agricultural mechanization to develop a scientific-based machine system for introducing innovative technologies for the cultivation of main crops and livestock production in different soil and climatic conditions of the Republic of Bashkortostan [4,5].

Research Results and Discussion

Currently in the region four programs aimed at improving the technical equipment of the agricultural sector: "Renovation, repair and modernization of the machine and tractor fleet in the framework of the State Program for the Development of Agriculture and Regulation of agricultural products, raw materials and food markets in the Republic of Bashkortostan", "Grant support for agricultural producers", "Support for income-generating projects", "Subsidies for the Russian equipment manufacturers" have been developed and are successfully operating with the support of the Ministry of Agriculture of the Republic of Bashkortostan. Over the last seven years, the agrarians of the republic purchased more than 20 thousand units of machinery and equipment for a total amount of 27.2 billion rubles. At the same time, only from the budget of the republic agricultural producers received subsidies in the amount of more than 6 billion rubles (**Tables 3**, **4**).

The efficiency of the republican state support rendered has significantly increased due to its implementation in conjunction with the federal subsidy program for Russian equipment manufacturers, within which since 2013 it has been used to reduce the cost of 1.1 billion rubles purchased by agrarians of the republic. A total of 7.3 billion rubles in subsidies was paid, or 27% of the total amount of purchases (**Table 5**). The share of foreign equipment in the total purchase volume does not currently exceed 11%.

Thanks to the provided state support measures, it was possible to stabilize a sharp drop in the number of main types of machines, and the number of main types of harvesting equipment, including combine harvesters, slightly increased. Along with this, the number of machines that have developed a standard ser-

Table 3 Dynamics of the purchasing of agricultural machinery and equipment

Year	Quantity, pcs		Bln, rub.
	Total	Including foreign	
2011	2,980	389	2.9
2012	3,590	436	3.9
2013	3,721	405	4.6
2014	2,620	301	4.1
2015	2,145	202	2.8
2016	2,185	176	3.5
2017	2,058	278	3.7
6 mnth. 2018	813	118	1.5
Total	20,112	2,305	27.0

Table 4 The nomenclature and the number of purchased agricultural equipment

Name	Quantity, pcs
Tractors	3,643
Combine Harvesters	1,584
Self-propelled forage harvesters	287
Seeders and sowing complexes	2,127
Tillage machines and tools	2,324

Table 5 Amount of subsidies paid, mln. rub.

Name of support programs	Year							
	2011	2012	2013	2014	2015	2016	2017	2018
Upgrading machine and tractor fleet (up to 55% of costs)	579	771	897	710	800	573	819	350
Modernization of 500 dairy farms (up to 50% of costs)	-	117	166	144	147	186	-	-
Subsidies to equipment manufacturers	-	-	31 (15%)	129 (15%)	201 (15%)	392 (25%)	254 (15%)	102 (15%)
Total	579	888	1,094	983	1,148	1,151	1,073	452

vice life and their average age has significantly decreased, and a decrease in load is also observed when performing the main types of mechanized agricultural work (**Table 6**).

At present, the following structure of the mobile fleet of cars has developed in the agro-industrial complex of the republic:

- Tractors of class 1.4 - 52.3%;
- Tractors of class 5 and more - 10.2%;
- Combine harvesters SK-5 “Niva” - 26.4%;
- Foreign combine harvesters - 24.5%;
- Forage harvesters KG-6 “Polesie” - 43.5%.

Due to the replenishment of the combine harvester fleet this year, it was possible to reduce the load compared to last year from 480 to 460 hectares per combine. At the same time, despite significant state support, the technical provision of the main types of equipment in some areas and agricultural enterprises remains low (**Table 7**) relative to the standards [4, 6].

Starting from 2011, a comprehensive program of updating the machine and tractor fleet has been carried out in the republic, providing state support for agricultural producers of all categories in various areas of technical equipment by subsidizing part of the cost of purchasing new equipment and upgrading agricultural equipment in operation.

To achieve the normative indicators of technical equipment, taking into account the annual write-off, at least 1,200 combines and more than 3,000 tractors of various classes are additionally required. Accordingly, it is necessary to complete the tractor units with an additional train of tillage and seeding machines and implements, including those that meet the requirements of a soil-protective, resource-saving farming system. The overall complex task for the coming years is to increase energy supply in the agricultural organizations of the republic to 230-250 hp. per 100 hectares of cultivated area with the existing value of about 170 hp [4, 10, 11].

To improve technical equipment with the support of the Ministry of Agriculture of the Republic, purposeful work is being carried out with enterprises of regional agricultural engineering. The enterprises located in the republic have mastered the production of about 130 items of various types of new agricultural machinery and equipment, many of which are not inferior in terms of technical and economic indicators to foreign analogues. The production of the self-propelled mower KS-100 Chulpan based on JSC “BashAgroMash”, the “Muromets-1500” combine harvester based on the “Muromets” Production Association of the Sterlitamak region, and the assembly of wheel-mounted tractors T-150K, Belarus-82 and Belarus-1221 was launched on the basis of the Chishminsky branch of the State Enterprise “Bashselhoztekhnika” (**Fig. 2**)

In 2017, for the first time, the enterprise JSC “BashAgroMash” (Sterlitamak) received accreditation at the Ministry of Industry and Trade of Russia, which is also included in the federal register of the largest manufacturers of agricultural equipment. In 2018, the company mastered the production of self-propelled sprayers. On the basis of LLC “Turbomashservis” (Sterlitamak), production is being prepared for serial manufacturing of telescopic loaders of various modifications.

A new and effective way to improve technical equipment is the organization of overhaul and modernization of equipment in service on the basis of specialized repair companies of the republic [7, 8, 9]. In

Table 6 Dynamics of average age and terms of operation of self-propelled agricultural machinery

Name	Year	
	2010	2018
Average age		
Tractors	17.9	15.9
Combine harvesters	14.8	11.8
Forage harvesters	11.4	9.5
The percentage of equipment above the standard operating life		
Tractors	85	68
Combine harvesters	76	53
Forage harvesters	62	50

Table 7 State and target indicators of technical equipment of enterprises of the agro-industrial complex for the Republic of Bashkortostan

Names of indicators	in the Republic of Bashkortostan				
	1990	2000	2010	2018	Target indicators
Load on 1 tractor, hectares of arable land	116	117	188	225	180
The number of tractors per 1000 hectares of arable land, pcs.	8.6	8.5	5.3	4.5	6.0
Load on 1 combine harvester, ha	140	187	560	460	350
The number of combines per 1000 ha of cultivated area, pieces; (*grain / fodder / beet harvesting*)	7.1/7.8/9.8	5.3/5.8/7.3	1.8/2.0/2.5	2.2/2.4/3.0	2.9/3.0/3.5
Power, hp on 100 hectares of cultivated area	278	230	202	170	230

the process of modernization, the base units are replaced with more advanced and economical ones. There are 18 such enterprises certified in the established order in the republic. In the future it is planned to increase the number of high-tech repair enterprises.

To coordinate the work on the organization of the overhaul and modernization of agricultural machinery in 2017, the Association of Repair and Maintenance Enterprises of the Republic of Bashkortostan was created. On this basis, the secondary market of machines and the Trade-in system are actively developing. The central place in the structure of interaction of organizations within the Association belongs to the agrarian science, which is represented by the Bashkir State Agrarian University.

On the basis of the Agrarian University in 2017, the work of the certified organization JSC “Bashagropromkomplekt” on the organization of the entrance control of spare parts was organized. Techniques are being developed at this site and the quality of various parts for agricultural machinery is being tested and, first and foremost, those manufactured at regional enterprises. Currently, republican enterprises have mastered the manufacture and restoration of more than 1,200 items of spare parts, including import-substituting, the price of which is several times lower than the original.

Most effectively in terms of repairing hydraulic drive units and fuel systems, manufacturing rubber-polymer parts and spare parts, including import-substituting, production activities are conducted in JSC “BashAgroMash” (Sterlitamak), LLC “Hydrosila” (Ufa), LLC “Bizhbulyak Polymer”, LLC “GALE” (Sterlitamak), LLC “BashDiesel” (Ufa), a branch of machine-tractor station “Central” “Dyurtyulinskaya Reapair Technical Workshop”, Chishminsky branch of State Unitary Agrarian Enterprise “Bashselkhoztekhnika”, LLC “Muromets”, site of the Sterlitamak plant “Inmash”, LLC “Rosagroservice” (Chishmy), LLC “Ilish Kirovets”, LLC “Akros RB”, “Bashkir State Agrarian University” - scientific support, LLC “Remontnik” (Kuyurgazinsky district), LLC “Ishlinskoye Repair Technical Enterprise”, LLC “Matrix Universal”, LLC “Bashagropromstandart”, CJSC “European Agrotechnics-Ufa” (Zubovo), LLC “AgroProf”, LLC “AgroLain” (Ufa) and others.

According to the results of our research and the data of repair companies, with almost the same resource compared to the company production, the cost of manufacturing new spare parts is on average no more than 35% of the cost of original parts. The cost of repair and restoration of worn parts are not more than 25%. At the same time, almost 50% of wearing parts for combine harvesters, self-propelled mowers and sowing complexes of foreign production are subject to repair and restoration. Russian counterparts can still replace those that require replacement when repairing 30% of parts, as a result, the proportion of original spare parts needed will not exceed 20%.

Findings

Scientific-technical and technological modernization of enterprises of the agro-industrial complex of the Republic of Bashkortostan and an increase in the level of technical equipment are most effectively ensured by:

- Strengthening of the federal state programs of subsidizing the purchase of machinery and equipment with measures of

Fig. 2 Mastering the production of agricultural machinery in the enterprises of the Republic of Bashkortostan

regional programs to support agricultural enterprises of the republic, the allocation of regional grants for the purchase of machinery, etc.
- Organization of overhaul repair and modernization of equipment in service on the basis of specialized repair enterprises of the republic. It is shown that almost 50% of worn parts are repaired and restored, while the cost of manufacturing new spare parts averages no more than 35% of the cost of original parts, the cost of repairing and restoring worn parts is no more than 25%.
- Coordination of work on the organization of the overhaul, restoration and modernization of agricultural machinery based on the creation of an association of repair-technical enterprises of the region.

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■■

Technological Support of Soybean Cultivation

by

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Abstract

The world's soybean crop area exceeds 100 million hectares. Soybeans are grown in 90 countries, and their production output reaches 300 million tons. In recent years, crop areas under soybeans have expanded significantly in the Russian Federation, China, and the countries of Southeast Asia. In 2018, the world's soybean harvesting area exceeded 120 million hectares and increased by 1.5 times as compared to 2000. The largest areas are in the USA, Brazil and Argentina, as well as in India and China. In Russia, soybeans are grown mainly in the Far East, with low yields of 1.5 tons per hectare. According to this indicator, the country is at the level of India and China, while in the countries of Central Europe, the USA, Argentina and Brazil it is 2-2.5 times higher. Soybeans are grown using three main methods: traditional, biotechnology-based, and organic. In Asia, a method of soybean growing on ridges is applied.

Keywords: soybeans, vegetable protein, harvest area, production output, yield, import, export, soybean processing products.

Introduction

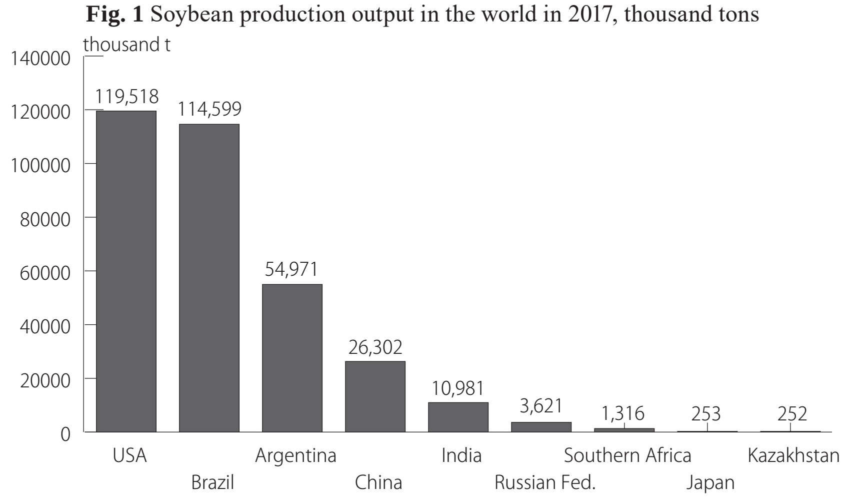
Soya (*Glycine max* (L.) *Merrill*) is widespread in global agricultural production. Valuable biological properties and high manufacturability have led to the rapid growth of areas and gross harvests of this protein-oil crop. It is grown on all continents. A third of the world's population uses soy-based products in their diets.

The research purpose is to identify trends and problems in soybean production, to determine factors that influence the yield and production output of this crop.

Materials and Research Methods

In the course of the study, the authors analyzed an array of FAO data on soybean production volumes in leading soybean producing countries over the period of 18 years (2000-2017), as well as data obtained from Rosstat and analytical agencies. Special attention was paid to the biological, environmental, and economic features of this valuable high-protein culture.

Fig. 1 Soybean production output in the world in 2017, thousand tons



Results and Discussion

Over the past 15 years, soybean production in the world has doubled, reaching by 2017 352,643 thousand tons, including 26,302 thousand tons in Asia. The largest global soybean producer is the United States, followed by Brazil and Argentina (**Fig. 1**). In Asia, primacy belongs to China and India (FAOSTAT, 2019).

In recent years, there has been a fairly high rate of increase in crop areas under soybeans in a number of countries where climatic conditions may be relatively favorable for growing modern soybean varieties (Goncharov, V. D., Rau, V. V., 2019; Dorokhov, A. S., Evdokimova, O. V., Bol'sheva, K. K., 2018). The growth in gross soybean harvests results from increased crop areas and yields (**Figs. 2**, **3**). So, the cultivated area increased from 92,573 thousand ha in 2005 to 123,551 thousand ha in 2017. The average soybean yield in the world increased from 2.3 to 2.8 t / ha.

The largest crop areas are concentrated in the USA (28% of the world production output), Brazil (26%), and Argentina (14%). Due to the high yield, the share of soybean production in the three leading countries reaches 78% (Krivoshlykov, K. M., Roshchina, E. Yu., Kozlova, S. A., 2016).

In Russia, traditionally soybeans are concentrated in the Far Eastern region, where the genetic center of its origin is located. At the same time, crop areas in the Central region of Russia have expanded significantly, largely thanks to state support. In 2017, the country's soybean production increased to 3,621 thousand tons, and the crop area reached 2,573 thousand ha (Belyshkina, M. E., 2018).

The State Register of Breeding Achievements Approved for Use in Russia includes about 250 soybean varieties, of which 30% are of a foreign origin. The introduction of these varieties into production on the territory of the country may mean a new dependence on the import of seeds and the related technologies.

The capacities of enterprises performing deep processing of soybeans in the Russian Federation reached 5-6 million tons per year, while domestic soybean production can provide only half of the necessary raw materials. Therefore, the cultivated area continues to grow, but the yield remains relatively low.

According to FAOSTAT, in Asia, soybean yields averaged 1.3 t / ha from 2015 to 2017, and in the United States - 3.1 t / ha.

In most countries, average soybean yields remain low. So, in India it does not exceed 1.0 t / ha. This indicator is highly dependent on the climatic conditions of the year. Even in countries where the technology of soybean production is at a high level, there are significant fluctuations in yield in different years.

In the United States, Brazil and Argentina, soybeans are grown in favorable climatic conditions, where the growing season is warm and long, and soil moisture is sufficient enough. For example, in the subtropical zone of Brazil and Argentina, the annual precipitation rate amounts to more than 900 mm.

In the United States and Latin America, genetically modified (GM) soybeans are cultivated in large amounts and high yields are observed. However, their consumption can have negative effects on people's health, primarily, because of the significant amount of pesticides used in production.

In Asia, most of the soybeans grown are used for food purposes, so there is high concern for the cultivation of non-GM soybeans. But the internal production output does not cover the existing needs, so soybeans have to be imported from the USA, Brazil, Argentina and other countries.

The total indicator of global consumption of soybeans in 2017-2018 amounts to 350 million tons, and China accounts for more than 100 million tons of them. With a deficit of domestic production, the country

Fig. 2 Crop areas of soybeans in the world in 2017

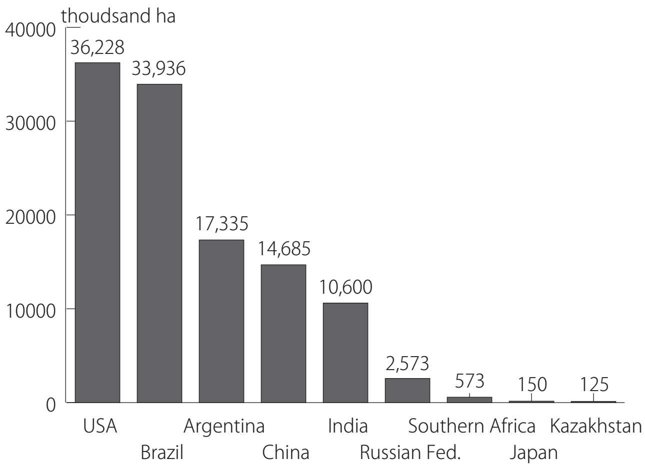
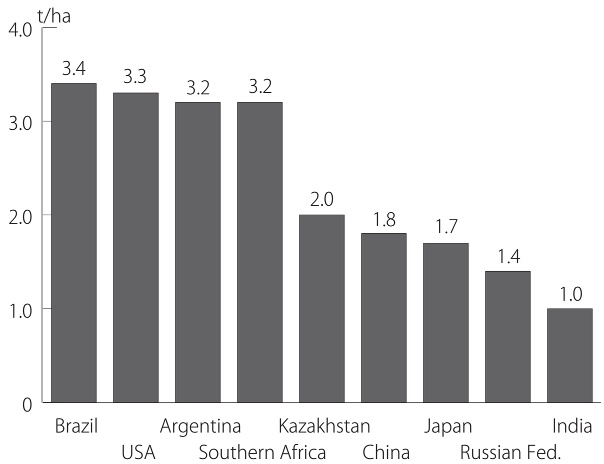


Fig. 3 World's soybean yield in 2017



is increasing imports, which is explained by the growing consumption of meat and dairy products. Under such conditions, the importance of soybeans for the country's forage base can hardly be overestimated.

In countries of Southeast Asia (Indonesia, Malaysia, the Philippines, Thailand, and Vietnam), there is also a significant increase in the imports of soy flour and beans: from 8 million tons in 2000 to 25 million tons in 2018. The reason is the same: changes in the diet structure of these countries' population have caused by the growth of their GDP.

According to the long-term forecast of the US Department of Agriculture, the global sales of soybeans will increase by 22% to reach 161 million tons by 2026. Imports of soybeans to China by this time are expected to amount to 109.5 million tons.

But due to the imposition of sanctions and trade embargoes, imports are at risk. In this regard, there is an acute issue of providing soybeans to the countries of the Asia-Pacific region by means of domestic production. Since land resources are limited, the only way out was to increase productivity. Another way to solve the problem in the coming years will be the reorientation of imports. The Russian Federation is one of the promising countries to participate in this activity.

Russian soybeans are valued both domestically and on the world market, as they are grown from seeds that are not genetically modified. An important problem to be solved still remains the development of domestic seed production and improving the quality of soybean seeds, since Russian soybeans are often inferior to foreign ones in protein content, and this is a key indicator for soybean processing enterprises (Zaytsev, N. I., Bochkarev, N. I., Zelentsov, S. V., 2016).

In the Far East of the Russian Federation in the coming years, a soybean cluster will be established to satisfy primarily the Russian economy needs for soybean protein, as well as to provide products for export. Far Eastern organic soybeans will be transported through the "green corridor" primarily to China, as well as to other countries of the Asia-Pacific region (Dement'yev, K. V., 2016; Malashonok, A. A., Pashina, L. L., 2016).

In many new soybean cultivation regions of Russia, unfavorable agroclimatic factors, primarily the lack of heat and moisture, largely determine the reduced yield as compared to other countries.

In addition to climatic conditions, soybean productivity is significantly affected by the level of technical and technological equipment of farms, the use of highly productive varieties, modern plant protection products, fertilizers, growth stimulants, etc. (Sinegovskiy, M. O., Antonova, N. E., 2018).

The development of technological varieties that are resistant to pathogens and adverse environmental factors, adapted to specific production conditions, and the development of varietal technologies that ensure stable productivity are the main tasks of sustainable soybean production (Linnikov, P. I., 2018).

Three main systems of soybean production are widespread in the world: traditional, biotechnology-based, and organic. A soybean production system using varieties obtained by biotechnological methods is often combined with no-till cultivation (No-Till). Since the introduction of herbicide-resistant soybeans, the spread of no-till cultivation of soybean fields in the United States and Latin America has increased by 35%. In Asia, a method of growing soybeans on ridges is applied.

Under the traditional cultivation of the crop, the soil is loosened at a depth of 8-10 cm in autumn, then plowed at a depth of 22-30 cm. these operations are followed by harrowing and pre-sowing cultivation with the introduction of herbicides into the soil in spring. The field should be maximally flattened out so that the size of clods should not exceed 3 cm. Soybean sowing begins at a soil temperature of 10-15 °C, the row spacing is 15-70 cm. Harrowing is carried out 3-4 days after sowing in order to control weed seedlings, then harrowing operations are repeated once or twice during the growing season and plant protection products and fertilizers are introduced.

Harvesting is carried out by direct combining and using a close cut method in the phase of full ripeness at a moisture content of 14-16%.

No-Till technology has become widespread in the United States and Latin America. It is used on 40% of the crop area in the USA, 45% in Brazil and 50% in Argentina. Its main advantages include reduced soil compaction due to minimized number of agricultural machinery passes, moisture accumulation in the soil, reduced risk of soil erosion, and reduced operating costs, including labor costs, servicing the fleet of agricultural machinery, fuels and lubricants, etc.

However, this technology has disadvantages as well. The absence of deep plowing for several years will lead to soil compaction and disruption of the water-air regime. Subsequently, productivity decreases, since the symbiotic nitrogen fixation carried out by nodule bacteria on soybean roots is possible only with good aeration. Another disadvantage of No-Till is high contamination of crops. To control weeds, herbicides are used, the remains of which accumulate in plants. This technology involves the use of transgenic soybean varieties, the environmental safety of which is currently not proven.

Organic soybean growing is gaining popularity. This technology excludes all chemicals, so only organic fertilizers and varieties obtained by traditional selection methods are used. Soybeans are capable of self-providing with nitrogen during the symbiotic fixation, additionally they do not require nitrogen fertilizers to be introduced. In the United States, organic soybeans occupy about 55 thousand ha, which is less than 0.02% of all areas allocated for soybeans. However, this technology has prospects, as the demand for environmentally friendly products increases. The countries of Central Europe, where the cultivation of GM soybeans is prohibited, are interested in using the technology. The main disadvantage of the technology is rather high costs of obtaining a unit of production, which are offset by a higher price in the market.

In Asia, soybean cultivation on ridges is widely used. This method is used in foothill areas on sloping lands and on heavy soils with excessive moisture. The ridge technology allows the soil to warm up more intensively, which has become an indisputable advantage in regions with a low average annual temperature. Using this technology, soybeans are grown in Heilongjiang province in China, on the border with Russia. The width of the ridges varies with climatic conditions in a particular region. So soybeans are sown in 2 rows in ridges with the row spacing of 65 cm at a distance between them of 10-12 cm and at a ridge height of 15-18 cm (Bay, S., 2014).

Scientists from Japan have developed a technology and technical means for sowing soybeans in ridges with a combined unit. The core of the technology is that the combined unit includes cultivating tools, a ridge former, and a seeder. In one pass, the soil is loosened to a depth of 10-20 cm, the ridges are formed and seeds are sown, followed by rolling. This technology includes elements of the No-Till technology, while also saving on operating costs (Matsuoa, N., Tsuchiyab, S., Nakanoa, K., Fukamia, K., 2019).

With any technology, the introduction of soybeans into crop rotation increases the sustainability and environmental safety of field agrosystems, helps to increase the vegetable protein production for feed and food purposes. The use of atmospheric nitrogen for yield formation helps to increase soil fertility and minimizes the use of mineral fertilizers.

Conclusions

1. According to the FAO, the world's soybean crop area exceeded 120 million hectares in 2018, which is 1.5 times higher as compared to 2000. The largest areas are in the United States (28% of the world's total area), Brazil (26%), and Argentina (14%), as well as in India (8%) and China (6%). The crop area in these countries was 82% of the world's total area, including 68% in the USA, Brazil, and Argentina.
2. Thanks to state support, soybean crops in Russia have significantly increased over the past decade and reached 2.5 million hectares in 2018, and production output exceeded 3.6 million tons. Most of the Russian soybean crop is processed into oil, mealб and oilcake by oil-and-fat plants and exported to China.
3. Soybean yield in Russia is one of the lowest in the world and averages about 1.5 t / ha, that is 2.0-2.5 times lower than in Central Europe, the USA, Argentina and Brazil. According to this indicator, Russia is at the level of India and China. However, Russian soybeans are valued domestically and on the world market, since the varieties are not genetically modified.
4. In 2017-2018, world consumption of soybeans amounted to about 350 million tons, of which more than 100 million tons accounted for China. In recent decades, the consumption of meat and dairy products has increased significantly in China. As the growth of agricultural production requires the increased feed base, that is why demand for soy protein increased as well. With a deficit of domestic production, the country is increasing imports.
5. Three main systems of soybean production are widespread in the world; they are traditional, biotechnology-based, and organic. In the countries of Southeast Asia, a method of growing soybeans on ridges is applied.

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Strategy of Technical Support of Grain Harvesting Operations in Republic of Kazakhstan

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Abstract

The regions of Kazakhstan are characterized by a sharply continental climate with a lack of moisture. Grain yield is low and is about of 0.7-2.5 tons per hectare. In the South, East and West there is a number of small farms. In the North, where large agricultural enterprises are placed, there is a shortage of mechanization personnel. Sixty percent of combine harvesters are older than 10 years. The research purpose is determining the optimal strategy of technical support of grain harvesting in different regions of Kazakhstan in accordance with agro-climatic and production conditions. Authors used analytical methods for calculating optimal variants and experimental studies. It was found that in the conditions of dryland agriculture of the South, West and East regions of the Republic it is necessary to use mainly combines of the 3rd class. In the conditions of irrigated agriculture of the South region, it is more expedient to use more productive combines of 5th and 6th classes. In the North region, the most effective are harvesters of 4th, 5th and 6th classes with wide reapers. The authors have found that the strategy of technical support of harvesting work in the Republic of Kazakhstan consists of a combination of the following technological decisions: integration of self-propelled combine harvesters of 3rd, 4th, 5th and 6th classes with a dominant share of combines of 3rd and 4th classes in the park; rigging of combines of 3rd and 4th classes with the headers of width of 6-9 meters, and harvesters of 5th and 6th classes with the header of width of 9-12 meters; use of combines of 3rd and 4th classes on grain harvesting on farms, and harvesters of 5th and 6th classes in the areas of irrigated agriculture in large farms; the combination of three harvesting technologies: direct harvesting, separate harvesting, combing ears out on the root; the use of grain storage bins for reloading and heavy-duty vehicles for transporting grain from combines reduces the required number of machines by 25-30%.

Keywords: technical and technological support of harvesting, direct harvesting, separate harvesting, towing on the root, combine harvesters, wide header.

Introduction

Optimization of technological

and technical solutions for crop harvesting depends on many factors as agro-climatic conditions during harvesting, acreage, type of crop rotation, crop yield, pricing policy for material and energy resources, organizational, economic and other conditions [Lachuga et al., 2012; Chepurin et al., 2011; Sheychenko et al., 2016; Gorbachev, Shreyder, 2012; Vorovkin, 2005; Bur'yanov et al., 2015]. The regions of Kazakhstan are characterized by a sharply continental climate in most of the territory and lack of moisture with all the features of the arid zone. Hence the low yield of grain (0.7-2.5 t/ha), almost 100% predominance in the rotation of spring crops, stunted stems (0.30-0.75 m), large fluctuations in the harvesting humidity of plants in the North region from 10-12% in the first half of the harvest period, to 25-30% at the end. High humidity of plants is the main reason for low harvesting rates in the second half of harvesting. Studies show that improving the efficiency of the harvesting process is possible due to a reasonable choice of technical and technological support of harvesting [Chepurin et al., 2011; Bur'yanov et al., 2016; Maslov et al., 2018; Gol'tyapin, 2017; Mkrtchyan et al., 2013; Maslov, Trubilin, 2016; Erokhin, Sazonov, 2015; Bur'yanov et al., 2016].

Currently, there are four trends in the technical and technological support of grain harvesting in Kazakhstan:

- Expansion of the previously used type of combines of 3rd and 5th classes at the expense of combines of 4th and 6th classes;
- Combination of three variants of the grain harvesting technology: the direct harvesting, separate harvesting, combing plants out at the root;
- Use of a widely branched type of combine and roller harvesters, the combination of direct harvesting with conventional combine and combing header to form wings, contributing to an increase in snow accumulation;
- Use in large farms of accumulators-reloaders, and also mainly heavy-load transport on transportation of grain from harvesters in connection with a long-distance transportations.

In the South region of Kazakhstan, combines of 5 and 6 classes with a capacity of 9-10 and 11-12 kg/s are used in irrigation conditions, since there are cultivated corn for grain and rice with a yield of 6 t/ha and above. However, for the farms of this region in the conditions of dryland farming, harvesters of 3rd and 4th classes (5-6 kg/s) are more appropriate according to economic criteria. In the West and East regions of Kazakhstan the most common harvesters are of the 3rd and 4th classes (5-6 and 7-8 kg/s). Combines of the 3rd, 4th, 5th and 6th classes are used in the North region of Kazakhstan. There is an acute shortage of mechanization personnel.

In the conditions of the North region, the share of the areas harvested by combing out on a root increases. The use of grain harvesting technology with a combing ears out on a root in the conditions of low productivity does not give essential increase in productivity of harvesting works. However, the use of the technology increases the snow accumulation in the fields in winter. The accumulation of moisture of winter precipitation in the soil in the spring is the main guarantee of good plant growth in the first half of the growing season.

For separate harvesting, the type of roller headers with a width of 6-12 m is used. Cars and tractor trailers with a load capacity of 4 tons and above are used for transporting grain to farms.

The research purpose is determining the optimal directions of the strategy of technical support for grain harvesting in different regions of Kazakhstan in accordance with agro-climatic and production conditions.

Table 1 Wheat yield in the regions of Kazakhstan (average for 2013-2017), t/h

Region	Mean		Maximal	
	Actual	Potential	Actual	Potential
South	1.65	2.06	2.09	2.50
East	1.23	1.54	1.42	1.80
West	0.56	0.70	0.84	1.00
North	1.06	1.35	1.53	1.90
Central	1.05	1.31	1.10	1.40

Materials and Methods

In theoretical studies were used statistical estimates of grain harvesting conditions in Kazakhstan, standard methods and standards, as well as analytical methods for calculating the optimal variants of machine use [Lachuga et al., 2012; Zhalnin, 2011]. Experimental studies were carried out at machine testing stations according to standard methods.

Results and Discussion

The main requirement of highly efficient machine use is the introduction of an optimal fleet of equipment in structure and quantity. On this basis, authors were studied the state of the harvester park in Kazakhstan, as well as regional agro-climatic and production features of its use in grain harvesting [Usmanov et al., 2015].

According to the Ministry of agriculture of the Republic of Kazakhstan, at the beginning of 2017 there were 41.5 thousand of combine harvesters in the country, 29.1 thousand (70.1%) of which is of 3rd class, 6.3 thousand (15.3%) of which is of 4th class, 3.5 thousand (8.5%) of which is of 5th class and 2.6 thousand (6.2%) of which is of 6th class. There are 4.9 thousand (11.9%) of harvesters of 4th, 5th and 6th classes produced in foreign countries, they are of 10 different brands. Harvesters is mainly presented by machines from the following countries: Russian Federation (LLC "Rostselhozmash", LLC "Krasnoyarsk harvester plant", JSC "Promtractor"); Republic of Belarus (PA "Gomselmash", PA "Agropromtekhnika"); Republic of Kazakhstan (JSC "Agromashholding"); USA (John Deere, Challenger, Massey Ferguson, Case, New Holland), Germany (Claas, Deutz Fahr, Fendt); Italy (Laverda); Finland (Sampo). The service life of 60% of combine harvesters exceeds 10 years, and the main share of them (more than 90%) is of 3rd class harvesters. The use of these combines is inefficient due to a significant decrease in their productivity [Shepelev et al., 2015]. The issue of technical re-equipment is real. According to the Ministry of Agriculture of Republic of Kazakhstan, crop losses would reach 25% and above due to the deterioration of equipment.

The average yield of wheat in the Republic over the past 5 years was 1.15 t/ha (**Table 1**).

The south region has the highest average and maximum wheat yields. This is mainly due to the irrigated land, the productivity of winter wheat reaches 4 t/ha or more. However, winter wheat cultivation on irrigated land has been declining in recent years because of priorities are given to other crops. Combines harvest rice and corn for grain, the average yield of which in fine years is 4.5 t/ha, and the maximum reaches 7.0 t/ha.

The calculation of the prospective profile of combine harvesters was carried out taking into account the possibility of harvesting the potential yield; this allowed determining the technological need for combines.

The largest share of acreage is in the North region of the Republic of Kazakhstan (**Table 2**).

There are farms of different categories: farms with the acreage of 300-3000 hectares, medium-size farms with the acreage of 3000-10,000 hectares and large farms with the acreage of more than 10,000 hectares. Large and medium-sized farms in the region shares more than 20% of all ones, 71% of the acreage is concentrated in them. The beginning of the harvest period (the third decade of August) is usually dry, but it usually rains in September. More than 90% of small farms with acreage of 25-500 hectares are concentrated in the East and South regions. The size of agricultural enterprises in these regions is of 130-7,000 hectares [Golikov et al., 2017]. In the Central and North region, there are large and medium-sized agricultural enterprises, and in the West, along with large and medium-sized, there are more than 80% of small farms. Fall in the South, Central and West regions is usually dry. The presented characteristic of the regions conditions is taken into account for justifying the type of combine harvesters.

In the North region, where the largest areas of grain with a relatively high yield, the share of high-performance harvesters of 4th, 5th and 6th classes is about of 32.4%, in the Central it reaches 46.8%, in the South it reaches 20.7%, in the West it reaches 14.6% and in the East it reaches 12.1% (**Table 3**).

It should be noted that in all regions the main share of harvesters of 3rd class is operated beyond the amortization period.

The increase in the share of harvesters of 4th, 5th and 6th classes in the North and Central regions is due to the limited timing of favorable weather in the fall and the desire of agricultural producers to maximize the productivity of machines during the harvesting process with a shortage of machine operators.

Combines of 3rd and 4th classes with headers of 5 and 7 m are not enough loaded during harvesting crops with a yield of 1.2 t/ha. To improve their loading, it is necessary to use a header with a large width (up to 9 m).

The authors calculated the change in productivity and product of the Acros-530 of 5th class with a header width of 11 m when harvesting grain with a yield of 1.2 and 1.7 t/ha in the North region of the Republic. Productivity per hour of the main time was 8.8 hectares, which is almost 2 times higher than that of 3rd and 4th classes combines. At the same time, the average load of the thresher is 58.3% with a yield of 1.2 t/ha, 80.7% at 15 t/ha and 83.1% at 17 t/ha. In the first case, the harvester is under loaded by about half, and in the latter it is loaded almost completely. When using rotary harvesters of 6th class with header of 12 meter productivity per hectare is even

Table 2 Acreage in the regions of Kazakhstan (2017)

Region	Thousands ha	%
South	2,498	11.6
North	15,556	72.2
Central	1,103	5.1
West	1,064	4.9
East	1,322	6.1

Table 3 Structure of the harvester park of Kazakhstan, %

Region	Harvester class			
	3	4	5	6
South	79.3	5.5	9.1	6.1
North	67.7	14.5	10.4	7.5
Central	53.2	42.4	3.1	1.3
West	88.2	5.4	3.8	2.5
East	87.9	9.4	1.5	1.2

Fig. 1 Header with combing out adapter

(A) on the basis of the Esil-760 harvester with a header capture of 9 m

(b) on the basis of the Esil-740 harvester with a header capture of 7 m

higher, as these combines operate at a yield of 1.2-1.7 t/ha with reasonable losses at speeds up to 10 km/h. Thus, the use of combines of 5th and 6th classes with wide headers can double the productivity per hectare for harvesting grain yields of 1.2-1.7 t/ha compared to combines of 3rd and 4th classes. Full loading of combines of 5th and 6th classes on such productivity can be provided at separate harvesting of single and double rolls, using wide roll headers (**Table 4**).

The perspective park of combine harvesters for Kazakhstan should include combines of four classes: 3rd; 4th; 5th and 6th (**Table 5**).

In the south region, where winter wheat, rice, corn for grain with high yields are cultivated on irrigation, will use combines of 5th and 6th classes. However, due to the large share of small farms, the combine park will be based on machines of 3rd class. In the west and east regions of the Republic, where the cultivation of grain is carried out on drylands with a shortage of moisture, it should mainly use combines of 3rd class. This is due to the large share of small farms (West and East regions), as well as low grain yields (West region). Harvesters of a higher class is advisable to use in the Central and West regions, providing they with wide header in large and medium-sized agricultural enterprises with a shortage of mechanized personnel, and in the East region only with high grain yields. In the North region, where higher grain yields, a large proportion of large and medium-sized farms with a pronounced shortage of mechanized personnel, the most effective combines of 5th and 6th classes, provided with wide header for direct and separate harvesting. In smaller farms will be used harvesters of 4th class equipped with wide headers.

Calculations show that during the transition to a promising type of combine harvesters and headers with the optimal amount of harvesters, it is possible to ensure that harvesting operations are carried out in the required agricultural times.

Separate harvesting remains an important technological solution, as it allows efficient use of high-class combines (of 9-12 kg/s) on threshing of bread mass and ensuring the harvesting of high-quality grain.

For the harvesting areas of Kazakhstan, it is projected the expansion in the direct harvesting with the use of combing headers. Experimental testing of such technology in a number of regions of Kazakhstan revealed its high efficiency in three directions: increasing the productivity of harvesting and reducing the energy intensity of the threshing process and fuel consumption when harvesting high-yielding breads, as well as the use of stubble left after the combing ears out to increase snow accumulation in winter. In spring, melting snow becomes an additional source of moisture in the soil. It was found the preference of stubble wings compared to the full combing out, as they accumulate more snow. For formation of stubble wings, it is recommended to alternate passes of combines in the field: one pass with the usual combine header with leaving on the field of low stubble (5-10 cm), the second one with the combing out header. Another technical solution was tested too: on a conventional harvester header of width of 6-9 m in the middle of its mounted combing out device of width of 1.0-1.5 m (**Fig. 1**).

After the passage of the combine harvester with a combined header on the field, there are areas with low stubble and between them a section with high stubble. This combine unit greatly simplifies the organiza-

Table 4 Recommended header width of combine harvesters for the different productivity

Productivity, kg/s	Harvester class, kg/s	Width of used headers, m	Required width, m
5-6	3	5-6	8-10
6-7	3.5	6-7	10-12
7-8	4	5-9	12-14
8-9	5	6-9	13-16
9-10	5.5	6-9	15-18
10-12	6	9-12	17-21

Table 5 Promising types of combine harvesters in Kazakhstan

Harvester class	Regions					In the whole country
	North	South	Central	East	West	
3	-	+	+	+	+	+
4	+	+	+	+	+	+
5	+	+	+	+	+	+
6	+	+	+	-	-	+

tion of harvesting for the formation of snow-retaining wings.

The greatest increase in yield of 0.5 t/ha was revealed at stubble wings of 1.5 m wide placed from 5 to 9 m together with soil grooving to a depth of 35 cm (**Table 6**).

To avoid downtime of harvesters, authors recommend the use of storage bins and use vehicles for transporting grain to large farms. The use of heavy-duty vehicles is due to an increase in the proportion of harvesters of 5th and 6th classes with a large volume of the hopper. At the same time, the need for machines is reduced by 25-30%.

Conclusions

1. The strategy of technical support of grain harvesting operations in the Republic of Kazakhstan consists of a combination of the following technological and technical solutions:
   * Introduction of 4-class profile of self-propelled combine harvesters: 3rd class (5-6 kg/s); 4th class (7-8 kg/s); 5th class (9-10 kg / s); 6th class (11-12 kg/s) with a dominant share in the fleet of combines of 3rd and 4th classes;
   * Harvesters of 3rd and 4th classes should be equipped with headers with a width of 6-9 meters, and of 5th and 6th classes with header with a width from 9 to 12 m with the possibility of laying double rolls;
   * Harvesters of smaller classes (3rd and 4th) are more effective in harvesting grain with a yield of up to 1.5 t/ha in farms, and ones of large classes (5th and 6th) are more effective in harvesting grain, corn and rice with a yield of more than 2.5 t/ha and in large farms;
   * Combination of three harvesting technologies: direct harvesting, separate harvesting, combing ears out on the root;
   * Separate harvesting with the use of wide headers (full-size design or double) allows to use high-class harvesters;
   * The technology of harvesting grain with combing ears out on the root in Kazakhstan is effective in adverse weather and for the formation of snow-retaining wings, which contributes to the accumulation of moisture in the soil in the spring and increase grain yield by 0.5 t/ha;
   * Combine harvester, equipped with a center combing out device up to 1.5 m wide is an effective means for the formation of snow-retaining wings.
   * The use of heavy-duty vehicles of more than 5 tons in the transportation of grain from combines increases the daily output of combines by 20-25%, and the use of grain storage reduces the required number of machines by 25-30%.
2. Practical realization of proposed technical support of grain harvesting in production in Kazakhstan will increase yields by 25-30%, reduce harvesting time to optimal agro-technically justified, reduce the need for machine operators.
3. The main provisions of the proposed strategy for updating the park of grain harvesting machines are largely applicable to the regions of the Russian Federation and countries directly bordering to Kazakhstan.

Table 6 Yield of wheat depending on the methods of moisture accumulation in the soil, t/ha

Exceeding above the control method	Average yield	Exceeding above the control method
Stubble (control method)	9.1	6.1
Stubble wings of 1.5 m through 5 to 9 m and grooving to 35 cm	10.4	7.5
Stubble wings of 3-4 m through 14 to 18 m and grooving to 35 cm	3.1	1.3
Grooving to 35 cm on the stubble	3.8	2.5
Deep shaft-free treatment of 30 cm on the stubble	1.5	1.2

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The Choice of Combine Harvesters and Their Adapters for the Conditions of Northern Kazakhstan

Šotnar, M., Pospíšil, J., Mareček, J., Dokukilová, T., Novotný, V. Influence of the Combine Harvester Parameter Settings on Harvest Losses. Acta Technologica Agriculturae. 2018. N21(3). 105-108.
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The Methodology of Modeling and Optimization of Technologies in Crop Production

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Abstract

For any model of economies, the procedures of choosing, building models and optimizing technologies in crop production are used, especially for resource-intensive crops such as sugar beet and its testes. The concept of chemical and technological intensification of agriculture in many countries is based on consumer perceptions of its supposedly unlimited capabilities. In the modern interpretation, the procedure of building models of technologies in agricultural production should be based on adaptive methodology. This technique has not been developed for machine technologies. (Research purpose) The research purpose was for developing a method of modeling and optimizing of machine technologies in crop production using the sugar beet. (Materials and methods) According to the national agricultural development program, it is planned to bring sugar security to the level of 80-90%. Technological improvement and machine technology play a major role in the program. It was found that used in many countries the common agricultural technology of sugar beet production includes the following operations: basic tillage; early spring and pre-sowing tillage; sowing; care of beet crops, including chemical protection; harvesting. It was found that Russian technologies in comparison with foreign ones do not provide the necessary productivity and reduce resource costs. However, foreign technologies are focused on chemical weeding, which pollutes the environment. Due to production features, Russian technologies are focused on integrated agricultural methods of beet cultivation, using mechanical, chemical and biological methods of crop processing. The article proposes the procedure of selecting, modeling, adapting and optimizing machine technologies taking into account local, i.e. zoned natural-climatic, production, economic, environmental, etc. factors based on a systematic approach. (Conclusions) Authors have developed a method of modeling, machine technology formation and optimization for the main systems of agriculture, taking into account the level of productivity and availability of resources. According to this method, it is possible to determine the list of machines, technological materials and their characteristics, based on production conditions, ownership forms and resources. The results of the research have been used to form the System of Technologies and Machines for Russian crop production.

Keywords: modelling method, optimization, machine, technology, sugar beet.

Introduction

It is possible to increase the level of self-sufficiency of the country in sugar and reduce the consumption of resources thanks to advances in biotechnology and innovative machine technologies.

The concept of mainly chemical and technogenic intensification of agriculture that exists in many countries is based on consumer perceptions of its supposedly unlimited possibilities, which negatively affects the quality of products and the environment (Zhuchenko, A. A., 2012).

In the modern interpretation, the procedure for constructing models of technologies in agricultural production should be based on an adaptive method. There is no such method for machine technologies of crop production.

The research purpose is developing a method for modeling and optimizing machine technologies in crop production using the sugar beet.

Materials and Methods

The common agrotechnology of sugar beet production, used in many countries, includes the following operations: basic tillage; early spring and pre-sowing tillage; sowing; care of beet crops, including chemical protection; harvesting. Considering Russian technologies for 1990-2014 in comparison with foreign ones, it can be noted that they do not provide the necessary productivity and reduce in resource costs (Lobachevsky, Ya. P. et al., 2017). In agricultural holdings, where most elements of Western technologies are used, the indicators for beet production are comparable to the best foreign results (Domanov, N. M., 2011). However, in terms of environmental indicators, technologies need to be improved.

Resource-saving technologies (Rst) are widely used in Russia (Apasov, I. V. et al., 2008; Shpaar, D. et al., 2006). They are commonly agronomic in nature and do not reveal the essence of modeling and optimization of machine technologies.

In the recommendations of scientists on soil erosion for intensive technologies (It), along with the above (Rst), the main soil treatment is differentiated depending on the agrophysical properties of the arable horizon and must be supplemented with techniques for maximum regulation of meltwater and storm runoff (Soldat, I. E. et al., 2011).

Pre-sowing treatment is aimed at maximum purification of the soil from weeds by agrotechnical methods, with high-quality leveling and crumbling. Usually it is combined with sowing, which preserves soil moisture.

The system of fertilizers application provides the creation of a deficit-free balance of humus and ensuring soil fertility. For this purpose, organic fertilizers, crop residues and green manures are widely used, so that the quantity of mineral fertilizers can be reduced by 30-50%.

Environmental safety is ensured by reducing the use of pesticides and fertilizers, performing inter-row mechanical treatments of the soil and reducing the pressure of tractor running systems on the soil.

In addition to the conventional production steps, the scientists recommend the use of combined aggregates in Rsfs and Ifs technologies. This increases productivity and reduces technology costs.

At the Kursk machine testing station, we tested a non-herbicide / environmental protection (Pnfs) technology. For improved basic tillage, we recommend to use layer plowing and modernized cultivators with innovative rotary rippers for pre-sowing tillage, pre-emergence and inter-row tillage. As a result, crop contamination, herbicide costs and environmental pollution are reduced.

When designing and selecting technologies, along with technological features and agro-engineering support it is necessary to pay attention to the economic components of sugar beet production, such as production costs and margin income (maximum profit). Thus, in the structure of the cost of sugar beet production in European countries, for example in Germany, most of the costs are spent on fertilizers and mechanization (Rogler, H., 2009). Farmers spend up to 1,500 euros per 1 ha. Margin income depends on the quota, as well as the resources spent, this is a variable value. Therefore, the effectiveness of machine technologies should be evaluated not by the maximum profit, but by the regulated one (Rogler, H., 2009; Artyunov, B. A. and others, 2007). The resources consumed must be considered as constraints in the technology optimization model (V. V. Mikheev et al., 2015).

It need to take into account local, i.e. zonal, climatic, production, economic, environmental, and other factors from the system approach during the procedure for selecting, modeling, adapting, and optimizing machine technologies (**Fig. 1**).

The procedure for selecting and adapting a technology from known or projected options has a logical scheme that takes into account the system of agriculture in the economy (FS), resource potential, productivity, main and additional factors of production. At the final stage, an expert opinion is issued on the type of machine technology. The choice of Mt is made after a comparative analysis of the production task and farm conditions. The analysis is performed according to the logical scheme "Yes-no-or" (respectively, "satisfy - does not satisfy - an alternative option is used").

It has been found that the key focus of machine resource-saving technology Rst needs to log in high technology Hl; intensive technology Il in the productive system of intensive technologies of It; machinery environmental technologies Pnt in a normal productive technologies Nl.

More advanced technologies have the following distinctive elements:

- Placement of sugar beet in crop rotations after the best predecessors, taking into account biologized crop rotations and electronic field maps;
- Application of improved or semi-fallow basic tillage, using plows for smooth and level plowing, in-soil application of optimal organic and mineral

fertilizers, with the required ratio of nutrients in accordance with the electronic field map;

- High-quality performance of autumn, early spring and pre-sowing soil treatments with combined tools;
- Seeding with highly productive and high-quality single-growth seeds at the final density (not less than 100 thousand/ha) to obtain a given number of plant seedlings, carried out by single-operation and combined units with auto-driving;
- The use of an integrated system of agrotechnical and chemical measures against weeds, pests and diseases; the use of chemical plant protection products environmentally friendly ways (in foam-air mixture bands at adjustable height), combined with foliar application with micronutrients and biologicals (S. D. Karakotov, 2016);
- Implementation of agro-technical measures to destroy soil crust, weeds and root beetles, like pre-emergence and post-emergence loosening of the soil both in rows and between them, the use of combined operations of loosening and fertilizing with nitrogen fertilizers, loosening and hilling of protective zones, with the use of inter-row cultivators and combined rippers, as well as equipment for auto-routing;
- The use of in-line or in-line transshipment methods for harvesting root crops by trailed and self-propelled combines, with the preparation of electronic yield maps (GPS technology).

With the accumulation of fundamental knowledge in agricultural technology, the introduction of innovative equipment and working parts, the classification of machine technologies and improvements can be expanded.

Results and Discussion

The procedure for forming technological machine operations on technologies should be completed by drawing up a map, an explanatory note on their justification, as well as a database on the main parameters of the equipment (**Table 1**).

In the Hl technology, there are used the main soil treatment using the improved steam method; in the Il and Nl technologies there are used semi-steam method, with the indication of used soil-processing tool.

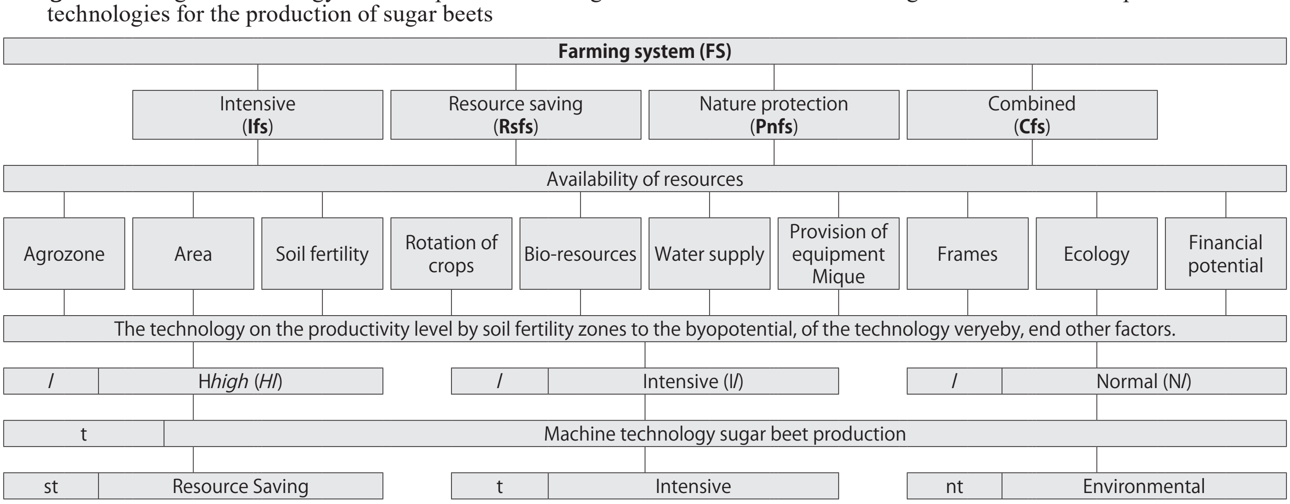
Autumn herbicide treatment was not used in the technologies due to their elimination in the crop rotation according to environmental requirements.

Modern approaches to the use of fertilizers were used in the designing of technologies. They took into account the score of arable land, biologized crop rotation, as well as the availability of resources of local organic fertilizers (grain straw, break manure crops, waste of livestock complexes. The use of mineral fertilizers was minimized. Foliar fertilizing with micronutrients was widely used.

Only mineral fertilizers were used in the Hl technology, since it used elements of a biologized crop rotation, the harvesting of the grain precursor was carried out with straw scattering across the field. Since autumn, beets have been fertilized with P80 K80 in the amount of 598 kg/ha, with $N_{10}P_{10}K_{10}$ in the amount of 215 kg/ha when sowing and N60 in the amount of 131 kg/ha when fertilizing, which in total amounts to 944 kg/ha for the planned root crops of 55 t/ha on soils with a fertility score of 80 or higher. For foliar feedings, the Microvit TM (or Aquarin-5) preparation was used in doses of 0.3 kg/ha (4 times), simultaneously with the introduction of plant protection products.

Il technology also uses elements of a biologized, environmentally improving farming system. Crops cultivated after green manure crops.

Fig. 1 Modeling the technology selection procedure taking into account factors influencing the formation of adaptive machine technologies for the production of sugar beets



After stubble breaking, grain soil make liquid organic fertilizer (ecologically improve action) at a dose of 20 t/ha of complex fertilizer applied at a dose of $N_{60}P_{60}K_{60}$ in the amount of 1200 kg/ha; $N_{10}P_{10}K_{10}$ in the amount of 187.5 kg/ha during sowing, N_{60} in the amount of 152 kg/ha as top dressing by cultivation, which amounts to 1,539.5 kg/ha with planned yield of 39 t/ha for soils with a fertility index of 70.

Foliar fertilizing was performed with Microvit TM (or Aquarin-5) in doses of 0.3 kg/ha (2 times), together with the introduction of plant protection products.

Table 1 Machine manufacturing technology map (example)

Name of adapters and operations	Type of technology		
	H*l*	I*l*	N*l*
Primary Cultivation			
Primary tillage:			
By disc tiller	–	–	+
By tusk	+	(+)	(+)
By disc header	+	+	–
By surface cultivator	–	–	–
Autumn application of herbicides on seedlings of weeds	(+)	(+)	(+)
Fertilizer applicatoin:			
Organic (solid and liquid) on surface	(+)	+	+
Mineral into soil	+	+	+
Plowing:			
Cultural plowing	–	–	(+)
Level plowing	–	(+)	+
Smooth plowing	+	+	(+)
Beardless plowing	(+)	–	–
Field leveling	(+)	(+)	+
Autumn plowing:			
Harrowing with levelling	+	+	+
Disking	(+)	–	–
Autumn slitting	(+)	–	+
Snow capture	(+)	+	+
Early Spring Soil Treatment			
Two-track moisture closing	+	+	+
Smoothing	–	–	(+)
Smoothing with tilling	+	+	+
Introduction of herbicides:			
Water delivery	+	–	–
In a solid way	+	–	(+)
In Stripes on the row lines	–	–	–
Pre-planting Cultivation			
Complete	+	+	+
Complete with herbicides	–	–	(+)
In stripes on the line of rows with herbicides	–	–	(+)
Sowing			
Sowing with fertilizer:			
Exact (e)	(+)	(+)	(+)
Dashed (d)	–	–	+
e/d with strip cultivation and herbicides	–	–	(+)
e/d with strip application of herbicides	+	+	(+)
Crop Tending			
Harvesting			

Note: “+” - preferential use; “(+)” - alternative operations; “–“ - unused operations.

The Nl technology uses traditional improved approaches to the application of fertilizers: application of organic and mineral compost prepared in the ratio of 20 t/ha of organic fertilizers and mineral fertilizers $R_{90}K_{103.5}$ which is 20.7 t/ha of compost. P_{10} superphosphate in the amount of 50 kg/ha was used for sowing, and N_{60} urea in the amount of 130 kg/ha was used for fertilizing during Il, which in total is at least 880 kg/ha, for the planned harvest of 30 t/ha for soils with a fertility score of at least 60.

In all technologies, plowing to a depth of 30-32 cm is used, with reverse or longline plows (Nl technology), with simultaneous cutting of the formation.

In three technologies, autumn processing with micro-leveling with harrows, was used to control the crust and weeds.

To accumulate moisture, the Il technology introduced snow retention by rolling, and the Nl technology introduced chipping and felling.

Early spring soil treatment (moisture closing) is used in three technologies: with the use of hydraulic coupling of harrows and crawler tractors at low pressure on the soil (the requirement of environmental friendliness).

Before sowing in Hl technology, operations are performed for loosening and leveling the soil, applying soil herbicides and sealing them with the soil with an overlap. Sowing is accurate (seeds of Crocodile variant or LMS-98 hybrids, with a productivity of 50-55 t/ha), with auto-driving on the course indicator (tractor equipment), an 18-row seeder of the Optima TuMe Moro type, with simultaneous application of fertilizers.

Il technology provides 2-fold pre-sowing cultivation combined with plowing before sowing. Sowing is precise (seeds of Medina or Crystal hybrids, with a productivity of 40-42.7 t/ha) by a combined 12-row seeder of the ED 602-K Classic type, with simultaneous band application of soil herbicides (saving the preparation and environmental friendliness) and fertilizers. Loading the seeder with fertilizers is mechanized.

In the Nl technology, cultivation and plowing of the field in two tracks are provided before sowing, and pre-sowing cultivation is combined with sowing (the conditions of resource preservation and environmental friendliness). Seeding is dotted with small norms (4 kg / ha, LMS-94 hybrid seeds) by 12-row seeder of SST-12V type with a crawler tractor (environmental requirements).

Technological operations on care of plants in these technologies are reduced to making mixes soil and post-seedling herbicides, insecticides, and micronutrients to pre-seedling soil in rows and between rows (technology Hl and Nl), the first inter-row cultivation (technology, Il), inter-row cultivation and fertilizing, inter-row treatment, deep soil loosening (technology Hl and Il) and hilling (technology Il and Nl). In the Nl technology, a crawler tractor is used for aggregating row-to-row cultivators (the soil-saving mode of low-fertile soil is provided, which is a condition of environmental friendliness).

The most typical technologies for farms are planned for harvesting. In Hl technology used a self-propelled harvester of the SKS-624 BS624 type on resource-saving technologies, with the distribution of tops on the field, in Il technology there are used two-phase method of harvesting, using machines of RBM-6 type, stripping of tops and scattering it across the field, and harvesting complex of KPS-6; in Nl technology there are used two-phase method of harvesting, using BM-6B after-cleaning machine and the collection of tops, with her hauling on the farm, and the self-propelled combine RKM 6-07 (engine YAMZ).

Initial data on technologies, operations and machine units are described in the technological map (Normative reference materials for planning mechanized work in agricultural production: Collection. Moscow: Rosinformagrotech, 2008. P. 22-27), and the standard MS Excel program calculates performance indicators.

The calculations of spent resources for the above-mentioned technologies are summarized in a table, and their list can be expanded at the request of the commodity producer (**Table. 2**).

High Hl technology has the lowest cost. It includes 23 operations. When using highly productive seeds of Krokodil or LMS-98 varieties, fertilizers and other intensification factors, the yield of root crops is at the level of 50-55 t/ha and the sugar content is up to 18.5% (Karakotov, S. D., 2016). The energy efficiency coefficient is the highest and is 4.85. Specific labor costs do not exceed 6.56 man h/ha, the minimum fuel consumption per unit of production is 2.28 kg/t, as well as the lowest indicators of specific metal consumption of 4.25 kg/t and energy consumption of 514.55 MJ/t. The volume of application of mineral fertilizers is 250 kg / ha, and their return by weight of root crops is of 200-220 kg/kg.

Intensive Il technology is performed in 34 operations. For sowing, the most common seeds of the Crystal and Medina varieties were used, providing a yield of more than 39 t/ha and a sugar content of up to 17.9%. Because of the lowered score of the soil, due to the conditions of medium farms, the inventory of liquid organic fertilizer and protected areas, subsurface introduction of liquid organic fertilizer in dose of 20 t/ha. Amount of application of mineral fertilizers is of 420 kg/ha and their impact is of 85-92 kg/kg. Efficiency ratio of energy consumption is small and is about of 1,98. However, the specific labor productivity and fuel consumption are close to Hl technology and equals to 0.20 man hour/t and 2.49 kg/t. The metal consumption and specific energy consumption are increased due to the greater number of operations and the use of different and more complex equipment (tractors and combined units).

In a normal Nl technologies provided by 33 of the operation. This is a farm-level technology with elements of resource conservation and greening. Seeds of domestic selection such as LMS-94 and LMS-98 were used for sowing, providing a yield of at least 30 t/ha and a sugar content of up to 17.5%. Due to the low soil score (about 60%), the technology provides for the introduction of organic compost in a dose of 20 t/ha and mineral fertilizers in the amount of 510 kg/ha, the return of fertilizers is of 58-82 kg/kg. For the main works, crawler tractors and composite combined units were used to ensure minimal soil compaction, combining soil treatment operations, sowing and applying plant protection products. The energy efficiency coefficient is average and is of 2.54, and labor and fuel costs are increased, which depends on the selected equipment.

Table 2 Resource expenditure indicators for Hl, Il, Nl technologies (example)

Technologies	Yield, t/ha	Labor costs		Fuel and lubricant consumption		Metal consumption		Specific energy consumption		Energy consumption coefficient
		man hours / ha	man hours / t	kg/ha	kg/t	kg/ha	kg/t	MJ/ha	MJ mg/t	
H*l*	55	6.56	0.12	125.50	2.28	234.00	4.25	28,300.00	514.55	4.85
I*l*	39	7.89	0.20	97.27	2.49	329.67	8.45	49,091.81	1,258.76	1.98
N*l*	30	12.87	0.43	158.43	5.28	177.78	5.93	29,484.89	982.83	2.54

The analysis showed that the lower the productivity of the technology, caused by low soil fertility and resource availability, the more increased (from the reference HL technology) the consumption of fertilizers, fuel, specific labor costs, metal consumption, specific energy consumption and the number of operations. The difference in performance technologies, Il and Nl is the number of operations applied fertilizers, unequal power, diverse in functionality and performance of machines with a lower annual load and a higher metal content.

Conclusions

A methodology has been developed for modeling and forming machine technologies and optimizing them for the main farming systems, taking into account the level of crop productivity and resource availability, which allows us to determine the list of machines, technological materials and their characteristics based on production conditions, ownership forms and resource restrictions. We have developed a methodology for determining the fleet of machines and selecting a strategy for their application for the main technologies of sugar beet production. It takes into account the potential productivity of fields, the availability of resources, and the size of agricultural enterprises. The results of the research are useful to the formation of technologies in farms and systems of machines for crop production in Russia.

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Benefits of Using Liquid Nitrogen Fertilizers for Russian Farm Enterprises

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Abstract

The main prerequisite for solving the problem of food supply for the Russian population is the increased use of fertilizers aimed at obtaining high and sustainable crop yields against the background of increasing soil fertility. Research purpose was to analyze the state of production and use of liquid nitrogen fertilizers in Russia and determine the directions for improving their application technologies. While making the analysis, the authors studied the documents of the Federal State Statistics Service of the Russian Federation, the scientific works of the leading institutions of the country, and the requirements of state standards. These have showed the advantage of liquid nitrogen fertilizers (a solution of urea-ammonium nitrate (UAN)) as compared with solid nitrogen mineral fertilizers in various soil and climatic conditions of the country. The average increase in the yield of grain and row crops amounted to 10-20% as compared with the use of ammonium nitrate. The authors have noted a more uniform distribution of fertilizers during application and a reduction in their losses. The observed high economic efficiency of the use of urea-ammonium nitrate in production conditions, which was made possible due to its mixed application with pesticides for foliar feeding of grain crops.

As a result of the synergetic effect of the initial components, the application rate of plant protection products was reduced by 15-30%, direct operating costs in 2.5 times, and labor costs in 2 times. The study has shown that increasing the use of liquid fertilizers in the country requires raising funds to develop the infrastructure for their use. In order to increase the efficiency of the use of liquid nitrogen fertilizers, a technology of differential application was developed taking into account the intra-field heterogeneity of the soil cover according to the main phases of plant organogenesis, which was proved with the results of plant diagnostics and the phytosanitary condition of crops. An analysis of the production and consumption of mineral fertilizers in Russia showed that domestic enterprises are able to fully satisfy the needs of farm enterprises in fertilizers. However, due to the disparity in prices for farm produce and material-and-technical resources, the use of fertilizers does not exceed 20% of their output. The use of a solution of urea-ammonium nitrate for foliar top dressing under industrial conditions gives an increase in the yield of grain crops of 0.5-1.2 tons/ ha against the background of the main fertilizer application. With the simultaneous mixed application of this fertilizer and pesticides, the costs of plant protection products are reduced by 15-30%, those of retardants - up to 50%, and the yield of grain and row crops increases by 5-10% as compared to their separate application.

Keywords: application of liquid mineral fertilizers, urea-ammonium nitrate, foliar fertilizing, variable-rate application of fertilizers, fertilizer application efficiency.

Introduction

According to the International Association of Fertilizer Manufacturers, global fertilizer consumption is constantly growing. In 2015-2016, it amounted to an average of 181 million tons of active ingredient (AI), or was 2.2% higher than in 2013. Increased intensification of agriculture, primarily through the use of fertilizers, is considered to be the main condition for solving the problem of providing food to the world population. In the medium term, the world market of mineral fertilizers will be able to produce 199 million tons of fertilizers (active fraction) when utilizing the capacity of enterprises by 80% (Zavalin, A. A. et al., 2014).

In Russia, there has been annual positive dynamics in the production of mineral fertilizers over the past 15-20 years. Due to the unique raw material base, the modernization of existing enterprises and the commissioning of new capacities, the volume of fertilizer production amounted to 20.7 million tons of equivalent tons in 2016, which is 13% higher as compared to 2013 (**Table 1**). Russian enterprises are among the key players in the global fertilizer market. The constant active population growth in the world aggravates the problem of food security, stimulates the growth of fertilizer production capacities, and intensifies competition among their suppliers.

However, due to the small capacity of the country's domestic market, more than 70% of the fertilizer output is exported to other countries.

The application volume of mineral fertilizers in Russia increased from 1.85 million tons (active fraction) in 2013 up to 3.1 million tons (active fraction) in 2018. In 2017, an average of 55 kg (active fraction) of fertilizers was introduced per 1 ha of crop area. However, this is not enough to obtain stable and high crop yields, as well as to preserve and increase soil fertility (**Table 2**).

In 2013, the production of mineral fertilizers in our country amounted to 7.5% of the world production. The needs of Russian farm enterprises can be completely satisfied - at the level of the world's developed countries (Surinov, A. E. et al., 2018).

The State Program for the Development of Agriculture of the Russian Federation for 2013-2020 provides, along with the main priorities for the further development of the agricultural sector, the preservation and increase of soil fertility through the use of fertilizers. In the future, by 2020, subject to the fulfillment of the objectives set by the Program, fertilizer application may increase to 80-100 kg/ha of crop area against 55 kg/ha in 2017. By 2030, the consumption of mineral fertilizers according to the "Development Strategy of the Chemical and Petrochemical Complex for the Period until 2030", according to conservative and innovative scenarios, should amount to 6.3 million and 8.7 million tons of active fraction, respectively (**Table 3**).

According to the calculations of the All-Russian Research Institute of Agricultural Chemistry, to ensure more intensive development of the grain industry, fully meet the needs of animal husbandry in feed and minimize nutrient deficiencies in arable land for different scenarios of agricultural development, 6.9-13.9 million tons of fertilizers (active fraction) should be annually introduced.

At the same time, solvent demand of agricultural enterprises for mineral fertilizers is limited and will have amounted to 4-5 mln tons (active fraction) by 2020. (Surinov, A. E. et al., 2018; Sychev, V. G. et al. 2016).

The research purpose was to analyze the production and use of liquid mineral fertilizers in Russia and determine the directions for improving their application technologies.

Table 1 Fertilizer production volumes in Russia

Indicators	2013	2014	2015	2017
Production volume, mln tons of active material	18.3	19.6	19.9	20.8
Export share in production, %	71	73	77	74

Table 2 Volumes of mineral fertilizer applied for crop cultivation in Russia

Indicators	2013	2014	2015	2016	2017
Amount of mineral fertilizers applied:					
total, mln t (active fraction)	1.8	1.9	2.0	2.3	2.5
per ha of crop area, kg	38	40	42	49	55
Share of fertilized area of the total crop area,%	46	47	48	53	58

Materials and Methods

When conducting research, the authors used the documents of the Federal State Statistics Service of the Russian Federation, scientific works of the leading institutions of the

Table 3 Forecast of the dynamics of production and consumption of mineral fertilizers on the domestic market of the Russian Federation, mln tons of active fraction

Indicators	Conservative scenario				Innovative scenario			
	2016	2020	2028	2030	2016	2020	2025	2030
Fertilizer production	19.6	22.5	24.3	26.9	21.0	29.8	37.0	45.1
Domestic consumption of fertilizers	4.7	5.1	5.7	6.3	4.9	5.8	7.0	8.7
Fertilizer exports	14.9	17.4	18.8	20.6	16.1	24.0	30.0	36.4

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Results and Discussion

According to the International Association of Fertilizer Manufacturers, nitrogen accounts for about 60% of the volume of mineral fertilizers produced. In Russia, this indicator is more than 40%. The annual growth in the production of nitrogen fertilizers in the world is an average of 10%.

According to the FAO, the share of liquid forms in the global volume of consumed mineral fertilizers is 9-10%, these are actively used in more than 70 countries of the world. The largest volumes of liquid fertilizers are used in the USA (about 30%), while in Europe the share of liquid fertilizers is 10-15%. Liquid ammonia is actively used in Denmark, and urea-ammonium nitrate (UAN) is used in France and Austria. In Asian countries, liquid nitrogen fertilizers are not used at all.

In Russia, the range of liquid nitrogen fertilizers includes:

- Liquid (anhydrous) ammonia - 82.3% of nitrogen;
- Liquid ammonia, or ammonia water - 19-21% of nitrogen;
- Liquid nitrogen fertilizers (UAN - an aqueous solution of urea and ammonium nitrate) - 28-32% of nitrogen.

In 1991, the amount of their application amounted to 0.8 million tons in physical weight (0.3 million tons of liquid ammonia and 0.5 million tons of UAN), or 10-12% of the volume of all used mineral fertilizers. In 2010, only 92 thousand tons of UAN were used, and in 2013 - 38.5 thousand tons. The production of this fertilizer type significantly exceeds the demand for it, which became the main reason for the export of products (Kolesnikova, V. et al., 2009; Solovyova, N. F., 2010). So, in 2014 its output increased by 29% as compared to 2013 and amounted to 598.8 thousand tons of active fraction.

The main reason for the low use of liquid nitrogen fertilizers was the lack of the necessary material and technical base in agricultural enterprises, primarily, warehouse equipment and transportation machines (Bezlyudny, N. N., Kovtun, V. M., 1989; Kormanovsky, L. P., Mishchenko, V. N., Kolesnikova, V. A., 1995). To develop a start-up integrated infrastructure along the entire supply chain − from the plant to the field − high investment costs are required from both producers of liquid nitrogen fertilizers and agricultural enterprises.

The results of our long-term studies in various soil-climatic zones of the country showed that in production conditions, especially in areas of insufficient moisture, the increase in yield of main crops from the use of UAN is higher than that from solid nitrogen fertilizers, due to more accurate application rates, uniform application and minimization losses (not more than 6-8%). Full mechanization of the processes of loading, unloading and soil application eliminates manual labor. UAN contains nitrogen in nitrate, ammonium and amide forms, providing a prolonged nutrition of plants with nitrogen and

Table 4 Productivity of winter crops when applying nitrogen fertilizers for top dressing in the tillering phase during production experiments, t/ha

Regions	Rate of nitrogen application, kg/ha	PK (background)	N_{aa}*	N_{KAC}*	HCP_{05}
Winter rye					
Smolensk	60	2.11	2.60	2.88	2.5
Tver	60	2.35	3.09	3.48	2.9
Winter wheat					
Tula	60	1.80	2.23	2.58	2.5
Samara	50	1.67	2.04	2.34	2.7

*Notes: N_{aa} - ammonium nitrate; N_{KAC} - liquid nitrogen fertilizers - solution of urea and ammonium nitrate

Table 5 Agronomic efficiency of the main application of UAN and ammonium nitrate during production experiments

Soil types	Fertilizer application rates	Yield, t/ha			HCP_{05}
		background	background + N_{KAC}*	background + N_{aa}*	
Spring wheat					
Dark gray podzolized medium loamy soil	background ($P_{60}K_{60}$) + N_{60}	3.21	4.16	3.86	2.2
Spring barley					
Gray forest soil	background ($P_{90}K_{90}$) + N_{90}	2.10	3.55	3.45	2.1
Sod-podzolic sandy loam soil	background ($P_{90}K_{90}$) + N_{90}	2.45	3.65	3.28	2.0
Corn grown for green mass					
Podzolized chernozem (black) soil	background ($P_{80}K_{80}$) + N_{160}	27.0	36.0	33.0	31
Podzolized gray soil	background ($P_{80}K_{80}$) + N_{150}	22.2	37.2	34.2	21
Sugar beet					
Podzolized gray soil	background ($P_{140}K_{160}$) + N_{160}	14.6	27.0	23.6	32

*Notes: N_{aa} - ammonium nitrate; N_{KAC} - liquid nitrogen fertilizers - solution of urea and ammonium nitrate increase crop yields by 5-20% as compared with solid nitrogen fertilizers. The coefficient of utilization of UAN nitrogen through the leaf surface for foliar top dressing is 20-30% higher than for root dressing with solid nitrogen fertilizers. Given the high efficiency and manufacturability, UAN is used mainly for foliar top dressing. The increase in yield of grain crops against the background of the main application is 0.5-1.2 t/ha depending on the application rates of nitrogen and the phase of plant development (**Tables 4**, **5**).

Under production conditions of Belarus, the Stavropol Krai, the Rostov Region, a comparative assessment of the agronomic efficiency of using UAN and solid nitrogen fertilizers showed the real advantages of using liquid nitrogen fertilizers (Bezlyudniy, N. N., Kovtun, V. M., 1989; Zavalin, A. A. et al., 2014).

According to the results of field and production experiments, the possibility of applying liquid nitrogen fertilizers and plant protection mixtures when their application periods coincide allows reducing the pesticide consumption rates by 15 ... 30%, that of retardants - up to 50% due to the synergetic effect of the initial components, and increasing the yield of grain and row crops by 5 ... 10% as compared with their separate application (Bashkirova, T. P., Mochkova, T. V., Bazegsky, E. P., 2007; Kolesnikova, V. A., Bashkirova, T. N., Mochkova, T. V., 2009; Samoylov, L. N., Yakovleva, T. A., Konova, A. M., 2011; Zavalin, A. A. et al., 2014).

Using reloading technology the authors conducted a study in KlinAgro LLC located in the Moscow Region. The study evaluated the technologies for separate application of ammonium nitrate and the Granstar herbicide and the mixed application of UAN-32 and Granstar at the early booting phase of winter wheat. It was revealed that the mixed introduction of UAN-32 and Granstar ensured a 2-fold reduction in labor costs and a 2.5-fold decrease in direct operating costs. The profit from obtaining an additional harvest of winter wheat grain at the selling prices of 2015 amounted to 1,280 rubles/ha, savings from the herbicide purchase - 486.5 rubles. Due to the synergetic effect of the starting components, the application rate of Granstar was reduced by 15%. The annual economic effect of the use of UAN-32 mixed with Granstar amounted to 1725.5 rubles/ ha.

Economic assessment of the use of UAN and ammonium nitrate was made in a pilot project based on the existing infrastructure in one of the agricultural enterprises of the Samara region (the UAN price - 10.5 thousand rubles / ton, that of ammonium nitrate - 12.5 thousand rubles / ton, fertilizer application area - 8 thousand hectares, fertilizers were delivered from the supplier's warehouse to the consumer and applied to the soil using the reloading technology). The assessment showed that the use of UAN at a rate of 80 kg/ha for pre-sowing cultivation saved direct operating costs in the amount of 3.36 million rub., capital investment for the billing period - 1.3 million rubles, and labor costs - 280 man-hours, as compared with ammonium nitrate. Moreover, in the structure of direct operating costs, the cost of fertilizers is 87-89%. (**Table 6**).

Self-propelled, trailed and mounted machines are manufactured in Russia and abroad for subsoil and surface introduction of liquid mineral fertilizers (LMF) in Russia and abroad. The farms of the Krasnodar and Stavropol Krai mainly use Agriget and Ammoniac machines of various makes produced by Agrohimmash LLC and sprayers ОП-2500 Agro, ОП-3000 Bulgar manufactured by KazanSelmash LLC. Liquid mineral fertilizers are transported using containers with a capacity of 4,500-9,000 L installed on vehicle bodies (production of LLC Agrokhimmash).

The design and installation of storage tanks for liquid mineral fertilizers in Russia is carried out by the Tsenterreservuarservis company.

Since 2009, in Russia there has been a steady increase in the production of domestic feed sprayers, which are not inferior in terms of technical characteristics to their foreign counterparts. At the request of consumers, they are equipped with on-board computers, GPS-receivers, systems for automated dosing of working fluids to work in the precision farming system. To introduce UAN, sprayers are equipped with deflector nozzles providing large-droplet spraying (with a droplet size of 700-1500 microns). Trailed sprayers are the most demanded for the use of LMF, 30% of them being supplied by foreign firms (Marchenko, L. et al., 2015).

To increase the efficiency of liquid

Table 6 Costs of applying UAN-32 and ammonium nitrate

Cost items	Application of UAN-32			Use of ammonium nitrate		
	total costs, thousand rub. per t	specific (unit) costs, rub.		total costs, thousand rub. per t	specific (unit) costs, rub.	
		per t	per ha		per t	per ha
Operating costs:						
excluding the cost of fertilizer	2,698.83	1,349.41	337.36	3,556.36	1,891.68	444.55
including the cost of fertilizer	23,698.83	11,849.41	2,962.36	27,056.36	14,391.68	3,382.05
Capital investments	5,874.80	2,937.40	734.35	7,170.27	3,813.97	896.29

mineral fertilizers in the conditions of limited resource capabilities of agricultural producers, given the high processability of liquid nitrogen fertilizers, the authors have developed the following technologies:

- Variable-rate fertilizer application, taking into account the intra-field heterogeneity of the soil cover;
- Mixed application of liquid nitrogen fertilizers, pesticides and retardants for the main phases of plant organogenesis, taking into account the results of plant diagnostics and the phytosanitary conditions of crops;
- Preparation of fertilizer solutions and suspensions with a programmable ratio of nutrients for their simultaneous application in one run of the unit (Izmaylov A.Yu. et al., 2016).

Conclusions

1. Capacities of domestic enterprises are able to fully satisfy the needs of rural producers in fertilizers. However, due to the disparity in prices for agricultural products and material and technical resources, the use of fertilizers does not exceed 20% of their output.
2. By 2030, the expected demand of Russian farm enterprises in UAN will amount to 117 thousand tons of active fraction.
3. The use of UAN for foliar top dressing of grain crops under production conditions gives an increase in productivity of 0.5-1.2 t / ha against the background of the main fertilizer application.
4. The possibility of simultaneous mixed application of UAN and pesticides in case their application periods coincide provides a reduction in the consumption of plant protection means by 15-30%, that of retardants - up to 50%, an increase in the yield of grain and row crops by 5-10% as compared to separate application of the products.

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■■

Trends in the Use of the Microwave Field in the Technological Processes of Drying and Disinfection of Grain

by

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Abstract

Increasing world production and consumption of grain is associated with the problem of preserving its quality. They are mainly associated with infection of the crop with phyto-pathogens. One of the solutions to this problem is decontamination of grain at all stages of its production and storage. From the point of view of environmental safety and energy intensity of decontamination and drying of grain, the use of an ultra-high frequency (microwave) field is considered promising. The research purpose is to analyze the volume of grain products and the need for its processing, review of technological processes, equipment and technologies based on microwave radiation in the processing of grain crops. It was found that up to 70 percent of the grain needs post-harvest drying, and 15 percent of the harvested crop needs decontamination. Analysis of the citation base showed an active scientific interest in microwave disinfection. The article identifies main trends in the use of microwave technologies. Microwave energy is used for drying, decontamination of grain and preparation of feed. It was found that the microwave field intensifies the active ventilation drying by 30-40 percent, reduces its energy intensity by 15-30 percent, and disinfects the harvested crop from mold spores. The article shows that the use of a microwave field allows micronization of grain during preparation for feeding, which reduces the energy intensity of the process by 20-30 percent compared to other electro-physical methods. The article describes the need for developing of installations for production lines with a capacity of 5-50 tons per hour. One of the current trends in the use of microwave installations in technological processes of grain processing and products of its processing is the combination of the microwave field with other types of electro-physical effects.

Keywords: grain, seeds, mycotoxins, grain drying, grain contamination, disinfection, microwave field, magnetron, electro-physical effect.

Introduction

The growth of the world's population, the standard of living in the world and specifically in the Asian sector leads to an increase in grain consumption, despite the overall decline in crop volumes over the past two years (**Table 1**).

According to Russian statistic agency, the wheat crop in Russia in 2018 amounted to 72.1 million tons. The total volume of wheat exports reported by the Expert-analytical center of agribusiness is 44.1 million tons (61%), which emphasizes the importance of this revenue item for Russia. However, one of the main restrictions on grain exports was its non-compliance with the requirements for contamination.

A number of standards regulates the rules of production, storage, grain processing, ensuring its safety for food and feed purposes. In Russia, these are Federal laws, norms of technological design of enterprises for post-harvest processing and storage of feed grain and seeds of grain crops and herbs, and other normative documents.

Both standards and regulatory documents on grain export/import have been developed at the international level.

Evaluation of grain quality for 5 years showed that about 10 million tons of harvested grain cannot be used for food and feed purposes (**Table 2**). And the number is increasing.

The problem of grain contamination with mycotoxins is an international, and many efforts and resources are involved in its solution. According to the "Alltek" company, which presented an analysis of grain contamination in 2013 in Europe, 100% of the wheat samples contains mycotoxins, 78% of which has of 3-11 types of these toxic substances. DON mycotoxin (deoxynivalenol) was present in 90% of the samples. 100% of the corn crop samples contains mycotoxins, and 93% of the samples contained more than six types of these substances. An extensive study conducted by Austrian scientists (Gruber-Dorninger, C., 2019), who presented an overview of the results of a 10-year study of feed contamination in 100 countries, also confirms the difficult situation in solving this problem. Thus, out of 74,821 samples, 88% were contaminated with at least one mycotoxin. The most common Fusarium mycotoxins are DON, fumonisins, and Zen (zearalenone). They were found in 64%, 60% and 45% of all samples. AFB1 (aflatoxin B1), T-2, and OTA (ochratoxin) were detected in 23%, 19%, and 15% of the samples. Fumonisin and DON showed the highest average concentrations: 723 mcg/kg and 388 mcg/kg. Despite actively used measures, the problem of grain contamination remains very acute. During the processing and storage of grain, the amount of mycotoxins in it increases (Hietaniemi, V., 2016; Pinotti, L., 2016; Rodrigues, I., 2012; Cheli, F., 2013).

The above shows that the disinfection of grain remains an important economic problem. One can collect high yields, but if the quality of grain is low, it cannot be used for food and feed purposes. Decontamination of grain must be performed at different stages of its storage and processing with the use of a microwave field, ozone, electro-activated air and a stream of charged particles.

The research purpose was to analyze the volume of grain production and the need for its processing, review of technological processes, equipment and technologies based on microwave radiation in the processing of grain crops.

Materials and Methods

The technology of post-harvest processing of grain and feed using microwave field is widespread. It allows one to solve several problems at the same time, such as disinfection and drying of grain, pre-sowing seed treatment, preparation and disinfection of feed.

One of the first publications in Russia on the study of the microwave influence on agricultural technology dates back to 30s. The reference to such early works is intended to demonstrate that close attention was paid to microwave grain processing technologies as promising and environmentally friendly.

In 1982, Ken Bratney Co started producing microwave grain dryers with a horizontal multi-chamber drying section. A screw conveyor moved the grain. The magnetrons of power of 1.3 kW were installed on drying vacuum chambers above the conveyor. There were used nine magnetrons per drying chamber. The combination of microwave heating with vacuum provided energy consumption of 0.13-0.26 kWh per one kilogram of evaporated water. This grain dryer costs about 100 thousand dollars.

Table 1 World wheat market estimate, mln t

Parameter	2015/2016	2016/2017	2017/2018	2018/2019
Grains total				
Production	2,015	2,137	2,106	2,081
Trading	346	353	368	369
Consumption	1,986	2,078	2,107	2,138
Stock	561	620	617	560
Change	30	59	-3	-57
Wheat				
Production	737	753	767	729
Trading	166	177	176	172
Consumption	718	735	738	740
Stock	227	244	273	262
Change	19	18	29	-11

Source: http://www.fao.org

Table 2 Assessment of the quality of grain harvested in Russia

Indicator	2014	2015	2016	2017	2018
The volume of the controlled grain, million tons	95.1	105.1	112.1	55.3	59.1
The volume of grain that does not meet the requirements for the infection, million tons	6.9 (7.26%)	9.0 (8.56%)	8.9 (7.94%)	9.4 (17%)	10.4 (17.6%)

The continuation of the "conveyor" theme of microwave grain dryers was reflected in the works of Soviet scientists. Nevertheless, their implementation was constrained by the limited possibilities of enterprises in access to microwave energy sources.

The beginning of the Millennium was marked in the development of microwave technologies b-y the wide introduction of small magnetrons. This made it possible to provide a uniform distribution of the microwave field and create installations that are more efficient.

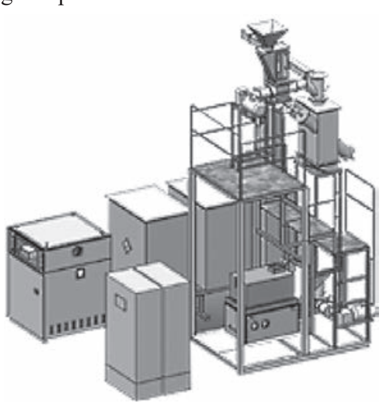
Today two directions of use of a microwave field in technologies of an agro-industrial complex are accurately divided on power of the used sources:

- The use of powerful (25-50 kW) microwave field sources;
- The use of low-power (0.6-1.2 kW) microwave field sources.

Installations with powerful magnetrons have significant disadvantages:

- Big size and heavy weight;
- Necessity of cooling, and the cooler must meet certain requirements;
- Devices must have means to protect the magnetrons from reflected fields.

Fig. 1 "Dextrin-3" installation for high-intensity microwave heat treatment of grain products



In such installations, it is difficult to ensure uniform heating of materials, since it is necessary to bring the microwave field to different parts of the processed material. Operational reliability depends on the reliability of a single magnetron. Its failure leads to a stop of the entire process. "Dextrin-3" is an example of such installations, produced by JSC "NPP "Istok" Shokina" (**Fig. 1**).

Brief parameters of the "Dextrin-3" installation:

- feed preparation capacity, t/h:
- cereals 1.0;
- legumes 0.6;
- disinfection and decontamination 5.0;
- pre-sowing stimulation 5.0;
- pre-grinding warm-up 5.0;
- microwave generator power, kW 30.0;
- generator frequency, MHz 915 ±12;
- power consumption, kW 45.0.

This installation is useful for decontamination and micronization of grain in the feed preparation. However, the above shortcomings did not contribute to active implementation.

Results and Discussion

According to the moving principle of the processed material, microwave installations are classified into conveyor and tower types.

In conveyor systems the material is moved along the conveyor belt along the installation. Microwave field sources are placed either above or below the belt in such a way as to ensure uniform heating of the material.

Their disadvantages include the design complexity, which provides a uniform supply of heated air to the drying zone. The material is fed in a thin layer, so the performance is low. In order to increase it, designers are forced to increase the length of the material processing zone, which increases the metal consumption and significantly increases size of installation.

In practice, such plants are used for drying small batches of seeds. This can be cereals at breeding stations, seeds of vegetables or herbs.

A series of MDBT microwave conveyor dryers by Linn High Therm company (Germany) is an example of such installations, designed for disinfection and drying of small items (**Fig. 2**). The block structure of the conveyor allows varying its length from 5 to 30 m. The width of the conveyor is of 200-1000 mm.

The maximum heating temperature of the product is 230 °C. The installation is intended for heating or removing water from food products, as well as in all processes where it is necessary to remove water or heat any material absorbing microwave radiation.

The conveyor-type microwave dryer was designed and produced by the Russian company "AST" (Ignatenko, T. V., 2013). The main purpose of the installation is a disinfection of bread and cereals, drying and disinfection of small batches of seeds and herbs (**Fig. 3**). Modifica-

Fig. 2 Linn MDBT conveyor microwave dryer

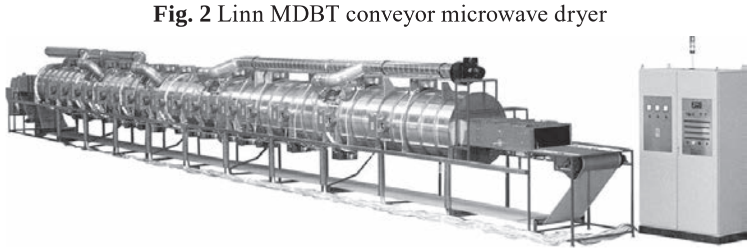
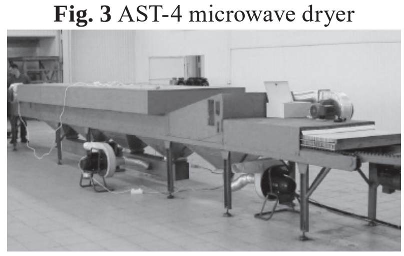


Fig. 3 AST-4 microwave dryer



tion of this installation allows it to be used for other bread products and feed processing.

Placing magnetrons along the conveyor allows flexible control of the heating process. This is very important for soft drying modes. Therefore, conveyor dryers are used not only for drying grain and seeds, but also for low-temperature drying of medicinal materials, heat-sensitive materials in food industry, bioengineering and chemistry. An example of such an installation is the Chinese conveyor dryer (**Fig. 4**).

The total power of such plants can vary from 30 to 180 kW, depending on the performance. To generate a microwave field, there are used so-called "household" magnetrons, which provides high maintainability and ease operation.

The large size of these plants make it difficult to use them in high-performance (20-50 t/h) technological lines for drying or decontamination of grain. Achieving this performance by increasing the length of the conveyor is very difficult.

Such problems are easier to solve using tower type microwave convective dryers. The Russian company "AST" in collaboration with the staff of the Federal scientific agro-engineering center VIM has developed several versions of such installations (Ospanov, A. B., 2017; Budnikov, D. A., 2018).

The hopper microwave convective grain dryer has two structural elements: the microwave activation zone and the grain-drying hopper (**Fig. 5**). First, the grain passes through the microwave activation zone, where under the influence of the microwave field, moisture moves from the center of the grain to its surface. Then the grain is moved to the hopper, where convective drying takes place.

This technology is acceptable when using microwave convective grain dryers in conjunction with bunker installations for grain ventilation (**Fig. 6**) (Dzhamburshyn, A. S., 2016; Puring, S., 2017).

Low-power magnetrons are used in the design of such grain dryers. Their uniform distribution over the volume of the microwave convective zone ensures the penetration of the microwave field throughout the grain layer. The installed power of the grain dryer is 70-90 kW. The installations are assembling from unified modules with the predefined performance. The tower version of the microwave convective grain dryers is useful because of its small size, which allows them to be placed in the premises of grain processing points, combining the process of post-harvest cleaning with grain drying. A mobile version is possible. In this case, it is possible to decontaminate grain in warehouses, decontaminate feed components in feed shops and process grain during pre-sowing.

The relevance of using the microwave field for grain disinfection can be assessed by the publication activity in the eLIBRARY.RU electronic library of scientific publications (**Table 3**). In total, 4,200 publications were found on the "Decontamination" topic. Of these, 1,095 (26%) are devoted to microwave disinfection, 1,060 (25.2%) are devoted to ozone disinfection, and 900 (21.4%) are devoted to ultraviolet radiation disinfection.

Disinfection of products using microwave fields is considered in in an overwhelming amount of publications of agricultural subjects. This shows the relationship of theoretical research in this direction with demand in production designs.

The relevance of research was also evaluated by publications included in the Web of Science citation database. The largest share of publications on this subject is made by researchers from Canada - 30% (Hemis, M., 2019; Palamanit, A., 2019), the USA - 26% (Olatunde, G. A., 2018; Smith, D. L., 2018), Algeria - 11%; Iran - 11% (Jafari, H., 2017; Ranjbaran, M., 2013), China - 7%; India - 6%.

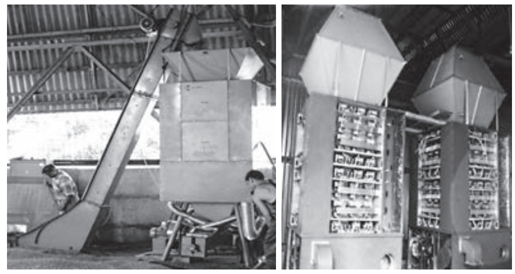
According to the direction of research in this area, publications are distributed as follows:

- Engineering research, which includes work on the plant designs, modeling their operation modes (Wray, D., 2015) - 37%;
- Agricultural topics, which include publications on the influence of the microwave field on the disinfection of grain and intensification of drying pro-

Fig. 4 Conveyor microwave installation

Fig. 5 Hopper microwave convective grain dryer by "AST" company

Fig. 6 Tower microwave convective dryer: a - in the thrashing floor; b - in the grain cleaning point



(a) (b)

cesses (Hemis, M., 2015) - 33%;
- Food technologies, which include works on the use of the microwave field in the technological processes of the food industry, the impact of microwave on the technological quality of products (Shen, L., 2019) - 26%.

The main purpose of the publications is to determine the optimal parameters and operating modes of technological installations.

One of the new trends in improving technologies and equipment for drying and decontamination of grain is the use of several electro-physical effects in installations. It is possible to manipulate the processing more flexibly. Thus, the use of the microwave field imposes certain restrictions on processing modes. If it is necessary to maintain the quality of the grain during processing, it is necessary to limit the temperature of its heating by a microwave field. In this case, the joint use of microwave radiation with other electro-physical effects will solve this problem.

The use of electro-physical effects in the post-harvest processing of agricultural products has been analyzed in the patent activity of researchers in various countries. According to the World Intellectual Property Organization, the number of patents on agricultural products drying (including using microwave fields) for 2010-2018 is: China - 8881 (1101), Russia - 1334 (686), Japan - 1260 (2), Republic of Korea - 789 (4). The number of patents devoted to the disinfection of agricultural products (including using microwave fields) for the same period is: USA - 1131 (89), Europe - 317 (17), China - 144 (2), Russia - 40 (11). At the same time, patents on the heat treatment of agricultural products, including using microwave: in China - 1551, Japan - 1111, Republic of Korea - 308, Russia - 202 pcs.

Table 3 Distribution of scientific publications on microwave disinfection by thematic headings

Thematic heading	Number of articles, pcs. (%)
Agriculture and forestry	463 (42.3%)
Food industry	176 (16.1%)
Medicine and health care	115 (10.5%)
Physic	33 (3.0%)
Engineering	32 (2.9%)
Environmental protection. Human ecology	26 (2.4%)
Chemical technology. Chemical industry	24 (2.2%)
Biology	23 (2.1%)
Electrical engineering	19 (1.7%)
Water resource management	14 (1.3%)

Drying is the main process of post-harvest grain processing. A large number of patents from almost all countries that grow crops confirms this: China, Japan, Russia, the Republic of Korea, the United States, Canada, France, etc.). A significant part of the improvements and inventions aimed at the use of electro-physical effects. The possibility of dissipation of a large specific power in the volume of processed material due to the use of microwave fields attracts the attention of researchers to the use of microwave emitters in the intensification of drying of grain and other agricultural products (207379216 Grain microwave drying apparatus. CN 18.05.2018 201721432881. X Jining university chongdian si F26B 11/14). Equipment with the influence of both one factor and several in the complex are currently developing. The most significant development is “Electromagnetic method and equipment for producing a biological effect” (108131935 Vertical grain drying machine. CN 08.06.2018 201711397438.8 Huang wenbo F26B 17/10). Electromagnetic waves that form an electromagnetic field include microwave, ultraviolet, infrared, laser, alpha and beta radiation, and electromagnetic wave equipment consists of a combined electromagnetic component, a combined reactor, a controller, and others. The presented invention can speed up the disinfection process and increase its efficiency compared to the use of a single electromagnetic wave.

This shows that the future belongs to technologies that use combined electro-physical effects in drying, decontamination and pre-sowing processing of grain.

Conclusions

1. With the growth of gross grain harvest in the world, significantly increases the volume of infected grain. Electro-physical effects, in particular the microwave field, can be used as ecological and low-energy methods of grain processing. Its use intensifies the process of grain drying by active ventilation by 30-40%, reduces the energy intensity of grain drying by 15-30%, disinfects the harvested crop from mold spores, micronizes the grain in preparation for feeding. The energy intensity of the process is reduced by 20-30% compared to other electro-physical methods. Authors have noted significant scientific interest in this research area. A large amount of patenting in this area is applied in China, Russia, and South Korea.
2. The search for optimal design parameters of plants and grain processing modes continues. It is necessary to develop installations for production lines with a capacity of 5-50 t/h.
3. The use of microwave installations with powerful sources is still common in practice, but their features limit the scope of its use.
4. For technological processes of small batches of grain seeds, there are used conveyor equipment with a distributed magnetrons.
5. Modular microwave convective installations of tower type can fit into many technological processes, and their use in the agro-industrial complex will expand.

6. One of the current trends in the use of microwave installations in technological processes of grain and its products is the combination of microwave field with other types of electro-physical effects.

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The Main Stages of Agriculture Mechanization in Russia

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Abstract

Until 1917 the Russian Empire was an agrarian country. Agriculture was considered the main branch of the economy, and grain was the main export item. This article presents a brief history of agriculture mechanization development in Russia since the 19th century. The main stages are characterized, and indicators of agricultural equipment availability in different historical epochs are given.

Introduction

The origins of human civilization are closely related to the agriculture development and its mechanization. More than 10 thousand years ago, the nomadic way of life of hunter-gatherers was replaced by man for the production and cultivation of the first domesticated plants and animals.

For many hundreds of years, the use of scientific methods and the mechanization increase made serious changes to the structure and effectiveness of agriculture.

XVIII-XIX Centuries

For the first time, agriculture rationalization with the use of various equipments was concerned in Russia in the 18th century during the era of Catherine the Great.

In order to spread progressive ideas of organizing agricultural work among the nobility to increase productivity and general welfare, in 1765, dignitaries close to Empress Catherine II organized the Free Economic Society (FES). In fact, it was the first scientific organization on issues of agronomy, animal husbandry and rational farming due to the science achievements (fertilizers, and later technology).

In 1785, I. M. Komov, Professor of agriculture at Moscow University, published the first book in Russia "About agricultural instruments." In order to familiarize the landowners of that epoch with this scientific work and other advanced technical achievements, the society began to publish the journal "Transactions of FES", articles about the latest methods of soil processing, information on the fertilizers use, etc. were published on its pages.

In the mid-19th century, FES expanded significantly and consisted of three sections: agriculture; agricultural machinery; agricultural statistics. An interesting fact is that society bought land near St. Petersburg and created a site there for trials and experiments. This was called the Okhta farm [1].

On April 25, 1830, tests of threshing fan machine invented by Andrei Veshnyakov took place in the Free Economic Society. FES members recognized that "Mr. Veshnyakov's threshing fan machine has an undeniable advantage over the machines of this series invented in Europe, both in the simplicity of its design, and in the action correctness." The machine processed up to 200 raw bread sheaves per hour, and dry bread - up to 300 sheaves, grinding the ears and cleaning the grain. Unfortunately, the production of these machines was not organized. Feudal landowners were not interested in the "ear harvester" built by N. I. Zhegalov in 1833 [2].

In 1869, the Imperial Agricultural Museum was established in St. Petersburg, which was managed by the Ministry of Agriculture and State Property. According to Alexander' II decree, the Museum at the Forest Institute was established with the aim of "giving rural owners the opportunity to get acquainted with the instruments for various agricultural works", distributing the best examples of agricultural machines and instruments, serving as a teaching tool for students studying agriculture [3]. So the museum had not only educational and applied significance, but also scientific.

At the beginning the museum had 7 departments: agricultural machinery and tools, crop production, animal husbandry, mineralogical, applied natural sciences, agricultural and technical buildings, a collection of drawings. The main department was the machine one, which included a workshop where tests and repairs of equipment were carried out. The department's exposition consisted of life-sized implements and agricultural machinery, which helped to familiarize visitors with their device and purpose. By the beginning of the 1870s, the museum had 25 departments, in which machines and equipment for all types of agricultural work were presented - tillage, land reclamation, sowing, harvesting, processing livestock products, gardening, sericulture, etc., tests of newly inbound vehicles were continued.

Along with the traditional museum collections display, the Museum carried out repairs of agricultural machinery, conducted its tests, provided drawings and samples of improved agricultural implements and machines to rural owners, provided assistance to institutions, organizations and individuals, was a methodological and educational center, and was the basis for scientific research, participants of many international congresses, exhibitions and conferences held in St. Petersburg sought to visit it.

The Beginning of XX Century

In 1907, the Bureau for Agricultural Mechanics of the Scientific Committee of the Ministry of Agriculture was established in St. Petersburg. It included Vasily Prokhorovich Goryachkin - Asociate professor at the Moscow Agricultural Institute, the Founder of agricultural mechanics. Dmitry Dmitrievich Artsybashev, who later headed the Scientific Committee of the Ministry of Agriculture of Russia, was appointed the head of the Bureau.

Initially, the Bureau was an advisory agency to the Scientific Committee, and 5 years later it turned into an independent research organization.

In 1907-1908, the Bureau focused on creating the basis for further work. During these years, tasks were put and it was decided to organize six machine test stations: in Moscow (at the Moscow Agricultural Institute), in Omsk, Elizavetgrad, Rostov-on-Don, in Bezenchuk of the Samara province and in the St. Petersburg province. During this period, the Bureau organized the purchase of foreign equipment, primarily in the United States. For its testing, the machine test stations' network was expanded.

In 1909, the Journal "Izvestia Bureau of Agricultural Mechanics" began to appear. 1912 was the year of the widest machines testing for the entire existence of the Bureau. This year, 111 harvesting machines (mowers, reapers, rakes) of European and Canadian production were tested. The tests were due to the fact that the Russian market was mainly filled with US-made machines [4]. At the same time, starting in 1900, the production of harvesting machines began to improve in Europe.

Since 1912, research and auxiliary laboratories were created in the Bureau, which conducted not only tests, but also studies of working bodies processes.

The activities of the Bureau of Agricultural Mechanics for 1917 provided the expansion of domestic agricultural engineering with the aim of replacing foreign machines in Russian farms with domestic ones. The last meeting of the Bureau was held on May 24, 1917.

The end of the XIX and the beginning of the XX century in Russia were marked by a significant increase in the technical equipment of agricultural production. This was due to objective reasons. Russia from an agrarian, peasant country was gradually turning into an industrialized country. The number of the urban population increased with a reduction in the rural population, on the whole, the population of Russia grew, and this required an increase in the intensity of agricultural production, and hence the replacement of manual labor by machine. At an even faster pace, the process of agriculture industrialization was going on in Europe and America. New, more modern, but also more expensive machines and tools entered the domestic Russian market, which encouraged breeders to organize the production of domestic cheaper equipment that was not inferior in quality [5]. By 1900, agricultural machinery imports grew 3 times. The rapid growth of artisanal agricultural production in Russia was noted.

In general, in the end of XIX century - the beginning of XX century there was a significant leap in the development of agricultural machinery production in Russia. This was largely due to the creation of the above-mentioned organizations: the Free Economic Society, the Imperial Agricultural Museum and the Bureau of Agricultural Mechanics. The exhibition-tests of agricultural machines and implements, arranged near Moscow on the Butyr farm from 1892 to 1910 were of great progressive importance. This made it possible to introduce amendments to the machines design and took into account new requirements.

On the eve of World War I, agricultural engineering took the 1st place in Russian engineering in terms of production [6]. At the same time, almost half of agricultural machinery and implements were imported. Of course, this was connected not only with certain successes of Russian science and technology, but also with state policy. So, since 1889 a new customs tariff has been in effect, according to this tariff those machines that were not manufactured in Russia or which production was insignificant and had no chance of success were passed duty-free, all the rest were taxed. **Fig. 1** shows the dynamics of the agricultural engineering development, which reflects the gradual displacement of imported equipment by domestic machinery.

The use of agricultural machinery (import and domestic production) since the early 1870s until 1896 increased by more than 6.5 times, and by 1912 - by 57 times [7]. This indicated an increase in the rate of agricultural production mechanization. However, the equipment level of peasant farms with improved equipment in general remained low. At the end of the XIX century most of the land cultivation was carried out by traditional tools. The set of agricultural implements that made up the peasant's yard was approximately the same: it was a harrow, a scythe, a sickle, a flail, a road-roller, a puller, a hook for hauling hemp. A zemsky survey of the Tambov province, conducted in the first half of the 1880s, found everywhere plow plowing and bread chain threshing. Village correspondents mentioned the presence of threshing machines only with individual owners. In one case, the headman had such a machine, in another - a local rich man owned a thresher, who threshed bread at the rate of 15 kop. for his villagers from the mop [8].

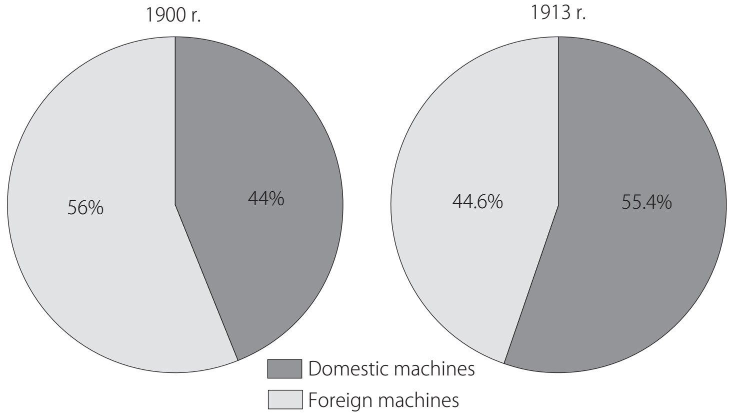
A traditional plow was the predominant arable tool in the village of the late XIX - early XX centuries. There were several reasons for this. The plow was a universal tool, it was used in plowing, sowing, cultivation.

The constructive simplicity of the plow allowed its modification to certain climatic conditions and soil quality. An important advantage of plow was its cheapness. Almost every peasant could make it from improvised materials. And any blacksmith could make an iron plowshare for a small fee [9]. The plow, unlike the plough, was light, and any horse was able to drag it. The plough required two horses, and they were not in every peasant's yard. Russian plough building developed in difficult competition conditions with specialized German and English companies. Therefore, domestic plough building was forced to produce cheap and reliable ploughs on which some parts of wood were placed for a long time.

These changes were not sufficient for a technological breakthrough, but allowed to improve the quality of land cultivation, and consequently, to increase productivity.

As a result of World War I, agricultural engineering was greatly reduced, and by 1917 the volume of production was below the level of the 80s of the XIX century. At the same time, in 1917, 3 million 522 thousand single-plow iron ploughs, 1 million 146 thousand multi-plow, 64 thousand cultivators, 910 thousand iron harrows, 333 thousand seeders, 1 million 156 thousand fans worked on the Russian fields [6].

Fig. 1 Dynamics of the ratio of domestic and foreign equipment used in agriculture of the Russian Empire



1920-1930-s

From the very beginning of its activity, the new Soviet government knew the importance of restoring the production of agricultural machinery. On April 23, 1918, the Council of People's Commissars adopted the "Decree on the Agriculture Supply with Production Tools and Metals."

But the possibility of financing new construction and reconstruction of existing plants in the country appeared only in 1924 after the end of the civil war and the formation of the USSR. In May 1924, serial production of the first Soviet caterpillar tractors “Kommunar” began at the Kharkov Locomotive Plant. Plants in Petrograd, Kolomna, Bryansk began to produce prototypes and small series of tractors. In 1926-1928 production of “Zaporozhets” tractors with a capacity of 16 horsepower was established (released 500 pcs.). Along with the expansion of its own production in 1921-1923 about 1000 tractors and a large number of agricultural vehicles were brought into the USSR from abroad. In 1924-1925 more than 1,500 tractors were imported, in 1926-1927 - more than 5 thousand units, in 1929-1930 - 23,800 units. Agricultural machinery was also imported. At the same time, the demand for agricultural machinery was satisfied by no more than 50%. In 1923-1929 the development of the “Fordson Putilovets” tractor with a capacity of 20 horsepower was accelerated at the Putilov plant in Petrograd (Leningrad), the output amounted more than 5 thousand units. In 1928, serial production of tractor plows, trailed tractor seeders and cultivators began in the USSR. Procurement of agricultural equipment abroad continued, which allowed a significant increase in the level of mechanization of the country's agriculture [10].

In 1927 the Fifteenth Congress of the Communist Party of the Soviet Union (b) was held, which proclaimed a course towards the agriculture collectivization. The emergence of large collective farms required the creation of appropriate agricultural technology.

In the second half of the 1920s, the Soviet Union took a course towards the industrialization of the country: new large plants, factories, hydroelectric power stations, and railway lines were built. New cities arose, and the urban population grew. Significant funds were required for the purchase of machinery and equipment abroad for the enterprises under construction, the need for a more complete supply of agricultural products to the cities increased.

The currency for the purchase of machinery and equipment abroad could be obtained, first of all, from the grain export. Thus, the demand for grain increased sharply. At the same time, at the turn of 1927-1928 serious difficulties arose with the procurement of bread in the country and a grain procurement crisis erupted.

According to I.V. Stalin and his inner circle, the solution to the problem of grain production and harvesting could not be delayed. Bread was needed urgently. Only large farms could produce bread relatively quickly and in large quantities. The party-state leadership, headed by Stalin, categorically rejected the stake on a prosperous peasant, the so-called "fist" [11]. In this situation, there appeared an idea to solve the grain problem in a short time based on the deployment of socialist type agricultural enterprises - collective farms and state farms. The country's leadership paid close attention to the deployment of large mechanized grain state farms and the creation of machine-tractor stations with them.

In accordance with the indicators shown in **Table 1**, in the years of the first five-year plans in the USSR, significant success was achieved in the agricultural mechanization development - the traction mechanization increased by more than 10 times.

By relative indicators of agricultural equipment, in particular tractors, the USSR came out on the 2nd place in the world after the United States on the eve of World War II [10].

1940-1980-s

In the years of World War II, the USSR was seriously damaged by agriculture, which could only be eliminated by the end of the 1950s and the beginning of the 1960s. During this period, it was decided to develop periodically machine systems for the comprehensive mechanization of agricultural production. The first Machine System (1957-1965) was developed on the basis of the domestic and foreign technology achievements of that time, taking into account the natural and economic conditions of individual zones. In 1954, the USSR Ministry of Agriculture organized a central interdepartmental commission and more than 20 working commissions. The commissions developed a draft Machine System on cultures, industries, and zones. This project was sent to MTS, collective farms, state farms, research institutes and educational institutions. Taking into account the proposals of the meetings, the new machines test results, as well as the study of foreign experience in mechanizing agriculture, the Machine System was systematized by type of work. Much attention in the development of the first Machine System was given to the universalization and unification of machines. In 1956, at the final meeting in Moscow with the participation of 900 specialists from all areas and sectors of agriculture, 816 machines, 290 devices and other equipment were included in the Machine System [13].

The first Machine System played a serious role in the transition of our agriculture to the comprehensive mechanization of all its branches, which made it possible to increase sharply the agricultural crops yield in the USSR.

By 1985 the number of tractors in the USSR consisted of 2.8 mil-

Table 1 Agriculture mechanization in the USSR in the late 1920s - early 1930s. (in terms of traction mechanization) [12]

	1926	1927	1928	1929	1930	1931	1932
Tractors (thousand hp)	200	255	278	391	913	1,530	2,177
Traction mechanization (%)	1.7	1.9	2.0	2.8	7.1	13.1	19.5

Table 2 The production volume of some of the main agricultural machinery types in the Russian Federation and the availability of agricultural producers (thousand units) [14]

Type of agricultural machinery	Volume of production		Availability of equipment from agricultural producers	
	1990	2012	1990	2012
Tractors	214.0	13.6	1,365.6	276.2
Tractor Plows	85.7	4.0	538.3	76.3
Seeders	51.1	2.3	673.9	115.4
Combine harvesters	65.7	5.8	407.8	72.3
Forage harvesters	10.1	0.89	120.9	17.6
Potato harvesters	6.4	0.027	32.3	2.7
Beet harvesters	0.0	0.18	25.0	2.8
Cultivators	101.0	24.2	602.7	108.7
Mineral spreaders	21.1	0.66	110.0	16.3
Mowers	22.6	4.2	275.1	37.5
Milking Plants	30.7	3.6	242.2	28.0

lion units, their total capacity - 232 million hp., harvesters (thousand pieces): grain harvesting 832, crop-harvesting 63, beet harvesting 53, silage and forage harvesting 257; the number of pre-installed aggregates and installations - 402 thousand units [10]. Some types of agricultural work were 100% mechanized.

1990-2000-s

The Russian economy reforming, which began in the 1990s, led to a drop in agricultural production. The number of arable land in the country decreased from 131.8 million hectares in 1990 to 115.5 million hectares in 2012, planted areas from 117.7 to 76.1 million hectares, respectively. The consequences of this period were reflected in the agriculture mechanization in Russia (**Table 2**).

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The Choice of Combine Harvesters and Their Adapters for the Conditions of Northern Kazakhstan

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Abstract

The main production of winter wheat is concentrated in the Northern regions of the Republic of Kazakhstan, where are high yields of food wheat of valuable quality. This requires new technologies for the cultivation of grain crops, as well as modern harvesting machines, selected taking into account the specific conditions of harvesting. The task of technical re-equipment of the harvesting park is urgent due to the rapid reduction in the number of harvesters: more than 60 percent of which have a service life of more than 10 years. The existing methods of selecting the harvester model do not fully disclose the relationship between the constructive throughput and the intensity of the grain mass receipt in the threshing device. The research purpose is justifying the choice of harvesters and their adapters taking into account the intensity of the grain mass receipt in the threshing device in the conditions of Northern Kazakhstan. The technological process of threshing bread mass during direct combine processing are presented in the form of a simplified block diagram. Authors have used equations to determine the throughput of the harvester on threshing. It was shown that the constructive (normalized) throughput of the combine harvester should correspond to the permissible level of losses of 1.5 percent. The harvesters of 3rd and 4th classes are not fully loaded for harvesting bread with a yield of 1.2 tons per hectare. Authors suggested increasing their load to use reaper with a greater width. The use of a harvester of fifth class when harvesting grain with a yield of 1.2-1.7 tons per hectare allows increasing the actual supply (and productivity) by 1.7-2.5 times compared to class 3 harvesters. It was found that in the conditions of the Northern region of Kazakhstan the most effective harvesters of 4th, 5th and 6th classes, equipped with wide reapers with a width of 5-12 meters both for direct and for separate harvesting.

Keywords: winter wheat, yield, combine harvester, throughput, harvesting technological scheme, reaper width, combine class.

Introduction

In Kazakhstan, about 80% of all acreage falls on the share of grain crops, most of them are sowed with wheat. The main production of this crop is concentrated in the Northern regions. Favorable natural conditions allow us to obtain good and stable grain yields, primarily food wheat with high gluten content, which is in high demand on world markets to improve the baking properties of flour. The total share of the Northern regions of Kazakhstan (Kostanay, Akmola, North Kazakhstan) in the total volume of wheat production is approximately 75%. Spring soft wheat has become the main export crop in Kazakhstan, the country ranks 7th in the world. The share of Kazakhstan grain in the world wheat market is about 5-6%. In 2017, the export potential is about 8 million tons (the State program for the development of agriculture of the Republic of Kazakhstan for 2017-2021, 2017).

In this regard, the need for sustainable development of grain farms in the agro-industrial complex of Northern Kazakhstan is increasing.

This problem cannot be solve without the use of modern cultivation technologies of grain crops, and modern harvesting machines that are selected to the special harvesting conditions of North-Kazakhstan regions.

Manufacturers of combine harvesters constantly update the model range and offer products with different technical data following the market demands. The most famous companies are CLAAS, John Deere, New Holland, Case IH, that produce about 40 models of combine harvesters with a threshing capacity of 4.7-12.5 kg/s. Scientists offer to install control systems on the reaper and harvester, as well as other technological and technical solutions that help to reduce grain losses (Chen, J. et al., 2018; Liu, H. et al., 2019; Zhang, K., 2018; Shepelev, S. D. et al., 2018; Almosawi, A. A. 2019; (Zhang, Y. et al., 2018).

There is the production of machinery of the "Rostselmash" harvester plant in Kazakhstan, which produces five models of combine harvesters. The main technical characteristic of the adapters in these machines is the header width, which varies in a wide range - from 3.7 to 12 m (Zhalnin, E. V., 2012).

According to the Ministry of Agriculture of the Republic of Kazakhstan, more than 60% of combine harvesters have a service life of more than 10 years. Therefore, the task of technical re-equipment of the machine fleet is urgent. It is also necessary to take into account that organizational and economic conditions have changed significantly in the country: the share of peasant farms has increased against the background of a shortage of mechanized personnel. Therefore, this issue cannot be solved only by replacing the spent their service life harvesters with new of the same class (Golikov, V. A. et al., 2017).

In general, the Republic is dominated by harvesters of third class, which occupy 78% of total (**Fig. 1**). However, in the Northern region, where are concentrated the largest areas of grain with a relatively high yield, the share of high-performance combines of 4th, 5th and 6th classes reaches 30%, while in the southern region it occupies only 9.4 %. This difference is due to the fact that in the Northern region, the timing of favorable weather during the harvest period is limited, with a shortage of machine operators, agricultural producers strive to maximize the productivity of machines (Šotnar M., et al., 2018).

Existing methods of choice of combine harvester model take into account the crop productivity, the amount of acreage in farms and the region, the availability of personnel and weather conditions of the region. At the same time, the relationship between the constructive (normalized) throughput and the intensity of the grain mass receipt for threshing in the threshing device in different conditions of use of the combine harvester is not fully described.

The research purpose is to justify the choice of combine harvesters and their adapters, taking into account the intensity of grain mass receipt for threshing in the threshing device in the conditions of Northern Kazakhstan.

Fig. 1 The structure of the combine harvesters by class

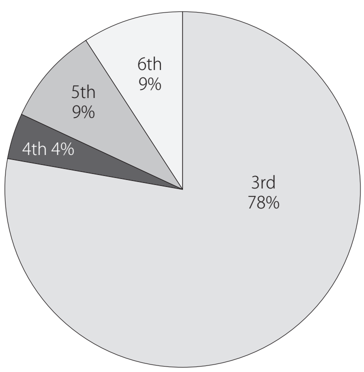
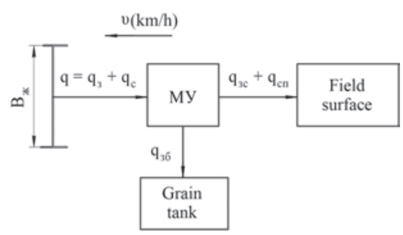


Fig. 2 Block diagram of the technological process of threshing bread mass



Вж - header width; q - supply of grain mass on a threshing in the threshing device (МУ); qс и qз - supplying in the threshing device of straw and grain; qзб - supplying of pure grain in the bunker; qзс и qсп - supplying on a field surface of grain (loss of grain) and straw with chaff

Materials and Methods

When mechanized harvesting in the Northern region of the country, the two technological harvesting schemes takes place: single-phase (direct harvesting) and two-phase (separate harvesting). Taking into account several assumptions for two technological schemes of harvesting, the intensity of the receipt of the mass for threshing in the threshing device can be considered identical. Therefore, the technological process of threshing the mass is considered on the direct harvesting of grain.

The technological process of threshing the mass is presented in the form of a simplified block diagram (**Fig. 2**).

According to the law of conservation, the grain mass received for threshing in the threshing device with the intensity q is equal to the sum of the outputs from the threshing device of grain, straw and floor:

$$q = q_з + q_с = q_{зб} + q_{сп} + q_{зс} \quad (1)$$

where q - intensity of supplying the bread mass on the threshing in the threshing device, kg/s;

$q_з$ and $q_с$ - intensity of supplying to the threshing device of grain and straw, respectively, kg/s;

$q_{зб}$ - intensity of supplying pure grain into the hopper, kg/s;

$q_{зс}$ and $q_{сп}$ - intensity of supplying grain (loss of grain) and straw on the field surface, kg/s.

The main characteristic of the throughput is the sum of the intensities of grain and straw intake at the entrance to the threshing device:

$$q = q_з + q_с \quad (2)$$

As a background characteristic of the harvested crop, the next ratio is used:

$\varphi = q_c / q_з$ (3)

To analyze the throughput of a combine harvester, authors take into account the following expressions:

$q_з = q / (1 + \varphi)$ (4)

$q_c = q \cdot \varphi / (1 + \varphi)$ (5)

The supplying of bread mass is determined by the following values:

- background characteristic φ of the harvested crop (or strawiness);
- yield $У_з$, kg/m^2;
- header width $B_ж$, m;
- working speed υ of the harvester, m/s.

So, let's write down:

$q = У_з \cdot B_ж \cdot \upsilon \cdot (1 + \varphi)$ (6)

From expression (6), it is clear that the combine harvester has no limit on the value of the input flow of bread mass. However, in production conditions, it is important that the value of losses for the thresher does not exceed 1.5%. Therefore, it is necessary some constructive (normalized) throughput or supply $q_{1.5}$, which corresponds to an acceptable loss level of 1.5%. Farmers calculate this value or get it from the test reports at machine testing stations.

Results and Discussion

Harvesting of grain crops in Northern Kazakhstan has a number of features:

- short cleaning period, the extension of the work period and high air temperature lead to an increase in losses due to self-drying of grain;
- zoned varieties of grain crops are characterized by significant layerage, the characteristics of stalks are significantly affected by the climatic features of the year, which with unfavorable conditions of harvesting leads to large losses of grain during direct harvesting.

Let us perform the analysis of formula (6) taking into account the features of harvesting grain crops in Northern Kazakhstan. Grain crops are short-stemmed and low-yielding. It is difficult to provide a constructive (normalized) throughput with low values of the background characteristic φ of the harvested crop (or strawiness) and the yield of $У_з$.

The operating speed υ has a limiting factor. Numerous data from field tests and economic observations indicate that the average speed of modern domestic and foreign harvesters, in which the technological process of threshing the bread mass is stable, does not exceed 2.0-2.5 m/s (7.2-9.0 km/h).

The results of calculations and their further analysis show that the harvesters of 3rd and 4th classes are not fully loaded for harvesting bread with a yield of 1.2 t/ha. To increase their load, it is necessary to use wider headers. However, in the foothills, their use violates the movement stability of the harvesting unit. The use of the Acros-530 harvester of 5th class with a wide header when harvesting grain with a grain yield of 1.2-1.7 t/ha in the Northern region of the Republic allows increasing the actual supply (and productivity) by 1.7-2.5 times compared to 3rd class harvesters. At the same time, the average load of the thresher in a 5th class harvester with a yield of 1.2 t/ha is approximately 64%, with a yield of 1.5 t/ha and 1.7 t/ha, it reaches 80%. In the first case, the harvester is underloaded by about a third, and in the latter it is loaded almost completely. When harvesters of 6th class working with header with a width of at least 12 m, per hectare productivity is even higher, since these units with a yield of 1.2-1.7 t/ha work with an acceptable level of grain loss at a speed of up to 10 km/h. Thus, the use of 6th class harvesters with wide-reach headers for harvesting grain with a yield of 1.2-1.7 t/ha can raise the per-hectare productivity by a half compared to combines of 3rd and 4th classes.

Summary

In the conditions of the main grain-growing Northern region of Kazakhstan, with a significant share of large and medium-sized farms with a pronounced shortage of machine-building personnel, the most effective combines of 4th, 5th and 6th classes equipped with wide headers with a width of 5-12 m for direct and separate harvesting.

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The Trend of Tillage Equipment Development

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Abstract

The existence of a technical system includes the stages of its creation, improvement, dynamization, and self-development. At the creation stage, the determining process is the technological process, satellites - a system of protection, functionality restoration, uniform input (supply) and output of material. The technological process is represented by plowing, deep loosening, peeling, disking, cultivation, harrowing, rolling and milling. Improving the system elements is aimed at reducing energy intensity, increasing versatility and reliability. Reducing energy intensity is possible due to the implementation of fluctuations, a decrease in the friction force, the complex nature of loading, the movement of the working body in the network of leading cracks. Soil-cutting working bodies can oscillate in the direction of the unit movement, along or perpendicular to the share blade, around the rack. Oscillations can be free (self-oscillations) or forced. A network of leading cracks is formed through the use of stress concentrators, especially on hard soils. In lancet paws, the stress concentrator can be an overhead element in the form of a bar, in chisel-shaped - a retractable sock. To reduce the friction forces, plate or rod dumps are installed, working surfaces are coated with release materials, electric grease is applied, water or liquid fertilizers are applied to the working surface, sliding friction is replaced by rolling friction, creating “hollow sections”, as a result of which the formation contact area with the deformer working surface is reduced. The creation of a complex nature of loading is realized in a combination of compressive and tensile stresses of the deformer most loaded part. Improving the system elements through universality implies a combination of technological operations, a combination of technological and transport functions. Improving the system elements in the direction of reliability implies the measures implementation that increases operational and technological reliability. The system dynamization basis is to increase productivity with the optimal combination of the working width and the tillage implement movement speed. The system self-development involves the maximum adaptation of the working bodies to various soil conditions and the stability of the process.

Keywords: tillage, energy intensity of the process, leading fractures network, system elements improvement, the system self-development, process stability.

Introduction

The existence of almost any technical system includes four stages: creation, improvement, dynamization, self-development.

Creating a system, filling it with structural elements, forming links between them is possible based on the implementation of a specific technological process. The most important physical effects on the soil are plowing, deep cultivation, peeling, disking, cultivation, harrowing, rolling, milling (Spokas, K. A., Forcella, F., Archer, D. W., Reicosky, D. C., 2007; Shmulevich, I., Asaf, Z., Rubinstein, D., 2007; Inbrahmi, A., Behtaher, H., Hbaieb, M., Maalej, A., Mouazen, A. M., 2015).

The working bodies for the implementation of the above technological processes include plow bodies, disk working bodies, rollers, milling cutters, cutting and combing working bodies.

Plough bodies are structurally subdivided into dump, non-root, cut, with a subsoiler, with a retractable chisel, disk and combined (Karpenko, A. N., Khalansky, V. M., 1989). Dump bodies are used for plowing with turnover and loosening of the formation. The body consists of a ploughshare, a blade, a field board. The blade and the share attached to the shoe form the working surface of the body. The plow body working surface is divided into cultural, half-screw, helical and cylindrical.

The prototypes of modern disk tools were made in the 19th century. The invention of disk implement was caused by the desire to replace sliding friction with rolling friction, since the working bodies; disks are clogged to a lesser extent with plant residues during operation. The disk blade is several times longer than the ploughshare, webbed and other working bodies of the same purpose. With this in mind, the cutting edge wears out more slowly.

Disk working bodies are installed on plows, cultivators, harrows, seeders, combined machines, discs. They are classified by the continuity of the blade part, by the shape of the disk, by the cut type and nature. By the continuity of the blade part, the disks are subdivided into working bodies with a solid or cut blade. In shape the discs are flat, spherical, corrugated, conical, grooved, wavy. Cutting smooth spherical disks have a cutout of the “camomile” type or a cutout of a semicircular shape. The character of the cutout can be symmetric or asymmetric; can have a logarithmic spiral or hexagon form. An asymmetric cut provides better pinching of plant residues and their grinding during cutting with sliding. A disk with the shape of a spherical surface is made by stamping from sheet steel and is sharpened.

The cultivators working bodies that perform surface tillage when caring for vapors or row crops are divided into cutting, combing, powdering, special-purpose organs (Akhalaya, B. Kh., Shogenov, Yu. Kh., 2017). To combing working bodies, which are designed for loosening the soil to a depth of 25 cm, include revolving, lance-shaped, chisel-like loosening paws. Reverse and spear-shaped paws on rigid racks are used for deep cultivation on cultivators-rippers. Reverse feet on spring struts are designed for pre-sowing loosening of the soil and destruction of rhizome weeds by combing them to the field surface to be cultivated. Chisel-like paws provide the best crumbling, unimpeded movement of soil from the sock cutting edge to the frame.

Research Purpose

The analysis of morphological features of the creation, improvement, dynamization, self-development of technical systems using the example of tillage machines.

Materials and Methods

Analytical review of patent materials and literature.

Results and Discussion

One of the most important systems elements is the working bodies protection from dangerous and non-dangerous overloads. Its design features should be linked to the way energy is used by the working body.

If the working body is active, that is, it directly uses the energy of the power take-off shaft, then the protection system must be organically integrated into the mechanism drive, which can be chain, belt, gear, and is represented by various kinds of couplings, shear pins.

If the working body is passive, then the protection system is provided either by the form of the working body, or additional devices. For example, a spring S-shaped stand of a spear-shaped or reverse leg works effectively on stony soils. Additional devices, in particular for plows working on stony soils, can be represented by mechanical, hydraulic, pneumatic safety devices.

If the working body is a combined one, for example, a drive or a tiller disk, then the protection system can be implemented in the method of attaching the rack to the frame. High-strength rubber dampers provide the necessary rigidity of the connection.

The second most important system element is the restoration of functionality. For example, according to agricultural requirements, the share blade thickness should not exceed 1 mm during the entire period of operation. For this, a metal reserve is provided on the share back. As a result of heat treatment, it is possible to obtain layers of varying degrees of hardness and with different wear rates, which can maintain the blade sharpness. As a result of heat treatment, it is also possible to obtain a granular metal structure, which will make it possible to realize the self-sharpening effect.

One-sided spear-shaped paws are made reversed. Or in case of loss of functional ability, the working bodies must be replaced. Then the technical staff needs the conditions to realize this opportunity. For example, the bolts heads that secure the ploughshare to the shoe are tetrahedral in order to exclude the possibility of turning them.

The third most important system element is the steady material input (supply). For this, semi-blocked cutting is provided, which also reduces the processing energy consumption. In particular, disc harrow batteries are typically X-shaped, V-shaped, or rhombus. With this arrangement, only two discs operate under blocked cutting conditions, and the rest under semi-blocked cutting conditions.

The system of steady material output is implemented in the designs of tillage machines as follows. The distance between the soil surface and the frame, between the working bodies in a row and between rows, should be sufficient to prevent clogging by plant debris and soil.

The system elements are improved in the direction of reducing energy intensity, versatility, and reliability.

Energy intensity can be reduced in the course of oscillations, a decrease in the friction force between the surface of the soil-cutting working bodies and the soil formation, the creation of a complex loading nature, the movement of the working body in the network of leading cracks.

Soil-cutting working bodies can oscillate in the unit movement direction, along or perpendicular to the share blade, around the rack. Oscillations can be free (self-oscillations) or forced.

Free vibrations can carry out:
- Spring-loaded composite share cutting edge;
- The ploughshare itself, pivotally connected to the blade, resting on elastic bands or a torsion spring;
- The whole plow body - due to a 90° bend of the plow body rack;
- Spear-shaped and reverse cultivating paws - in the unit movement direction (for better weed gathering).

Forced vibrations are caused by the operation of various types of vibrators to reduce pulling resistance and improve the plowing quality. They are committed by:
- Composite share cutting edge;
- Ploughshare;
- Plough body;
- The plough frame.

The lancet paw operation is accompanied by an oscillation of the cutting working body around the rack due to the mechanism of the active drive (O. Vernyaev, 1983). Compared with the passive analogue, the traction resistance of the active paw with a working width of 610 mm and an oscillation amplitude of 8° is 30% less. This direction is supported by scientists from the American National Institute of Agricultural Engineering.

However, plow bodies operating in vibration mode are ineffective when operating at high speeds and are quite complex, this reduces the structure reliability.

A leading cracks network is formed by stress concentrators, especially on hard soils. In lancet paws this can be an overhead element in a bar form, in chisel-shaped - a retractable toe. In plow housings, a tooth-shaped stand can perform the field crop function. In V. M. Boykov’s plow a leading cracks network is created by the conical surfaces of the toe cap.

The cost for overcoming the frictional forces in some cases is 40-50% or more of the total resistance of the working bodies. Various methods are used to reduce friction forces and struggle for adhesion:
- Establish lamellar or bar dumps;
- Cover work surfaces with release materials;
- Apply electric grease;
- Supply water or liquid fertilizer to the work surface;
- Replace sliding friction by rolling friction;
- Create “hollow sections”, resulting in a decrease in the area of contact of the formation with the deformer working surface.

The effect of electric lubrication is achievable when passing through the direct current dump housing, of the same charge to the soil. The water film arising due to electroosmosis reduces the attraction between the rubbing surfaces (Vadyunina, A. F., Korchagina, Z. A., 1986).

The most effective method was to increase the specific pressure of the formation on the working surface of the plow body as a result of the plate or bar dumps installation capable to self-cleaning.

The creation of a complex nature of loading is realized in a combination of compressive and tensile stresses of the most loaded deformer part.

Known attempts were to change the flat share geometry that has a constant angle of cutting between the surface and the furrow bottom. So, the plow-dump surface can be made in the form of a single helical surface with a variable radius of curvature. Or the share itself may have convex and concave portions of the surface forming the paraboloid. At the Federal Scientific Agroengineering Center VIM a ploughshare was proposed with a variable cutting angle decreasing from the deformer field edge.

The share working areas include the main, blade and bow parts. Structural changes in the ploughshare surface are directly related to its functioning mode. In the cleaving mode the main part of the ploughshare surface plays a decisive role (Ksenevich, I. P., Varlamov, G. P., Kolchin, N. N. et al., 1998). In the fracture mode the main work is performed by the blade part and the blade itself. It is established that the pressure on the cutting edge is in the range of 0.1-0.8 MPa.

With the predominance of the fracturing mode an energy consumption decrease is proved in the case of a combination of depressions, teeth, drop-shaped protrusions in the cutting edge, which additionally create tensile stresses.

The manufacture of plowshares with a cutting edge that creates creasing and tensile stresses is rather laborious. The effect of the shear and tensile stresses combination will be reproduced if the cutting edge is fragmented and the blade is transformed at an angle at which elastic deformations will prevail.

The operation of a plane-cutting paw with a variable angle of crumbling also reduces the interaction energy intensity during combinations of bending and torsion deformations (Burchenko, P. N., 2012). However, the design of the paw wing does not take into account the possibility of the cutting edge blade working in a joint mode of crushing and stretching the formation.

The blade edge of the left and right wing of the paw can be deflected from the bottom of the furrow towards the field surface by an angle sufficient to overcome elastic deformations with minimal values of the friction force. Then the cutting edge and blade work on crushing and stretching, and the paw wings - on bending and torsion, which will reduce the tillage energy consumption (Starovoitov, S. I., Grin, A. M., Lebedev, D. E., 2016).

Combining technological operations, combining technological and transporting functions, it is possible to achieve the universality necessary for the improvement of system elements.

So, chisel-shaped paws are characterized by additional placement of side rippers, stretched strings, and their use in sowing, fertilizing, and pesticides. For lancet paws, it is proposed, depending on the viscosity of the cultivated soil, to change the angle of the wings solution. For the purpose of additional crumbling of the layer on the cultivator lancet paw, bars with a round solid section can be placed. The plow body can be equipped with a spring-loaded blade wing.

Elementary working bodies can be placed on one frame, each element on a separate frame, the deformer performs many functions. The combination of technological and transporting functions is characteristic of the working bodies-movers.

In our opinion, the use of such concepts as operational and technological reliability is permissible for tillage working bodies. Improving operational reliability is the use of wear-resistant or multilayer material, heat treatment (Izmailov, A. Yu., Sidorov, S. A., Lobachevsky, Y. P. et al., 2016). In particular, for lancet paws, it is proposed to carry out a thermo-deformational effect on the back side of the cutting edge. With a softer top layer, a self-sharpening effect will be created.

Technical solutions that increase the technological reliability of plowing with a plow body, minimizing the appearance of a "plow sole" are known. Another example is S. G. Mudarisov's plow body. The upper part of this tool is a Cornu spiral (also known in the western literature as Euler spiral), which eliminates formation seizure when it is laid in the furrow during plowing.

Factors that reduce the soil cultivation technological reliability by disk working bodies include clogging of the battery with crop residues and soil, slipping of the cutting edge relative to the plant mass at the time of cutting. To solve the problem, they use cleaners, establish the optimal distance between the disks and coordinate the individual placement of the working bodies. The gap between the scraper and the battery disc should be 2-4 mm. When placing the working bodies individually, rigid or elastic struts are used. So, the distance between the working bodies of disk plows should be 600 mm. The use of straight inserts with a curved cutting edge on the disc surface eliminates the possibility of cutting edge.

Improving technological reliability is to ensure stable slip of the formation during its lifting, in particular when designing chisel-like paws and disk working bodies.

To ensure the movement and weed gathering from cultivating paws, it was proposed to make the blade curved, the curvature of which changed according to the law of a logarithmic spiral or was represented by a set of conjugate segments of a logarithmic spiral. The flat cutting contour of the cultivator foot provides stability to the depth of movement.

The technical system dynamization is associated with an increase in the tillage tool productivity, which depends on the movement speed and the grip width.

It is advisable to change the width of the grip in accordance with the traction characteristic and the use of block modules. The hinged mounting of the block modules will allow copying irregularities in the field surface and will make it possible to transfer the gun from its working position to the transport one.

The self-developing system is characterized by the optimization of the operating conditions of the working bodies with their maximum adaptation to various soil conditions and the stability of the process. The maximum adaptation term is applicable to the selection of the crumbling angle for the ploughshare share, the angle of attack for the disk working body, the angle of the solution for the lancet paw, with minimal traction resistance and high quality soil treatment.

The technological processes stability is associated with the stability of the frame position, in particular the plow, in the longitudinally-vertical and transverse-vertical planes, the movement depth, the width of the front plow body.

Conclusions

1. The technical system existence includes the stages: creation, improvement, dynamization, self-development.
2. The technological process is decisive in the stage of creating a technical system, and satellites are a system of protection, restoration of functionality, uniform input (supply) and output of material.
3. Improving the system elements is aimed at reducing energy intensity, increasing versatility and reliability.
4. Reducing energy intensity is possible with the implementation of oscillations, a decrease in the friction force, a change in shape,

the working body movement in a network of leading cracks.

5. Improving the system elements in the direction of universality implies a combination of technological operations, a combination of technological and transport functions.
6. Modernization of system elements implies the implementation of measures that increase operational and technological reliability.
7. The basis of the system dynamization is to increase productivity due to the optimal combination of the working width and the speed of tillage implement movement.
8. The self-development of the system involves the maximum adaptation of the working bodies to various soil conditions and the stability of the process.

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N. A. Borodin's Firsthand Study of the USA Power Farming Experience: the Lessons from History

by

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Abstract

This article is devoted to the history of how a Russian delegation sent to the USA by the Provisional Government in 1917 was learning firsthand about the American experience of using machines to enhance agricultural crop yield (power farming). This mission included N. A. Borodin and M. I. Volkov, both of them acted on behalf of the Provisional Government's Ministry of Agriculture. The American Government received the delegates of the new Russian Government very hospitably, giving them every assistance to visit various research, training and production facilities, and helping them with a loan of $ 100,000,000 granted to the Provisional Government. The mission's program included the visits to factories, that produced agricultural machinery, the 1917 Annual National Power Farming Demonstration, and the agricultural colleges. On Borodin's initiative, two Russian specialists were later sent to the USA to be trained in power farming and two American workers moved to Petrograd to share their knowledge and skills in agricultural machinery production. Borodin also purchased the samples of tractors, mowers, seed drills, harvesters, cultivators, cold storage facilities for storing foods, etc. for Russia.

Analysis and Discovery

Nikolai Andreyevich Borodin (1861-1937) was a prominent public figure, deputy of the First State Duma who believed in the economic recovery of his country, promoted the implementation of the best international practices in various agricultural sectors (fish farming, arable farming, agronomy, selection, power farming, etc.), and was famous for his works in the history of fishery and organization of fish farming (Izyumov, 2012). Borodin received a classical university education: he graduated from the Natural Sciences Division of Imperial St.Petersburg University's Faculty of Physics and Mathematics in 1884. During his studies at the University, he was an activist who attended and actively participated in the students' political meetings and Ural Cossacks' Fraternity's activities in St. Petersburg. In 1885, he returned to Uralsk, his hometown, and got a job as a file clerk at the Ural Economic Administration.

In 1891, Borodin was sent by the Ural Cossack Host on a two-year mission trip to the European countries and America to study fish farming and attend the World's Columbian Exposition in Chicago (1893). He took his family with him: his wife L. S. Donskova, a graduate from the Bestuzhev Higher Women's Courses, and his 2-year old son, (Uliankina, 2013). Borodin was profoundly impressed with his American trip; he admired freedom and democracy that prevailed there, the populace's commitment to the scientific and technological progress, and the competition in all areas of economic activities. Later on, in 1915, he would publish a book in Paris detailing the USA's economy (Borodin, 1915). This book became a guide for many economists, activists of cooperative movement, politicians, and entrepreneurs who were acutely aware of the necessity in profound changes in all areas of the pre-revolutionary Russian economy. The tables and diagrams, presented in this book, which contained data on different demographic, geographic and performance characteristics of the American and Russian economies, were of great value. These statistics could be easily used to compare the economic growth rates of the two countries.

Political activities of the underground organizations in Russia, including social democratic groups that Borodin was a member of during his university years, increased during the reign of Nicholas II. In 1886, Borodin was arrested for his membership in D. Blagoyev's Social Democratic Group, but soon released after N. N. Shipov, the Ataman of the Ural Cossack Host, interceded for him.

In the Urals, Borodin organized an experimental fish farm, conducted experiments on artificial insemination of sturgeon and sevruga eggs and on growing them in a nursery. His education in natural sciences enabled him to carry out properly the ichthyologic researches aimed to enhance the fisheries' productivity.

In 1899, Borodin moved to St. Petersburg where he built an amazing political career: from a Ural Cossack to the deputy of the First State Duma (1906). He was an active participant in the discussion of laws related to agricultural, religious and national issues.

In 1917, A. I. Shingarev, ex-Minister of Agriculture, suggested to N. A. Borodin to go to the USA as part of an extraordinary mission, commanded by the Provisional Government and led by B. A. Bakhmetiev. Even before World War I, the Russian Government had been sending technical experts to the United States to purchase military machines. The representatives of the Military and Industrial Committee (B. A. Bakhmetiev and P. A. Morozov), All-Russian Zemstvo Union (A. N. Sakhnovskii and R. M. Polyakov), and Agricultural Agency of Ministry of Agricultures worked in the United States. They were not only studied the American technological achievements in but also purchased new military and agricultural equipment for transportation across the ocean.

Apart from N. A. Borodin, the 1917 Mission included General V. Ch. Roop as an army representative, professor Yu.V. Lomonosov who represented the Ministry of Railways, V. V. Oranovskii who represented the Artillery Department, V. I. Novitskii from the Ministry of Finance, and the experts in different areas. The most numerous among them were the Ministry of Railways' representatives (9 persons). The Russian delegation consisted of 32 persons. They travelled to Vladivostok by a specially allocated express train "Petrograd-Vladivostok". From Vladivostok, the Mission sailed first to Japan and then to the U.S.A. via Canada.

The first American city they saw was Chicago. As Borodin recalled later, "The first two weeks of our stay in the United States consisted of continuous ceremonial meetings attended by tens of thousands of Russians and Americans" (Borodin, 1930: 168). Then the Mission visited New York and Washington. In Washington, the Mission members were received at the House of Representatives, Senate and in the White House where they were received by the US President.

The US Government granted the Russian Government representatives a loan of $ 100,000,000 for procuring all necessary equipment. The Ministry of Agriculture had an agency (Russian Agricultural Agency) in the USA and there had already been the purchases of agricultural machinery and only the money was lacking to meet the needs of Russian peasant holdings. The loan was expected to resolve the Agency's financial difficulties.

Beside the tasks that had been assigned to Borodin and consisted of ordering agricultural machinery and refrigerating facilities, he had to visit several other states to learn about the organization of teaching and learning at the agricultural educational institutions.

Borodin described what he saw and learned, his experience and impressions, in a book co-authored by M. I. Volkov. In August 1917, the entire Mission visited the International Harvester Company, an American manufacturer formed by merger of the McCormick Harvesting Machine Company and the Deering Harvester Company in 1902. The first reaper factory was built by an inventor Cyrus McCormick in 1847 and, by 1917, the International Harvester Company had more than 15 independent branches that annually manufactured about 1,000,000 agricultural machines. The workforce at the factory and its branches numbered more than 40,000 people (Borodin and Volkov, 1918).

During World War I, the manufacture of machines by the International Harvester Company declined sharply. In 1914, for instance, 40,000 reaper-binders were manufactured and, in 1916 and 1917, the number of reaper-binders dropped to 23,000 and 10,000, respectively. This reduction in production was mainly caused by the lack of sales in war-struck Europe and the territories' transition due to the war (Borodin and Volkov, 1918).

The International Harvester Company (often shortened to International) produced tractors, reaper-binders, mowers, seed drills, cultivators, corn drills, corn reaper-binders, etc. Their production process was based on the complete division of labor due to the use of specialized machines. Some floors had 30 to 40 similar machine tools of colossal productivity, with one person (often a woman) operating 4 machine tools simultaneously. The plant's daily output was enormous: 50,000 cutting blades, 7,000,000 bolts and buts, 6,000 pins... At the same time, each major component of agricultural machines was tested before assembling.

The dye factory was a huge facility with large paint tanks into which large machine parts were loaded using an overhead crane. After painting, the parts were dried and then sent to the company's warehouses. There was a railway line inside the factory and the trains transported parts from one production facility to another.

The factory's twine mill was separated from the rest of factory. It produced 220 tons of binding twine daily but, during the war, its daily twine production dropped to 180 tons. Twine was produced from the fiber of Agave sisalana, an aloe-like plant. As an experiment, the factory's management decided to study the experience of the Russian producers of hemp twine and in 1917 several hundred acres of hemp were planted. However, the quality of the resulting twine was low compared to that of the International's twine made from sisal. Sisal was processed using special scutching, combing and finishing machines, mainly produced by the International. To become a binding twine, the fiber went through several technological stages that used 8 different machine tools (Borodin and Volkov, 1918).

The factory had its own machine-tool production facility where they produced specialized equipment for their own needs and for other enterprises. The company's design department counted about 200 people who were improving and modernizing the existing machines and designing and inventing the new ones. Machine tools were created by their engineers and patented; therefore most of this equipment was unique and could not be found elsewhere.

The factory floors had special rooms with tables where workers ate their lunch. Each worker had his own locker for storing personal items and working clothes.

One of the factories visited by Borodin produced tractors and its workforce comprised 2,400 workers. This factory produced about 50 tractors daily. These tractors were of different types: 8-16 hp, 10-20 hp, and 12-25 hp (Borodin and Volkov, 1918). The first figure was drawbar horsepower and second figure was belt horsepower. All these tractors were fueled by kerosene.

Apart from their main production facilities, the International Harvester Company's assets included steel plants, own iron and coal mines, timber lands, etc. In 1917, Russia purchased 2,500 binders, 40,000 reapers, 10,000 mowers, and 4,000 horse-drawn rakes from the International which, together with additional tools, amounted about $ 4,000,000 (Borodin and Volkov, 1918).

America impressed Russian visitors with a great number of various exhibitions. The first tractor show named National Power Farming Demonstration was staged in Fremont, Nebraska, in 1913. During this tractor show, 39 tractors built by 23 companies plowed a field while thousands of farmers watched the machines at work. Many farmers walked behind the plows, often stopping to measure the depth of the furrows. (Twentieth Century Farmer, August 30, 1913, 6; October 4, 1913, 5. Cited from: Reynold M. Wik. Nebraska Tractor Shows, 1913-1919 and the Beginning of Power Farming. Gas Engine Magazine. December/January 1998. https://www.gasenginemagazine.com/farm-shows/nebraska-tractor-shows-1913-1919-and-the-beginning-of-power-farming). The farmers were so impressed with the tractors that the show was repeated in autumn 1914, with 27 companies exhibiting 49 machines and 35,000 visitors attending the show.

In 1915, the third annual tractor show in Fremont presented twice as many tractors built by more than 40 companies, with more than 60,000 people watching the tractors plow the field. The show organizers had purchased 1,000 acres for demonstrating power farming in action. These demonstrations proved to be extremely commercially effective, and tractor sales increased dramatically.

In 1916, when the previous tractor shows were so successful, the Tractor Manufacturers Association decided to sponsor up to eight tractor shows in eight states. These shows attracted about 500,000 visitors. In 1917, when the demand for tractors was high enough that less advertising was needed to sell agricultural machinery, the Tractor Manufacturers Association decided that one show in Fremont would be enough. The 1917 tractor show exhibited 125 machines built by 60 different companies. The range of the exhibits was very impressive, with tractor sizes varying from a mammoth 60-120 hp tractor moving across the filed with 12 to 16 ploughs to a small 8-16 hp tractor with only 2 ploughshares, with about dozen types of machine in between these two. Borodin described how, in the morning of August 8, more than 100 machines began to plough the test fields. The farmers were closely watching the machines at work to choose the tractors suitable for their needs. The next day various ploughs were demonstrated. Ploughs were often produced by the companies other than those that produced tractors so that the farmers had to buy tractors and ploughs from different companies.

Most of the show's attendees were the farmers from Nebraska, Kansas, Iowa, South Dakota, Colorado, and Wyoming. Apart from the Americans, there were visitors from the UK, France, Russia and Mexico. In the evenings, the Society of Automotive Engineers (SAE) held conferences attended by many farmers because buying a tractor was just the beginning: a farmer needed to know how a machine operated, to be able to identify the cause of failure and fix it quickly.

Borodin was aware that the success of tractors in Russia would depend on the availability of service stations or, at least, of qualified specialists capable to repair farm machinery. In fact, procuring tractors abroad, the Ministry of Agriculture did not provide training for farm machinery operators. In the United States, however, this problem was solved by opening two tractor operator training schools. One such school was located in Kansas City and could accommodate 1,000 students. Later on, two young men from Russia were sent there for training on Borodin's initiative.

Summarizing their overall impression of the 1917 tractor show, Borodin and Volkov wrote, "The show clearly demonstrated that the tractor had already acquired the full right of citizenship in the American agriculture" (Borodin and Volkov, 1918). They also wrote that the machines presented at the show differed from each other not only in the features of their design but also in their main characteristics: some were wheel tractors and others were crawler tractors with caterpillar track. The tractors mostly operated on kerosene (the only exception was the Moline tractor), which was a huge breakthrough compared to previous tractors that, like cars, were gasoline-fuelled. The most popular tractors in the USA were small tractors rated at 10 to 20 hp. Huge machines rated at 60 to 70 hp were more difficult to operate and more expensive but the Russians continued to buy these for $5,000-6,000 each while they could buy small tractors for $1,000 instead. Small (three-wheeled) tractors could easily pull three 14-inch ploughs, making the furrow 7 inches deep. The same tractors produced 20 belt horsepower and could run a threshing machine. Such tractors were exhibited at the show by J. I. Case Threshing Machine Company and the International Harvester Company (Mogul and Titan models).

As for advantages and disadvantages of the two types of tractors, the wheel type and the caterpillar type, Russian engineers, who had attended the tractor show, concluded that caterpillar tractors would be useful in the wetlands, potholed areas and areas with clay soils where plowing with a wheel tractor would be difficult. For Russian peasants, Borodin mostly bought wheel tractors that were easy to use and suitable for different types of soil (Borodin and Volkov, 1918).

Beside tractors, the attachments used for converting common Ford cars into tractors were also exhibited during the 1917 tractor show although not as part of it. These devices which became known as the poor man's tractor consisted of a rear axle and wheels and could be used for pulling ploughs, harrows, drills, mowers, and other implements and cost around $ 150-250. Attachment manufacturers were determined to garner a chunk of the tractor market as their products sold much cheaper than a full-size tractor. Tractor manufacturers, naturally, were not enthusiastic with this competition and objected to the participation of attachment manufacturers in the demonstration. Therefore a special demonstration that was not sanctioned by the tractor show organizers was held outside Fremont. All of the attachment manufacturers (Pullford, Smith Form-a-tractor, Staude Mak-a-Tractor, etc.) presented their products at this show (Bill Vosler, June 2017. Tractor Conversion Boom. Farm Collector (Dedicated to the Preservation of Vintage Farm Equipment) https://www.farmcollector.com/tractors/tractor-conversion-boom-zmbz17junzhur; Dave Delaney 14 June, 2015 Tractor maker was careful to hedge its bet. Historical Society of Quincy & Adams County https://www.hsqac.org/tractor-maker-was-careful-to-hedge-its-bet).

One of the problems Borodin was concerned with was professional training in agriculture. He approached David Fairchild, a well-known botanist and plant researcher, as well as the head of the US Department of Agriculture's Office of Seed and Plant Introduction. Borodin brought David Fairchild a recommendation letter signed by R. A. Regel, head of the Bureau of Applied Botany in Petrograd. In the person of Fairchild, Borodin found a kind and friendly adviser, ready to offer help if needed. The heads of agricultural colleges obtained recommendation letters as well as the numerous printed materials concerning the matter that interested Borodin through Fairchild.

Borodin visited agricultural colleges in Ithaca, New York; Lancing, Michigan; Ames, Iowa; Madison, Wisconsin; and Lincoln, Nebraska. Most of these visits were short and mostly focused on the Extension Departments established in all state colleges. These Departments were responsible for agricultural knowledge dissemination related to the application of scientific research and new knowledge to agricultural practices through farmer education. During the visits to educational institutions Borodin met with outstanding scientists working in the fields of agriculture, and attended the summer courses for agronomists.

Upon his return to Russia, Borodin wrote a review of American agriculture. In 1919, he was sent on another mission to the United States, this time by the Omsk Government where he served under A. V. Kolchak. After Kolchak's defeat, there was no way back to Russia for Borodin. He stayed in America and began lecturing on cooperation at the Russian People's University in New York. In 1928, he got a job at the laboratory of comparative zoology in Harvard where he was cataloguing and taking stock of the museum collections. Borodin could not share and implement in his homeland the vast experience he had gained during his American trip. Moreover, the tractors and cold storage facilities he had bought ended up stuck in the warehouses in some ports and never made it to the Russian peasants who they were meant to help. American workers who had come to Russia on Borodin's behalf to work in Russian factories were met with extreme hostility by Russian proletarians. The factory workers scornfully called their American colleagues 'Burzhui' ('Bourgeois', a word used in post-revolutionary Russia with a negative connotation). What particularly irritated them about the Americans was the fact that, they wore white shirts and clean suits outside their working hours, that Russian workers could not afford - not only because they lacked money for this but also because they wanted to distinguish themselves from White Collars and emphasize their proletarian background. After the October revolution 1917, after witnessing dramatic global transformations taking place in Russia, the Americans left Russia to return home on their own nickel (Borodin, 1930).

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Agricultural Robots in the Internet of Agricultural Things

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Abstract

The article considers the approach to solving the problems of precision agriculture based on the concept of the Internet of Things. The aim of the study is developing a theoretical approach to the use of field sensors, agro-robots and unmanned aerial vehicles in solving problems of precision agriculture using the paradigm of the Internet of Things. The authors introduced and proved the position that every agricultural thing can be represented as a service. It description contains a standardized description of the functionality and conditions of its use. The article shows, that things can work with a variety of sensors that can communicate with each other. The article proposes to use of service-oriented architectures to build appropriate solutions. It was confirmed that in the process of solving problems, several autonomous and independent services of agricultural things could exchange messages with other things that have different functional and information capabilities. The choreography of services of agricultural things is used to organize the processes of precision agriculture. The orchestration of such services is used to ensure the information needs of individual things. We have developed a general scenario of typical agricultural things operating in the paradigm of the Internet of Agricultural Things (IoAgT) in solving the problem of active field monitoring. The monitoring process is described as sequential movement along the selected routes of ground agrirobots and drones to commit together with the field sensors of the current situation in the field in different periods of agricultural production - from sampling soil to detect critical situations related to plant diseases, the presence of weeds, pests, and eliminate them. The article shows potential applicability of the proposed approach to a concrete example of solving the problems of monitoring a field sown with grain culture. The article recommends using service-oriented architectures in the implementation of precision farming processes, building algorithms for choreography and orchestration of agricultural things services.

Keywords: robot, agriculture, navigation, Internet of Things, Internet of Agricultural Things, service-oriented architecture.

Introduction

In the last two or three years, due to the active development of telecommunications technology, much attention is paid to the use of the Internet of Things (IoT). In it, Internet technologies are used to combine intelligent objects equipped with electronic sensors and actuators in complex multi-level networks (Wang, X., Liu, N., 2014; Kranz, M., 2018). It is expected that modern agricultural machinery will increasingly be equipped with technological and communication capabilities designed to perform tasks and assess the condition of equipment. The use of IoT in agriculture can significantly increase the level of informatization of the industry and will allow obtaining effective automated solutions without human intervention (Godzhayev, Z. A., Grishin, A. P., Grishin, A. A., 2016).

In the Russian Federation, this area is still in the initial stage of development. The main deterrent factor is the high cost of intelligent solutions: foreign samples of agrobots, subscriptions to accompanying services, sensors of physical and chemical composition of soil, weather stations, etc. Russian experience demonstrates only some experimental samples of robotic devices for agricultural purposes and field sensors (Abrosimov, V. K., Eliseyev, V. V., 2019)

The second factor is incommensurability of development rates of modern robotics technologies and methods of agriculture. The development of technical means for ground and air robotics, mathematical methods of information processing is ahead of the improvement of rather conservative processes of agro-industrial production. The developers propose to introduce the necessary elements for the efficiency of IoT: modern means of technical vision, ultra-precise navigation, image recognition, special software. Nevertheless, all of them are still high-cost. In addition, there are need of increasing the autonomy of agricultural machinery functioning in difficult field conditions and the use of intelligent methods of information processing and decision-making. However, the statistics required for this are usually not available, or such databases are only being created.

The research purpose is developing of a theoretical approach to the use of field sensors, agricultural robots and unmanned aerial vehicles in solving problems of precision agriculture in the paradigm of the Internet of Things.

Materials and Methods

In recent years, the Internet of Agricultural Things (IoAgT) has been discussed sporadically in the scientific literature in relation to agriculture. As of the end of 2016, agriculture accounted for about 6% of all IoT projects implemented worldwide. So far, this direction is quite new; however, 3 years ago (by 2016) there 168 publications on these issues have already been made at 52 conferences, in 60 books and 56 journals (Verdouw, C., Wolfert, S., Tekinerdogan, B., 2016). According to experts, IoT solutions and digitalization in agriculture will bring a total economic effect of 4.8 trillion rubles per year, or 5.6% of Russia's GDP growth. Refracting modern interpretations of the Internet of Things for precision agriculture (Shpaar, D., 2009), we can fix three main provisions:

- the concept of IoAgT is associated with specific physical objects, different in design and level of intelligence;
- the IoAgT concept provides the organization of branched multi-level networks, in particular consisting of field sensors, sensors of executive systems of agricultural machines, sensors of attachments, etc;
- in the concept of IoT, active interaction between things is realized.

Let us also set the generally accepted position of the Internet of Things paradigm for IoAgT: each agricultural thing must represent the interface of its state and functions for interaction, accessible to other agricultural things.

To implement IoAgT in solving individual practical problems, it is necessary to identify agricultural things (objects) between which interaction will be established, describe them as functional or information services and build a network of interaction between them so that different sensors of some things involve sensors of other things. This approach allows us to consider IoAgT as an important component of artificial intelligence (Dharmaraj, V., Vijayanand, C., 2018).

A number of fundamental works on the Internet of Things proposes service-oriented architecture (SOA) as a theoretical basis for its use (Bieberstein, N., Bose, S., 2007). Such architecture assumes uniform rules for objects communication, providing, processing, information exchange. In SOA, an object functionality is represented as a service available to other objects. This allows us to draw certain analogies between SOA technologies, the Internet of Things and the methodology of System of Systems (Mo Jamshidi, 2009).

Indeed, in SOA, the concepts of choreography and orchestration of services are used to organize the interaction of services. Choreography in SOA refers to the sequence and logic of multiple processes coordinated by messages. In means of choreography description, the special role is given to support of information exchange and management of a state of an information component of each service. In this task, the choreography of services can be used for interaction between agricultural things in sequential decision tasks of precision farming.

Orchestration of services consists in the fact that each service, implementing its own functionality, can request and use other services through the Orchestrator or by direct communication, both for its information support and for actions. All interactions are carried out according to the request-response scheme using standard protocols of information exchange. In the problems under consideration, the orchestration of services will be required to solve situational awareness problems, in which each agricultural thing can request another thing to use its capabilities (functional, information and active services) to solve its own problems.

Therefore, we introduce the initial assumption that each agricultural thing is a service described by information containing a standardized description of its functionality and conditions of its use.

Let us define the concept of agricultural thing. There is no single definition of the "things" term, as well as a single strict understanding of the term Internet of Things. The analysis shows that several groups of agricultural things can be considered in the problems of precision agriculture.

The first group is field and weather sensors, which can provide a variety of information. Classifying them for use in the IoAgT paradigm, we can distinguish two main roles of sensors in agricultural production tasks:

1. Information role. Wireless sensor networks for agronomy in the process of monitoring the soil and microclimate of crops are able to measure and predict soil moisture, control temperature, duration and intensity of lighting, presence of chemical elements in the soil, on the leaves of plants, etc. Information sensors also include all sensor devices that produce appropriate signals. Mechanical sensors (Crop-Sensor) are also being developed, which measure the resistance force at a constant height, depending on the mass and number of individual plants, when deviating from the vertical position. Special sensors can measure moisture, density, electrical conductivity and other soil characteristics. Optical sensors are used for the weed control. The so-called sensors of actual weather (temperature, humidity, wind, rain, frost) are of particular interest. Processing of data of information sensors allows not only raising an alarm signal, but also calculating the amount of fertilizers for a given soil area, determining the disease of the plant, presence of pests, etc.;
2. Functional role. Numerous sensors implement the regulating functions: irrigation, differential fertilization, etc. A special case is the active (executive) role associated with the operation of various mechanisms of modern robotics, the involvement of which is also carried out by the appropriate sensors.

For the purposes of using sensors in the IoAgT paradigm, it is important to note that information sensors produce output signals that after appropriate software processing can be converted into input signals of other sensors, both functional and active. The reverse assumption can be considered correct: functional and active sensors can request data from information sensors. Such cross-links are designed to provide high flexibility of solutions.

The second group is various means of mechanization such as carriers of mounted equipment that perform specified or created online routes, in particular they are unmanned tractors and agro-robots. The analysis of tasks, which could be assigned to agrobots, allows forming a kind of perspective image of the ideal ground agrobot. He should have clear objectives and goal-setting, be situationally aware, autonomous in terms of determining his location and moving in space across the fields, make independent decisions in difficult situations, have his own knowledge base. It should exert minimal pressure on the soil. The technical design of the robot must be dust and moisture proof. Agrobot should be equipped with a variety of attachments, specialized manipulators for solving agricultural issues. Its management system should be interfaced with other information systems of agribusiness. To ensure reliability, the agrobot must be equipped with a self-diagnosis system, in ideal case it must fix itself. These robots do not need to be anthropomorphous.

Modern agro-robots are developed as multifunctional. However, their functionality is inextricably linked to the mounted attachments that provide situational awareness of the agro-robot (Abrosimov, V., 2018). Each agro-robot has a control system (CS), a system for analyzing the environment, for example, an electronic vision system (EVS), a system of actuators (System of Robot Moving - SRM) and a system of conditional impact on the environment (Active System - AS) with the use of mounted attachments - samplers, fertilizer spreaders, etc. To EVS sensors we refer a variety of technical means - optical, ultrasonic, infrared, etc., allowing to receive information about the field during the movement process. SRM sensors are installed on the actuators and activate the functions of the robot movement: movement, maneuver, stop, etc. The AS system affects the soil and plants. It is important to note that the information, technical and active capabilities of each robot are objectively limited by the characteristics of these systems.

The key tasks of agrirobots include positioning tasks (Bashilov, A. M., Legeza, V. N., 2014). The introduction of precision farming concepts has increased the requirements for the accuracy of agricultural robots positioning to limit of 1.5-2.0 cm. By any way, the problem of accurate agricultural robots positioning is already close to solving and achieving the almost necessary accuracy. The solution will be based on the combined data of GPS and GLONASS satellite navigation systems (accuracy is up to 0.5-2.0 m) and additional systems that improve accuracy ("automatic taxiing"). These include a variety of local navigation systems (radio beacons and receivers installed on the robot) with the calculation of coordinates by triangulation, positioning technology based on cellular communications, infrared and ultrasonic radiation, etc.

Loss of the GPS/GLONASS signal, which determines the position of the agrobot on the field, at this stage completely "disarms" the agrobot. It stops working and waits for the connection to be restored, or returns to the starting point of its route.

Despite the fact that the issues of its use are not yet fully reflected in the Russian legislation, the supply of unmanned aerial vehicles for the needs of agriculture on the market is quite significant in terms of volume and active in terms of promotion methods (Fetisov, V. S., 2014). The class of tasks that a drone can perform is quite extensive and repeatedly described. The main ones include monitoring, surveying and electronic mapping of fields, specification of borders, determination of vegetation indices of crops; multispectral survey for recognizing the situation on the field, identifying plant diseases, identifying and destoying pests, irrigation and spraying of individual field zones. All these functions are implemented through simple controllers. Input signals of controllers can be also the data of information field sensors transformed by the software. This principle is sufficient for the implementing the IoAgT paradigm

Third group is the intelligent mount equipment for individual tasks. Various types of equipment are being developed for soil sampling, differential fertilization, weed and pest control, etc. However, it is easy to see that modern equipment are essentially also use sensors. This is especially evident when considering precision farming solutions. For example, in one of Amazone's weed control solutions, the system uses an attachment nozzle to apply herbicides when a weed enters the field of view of the sensor at a distance of 50 cm. When a high overgrown weed is detected, the herbicide consumption automatically increases.

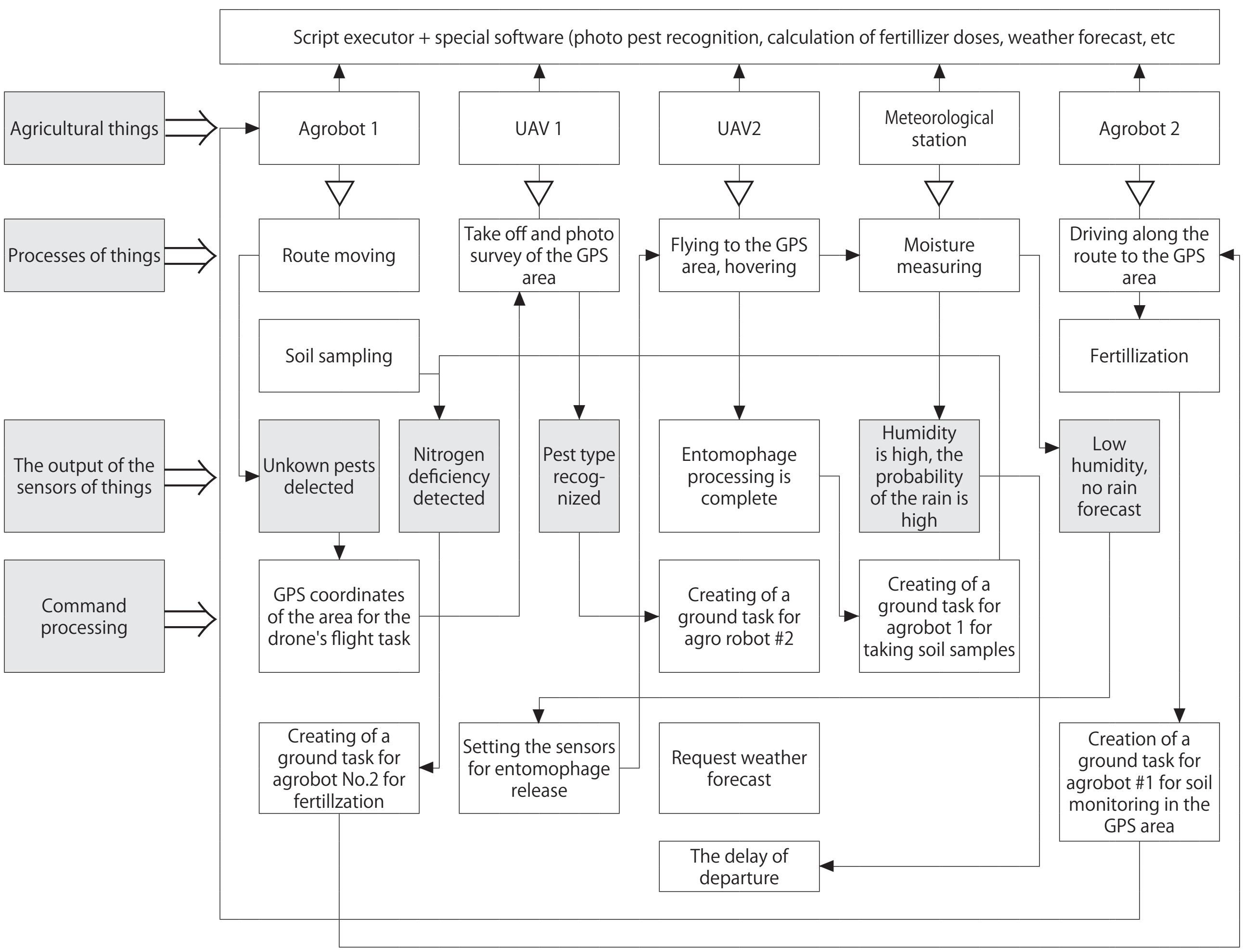
There are other examples. This indicates a significant potential for the introduction of intelligent technologies in these devices and processes.

Agricultural things are highlighted. It is shown that they all work using a variety of sensors. The functionality of things can be represented in the form of a service that is described by parameters and presented to other things. In this case, it is advisable to use service-oriented architectures to build appropriate solutions.

Results and Discussion

Quite a convenient example of using the developed technology is the process of monitoring agricultural

Figure Choreography and orchestration of services of agricultural things during the process of field monitoring



land. For this purpose, one can use a variety of agricultural things - sensors, ground and air robots. It is important to take into account that monitoring can be both exclusively informational and active, including the phases of decision-making, carrying out the necessary measures for fertilization, weed and pest control, and monitoring the effectiveness of the work carried out at the final phase.

Let us present the task of active field monitoring as a choreography for agricultural things. Indeed, the monitoring process can be described as a consistent movement along the selected routes of ground-based agricultural robots and drones in the interests of fixing the current situation on the field in different periods of agricultural production: from the moment of taking soil samples for its soil-chemical analysis to the detection of critical situations associated with plant diseases, weeds, pests and their elimination.

We describe a general scenario of typical agricultural things operating in the IoAgT paradigm.

The initial situation: it is necessary to sow grain crop on the field with significant slopes and individual boulders. On the edge of the field, there is a platform where two agricultural robots of ground type with various mounted equipment are located and serviced. The first robot has the soil sampler and the video camera with a wide viewing area, the second one has the mounted equipment for fertilization with the corresponding sensors. In the available field's neighborhood located dronefield, where based two unmanned aerial vehicles (UAVs) with various payload. One has a multi-spectral camera weighing up to 2 kg, another one has a device for biological crop protection, with a total weight up to 5 kg. The field also houses one stationary weather station presented as a set of geographically dispersed wireless digital weather sensors that provide various types of measurements, including ambient temperature and pressure, wind speed and direction, humidity, light characteristics. The task is periodic monitoring of the field sown with grain (before entering the tube).

In the considered IoAgT paradigm, for example, the following monitoring option can be proposed (see **Figure**).

The functionality of all selected agricultural things are performed in the form of services and registered in a special register with their names so upon request they can be found and used. The basis for the interaction of things is a software bus with special software (SPO) and the program "Script performer", which implements the choreography of services.

Agribot No. 1, acting as a seeker of urgent situations, moves on a predetermined route avoiding the boulders and removing the possibility of accidental hitting the ground field sensors around which are set the no traffic zone. Monitoring of the crops state is carried out with the use of onboard information equipment of the agro-robot that is a video camera. The software analyzes the video image. At the detection, for example, a large cluster of pests, the location (GPS-coordinates) of the infection is saved and transmitted to the SPO. According to the "if... then..." rule the GPS coordinates of the infection are transmitted to the drone controller, which activates its flight task. The drone takes off, arrives at the point indicated by the agro-robot, specifies the scale of infection by photo and specifies the area where the extermination of pests is necessary. The SPO based on data processing of the UAV recognize the type of pests, gives the current location of the UAV flight to UAV No. 2, which has equipment for the placing of entomophagous parasitic insects. However, according to our assumptions, the selected entomophages are sensitive to humidity. UAV No. 2 requests the weather station service about the weather forecast for the near future. The weather station displays the message "the probability of rain is high". Due to the approach of rain, work is automatically postponed. Upon the rain is finished, the humidity sensor informs that the weather situation contributes to the release of entomophages and launches an active function that is the drone's engines. UAV No. 2 takes off, moves to the specified point and processes the location of pests with entomophages, issuing a signal about the completion of work and forming a signal for taking soil samples for agro-robot No. 1. Agrobot No. 1 moves along the route to the GPS-area, automatically takes soil samples. UAV No. 1 delivers samples to the field station for analysis of the physical and chemical composition of the soil, where there is a lack of nitrogen. The SPO calculates quantity of fertilizers, which need to be brought in GPS-area and issues: first, setpoints to the sensors of the fertilizers located on the hinged equipment of the agrobot No. 2 and, secondly, a signal on involvement of its executive mechanisms. Agrobot No. 2 moves to the GPS-area, introduce fertilizers and forms a command to sensors of executive mechanisms of agrobot No. 1 for further monitoring for the analysis of efficiency of the carried-out field actions.

Thus, in the considered monitoring process, several autonomous and independent services and things exchange messages in order to monitor the field by several things (objects) having different functionality, which is the essence of the choreography of services. Using the choreography of services in the SOA architecture and in the IoAgT paradigm with the involvement of a variety of agricultural things, a number of tasks of precision agriculture are consistently solved.

In the process of choreography of services, the orchestration of services and things is realized in a situation where the second drone requests the field weather station regarding the information about the rain it needs to make a decision about the start of departure to solve problems.

Summary

The introduction of principles of precision agriculture in the Russian conditions depends on the development of new approaches to the construction of such complex processes with a significant intellectual component. However, despite significant achievements in the field of applied robotics, the agricultural market objectively does not yet aspire to its active intellectualization.

Among the promising technologies is actively developing the Internet of Things. Its main technologies are being tested. Nevertheless, the world's leading companies developing architectures and software to implement the concept of the Internet of Things are already analyzing the applicability of their solutions for agriculture and offering such solutions. In essence, the main task is to use the advantages of IoT to improve the efficiency of agricultural production and, perhaps most importantly, the coordination of individual elements of agricultural systems based on information obtained on-line.

In relation to agriculture, things can include field sensors, various agricultural machines such as tractors, agro-robots, drones, intelligent attachments. The main features of agricultural things are their physical nature, their ability to be embedded in the network and interact with each other (ideally without human intervention), giving and receiving information, actively using the functionality of things.

The IoAgT solutions offered in the software market are modifications of the IoT ideology for other tasks. They contain necessary elements: databases of "smart" objects, universal templates, the server of communication with objects, the server of specialized utilities, graphic editors, etc. At the same time, these elements are often functionally redundant and very expensive. Therefore, the methods of solving traditional intellectual problems when used in management systems of agricultural products must be adapted to the practical needs of agricultural production. However, in the next 7-10 years, it is premature to talk about the need for a high degree of intellectualization of things (learning from experience, self-organization, self-recovery from breakdowns, etc.).

Currently, the preferred solutions are "sharpened" for specific practical tasks, based on the paradigm of the Internet of Things. The main attention should be paid to create the high situational awareness of various agricultural things in the changing weather and geographical environment, the formation of uniform interaction standards, the presentation of functionality of things in terms of functional and information services from information exchange between them and, most importantly, control each other.

Service-oriented architectures with the implementation of precision farming processes in the form of choreography of services of Agricultural Things and ensuring the effective operation of such services through their orchestration can become an effective theoretical basis for the construction of appropriate application solutions.

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Improving the Resource, Reliability and Efficiency of Worn-out Machines with New Methods of Their Maintenance

by

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Abstract

To increase the reliability and efficiency of worn-out machines in agriculture and transport, one can use low-cost non-labor-intensive non-traditional tribotechnics in the course of maintenance of machines and equipment. This task is relevant for many countries of the world, including in Asia and Africa. The research purpose is to analyze and to confirm the effectiveness of three low-labor-intensive innovative service methods for improving the performance of agriculture machines and automobiles. Triboengineering testing of mineral powders and emission of 50 volt electric charges into the oil was carried out during the laboratory tests on the tribometer and in operation. It has been found a reduction the friction and wear in 1.5-2.5 times at the parts after introducing the serpentine tribocompound. Non-disassembly repair allows achieving 1200% of the profitability of technical service and increasing the pre-repair resource of units up to 2-3 times. Emission of electric charges and metal ions into motor and transmission oils reduces the friction coefficient at low loads from 0.096 to 0.037, reduces the consumption of motor fuels by at least 3.2%, and in some cases by 17-24.2%. According to operational data, the reduction in the consumption of gasoline, diesel and gas fuel reaches 10-12%. The power of internal combustion engines and their environmental friendliness are improving. Irreversible mechanical and chemical modification of the activator facilitates the fractional compound of motor fuels, creates new hydrocarbons in these up to 37%, reduces their consumption; fuels are purified from sulfur up to 50%, and purifies from resins in 7-9 times. Emissions in exhaust gases are reduced: nitrogen oxide by 17%, nitrogen dioxide by 14%, carbon monoxide by 49% percent, diesel smoke by 7.8%; the freezing point of diesel fuel reaches minus 45 degrees Celsius.

Keywords: fuel activator, maintenance of machinery and equipment, tribocompound, non-disassembly repair, emission of charges in oil, friction geomodifiers.

Introduction

New low-cost influences on units of internal combustion engine are used in addition to high-quality service as a mandatory non-standard work for preventing contamination of oil and air in them, especially in the dusty environment of Asian countries and for improving the resource, reliability and efficiency of worn-out machines.

Since 1988 in St. Petersburg, serpentine tribocompound have been created and widely implemented. It became the most popular innovation in technical service of machines and equipment. It was quickly tested by dozens of research institutes and large industrial enterprises of the Russian Federation (Dunaev, A. V., 2018), military and civilian universities (Lazarev, S. Y., 2016; Shabanov, A. Yu., 2016), and universities of the agro-industrial complex since 90s (Balabanov, V. I., 2019; Gvozdev, A. A., 2016). Naturally, much attention is paid to Russian compounds in Europe, Asia, and Africa (Makoto Kano, 2015; So Nagashima, 2015). New inorganic and organic compounds are also being developed (Grigor'ev, V. S., 2015; Ostrikov, V. V., 2018), but serpentine tribocompound lead in the range of its use and technical and economic efficiency.

Since 1990 in Japan used five tribocompounds. Their use in China and other Asian countries are extending, where the machines are processed with triboengineering powders of these friction geomodifiers of magnesium hydrosilicates $Mg_6[Si_4O_{10}](OH)_8$. Non-disassembly repair of any friction units of machines and equipment working with oils and fuel increases the profitability of technical service up to 300-1200% (Dunaev, A. V., 2018).

Friction geomodifiers are easy to prepare, use (needs staff of average qualification, without equipment), environmentally friendly, cheap. They cause a gradual build-up of anti-wear, oil-based coatings with carbon thickness of 1-600 microns, and in unique cases up to 1000 microns on the friction surfaces during operation (**Fig. 1**) (Dunaev, A. V., 2018).

Tribotechnical use of river silt and minerals has a history from ancient Egypt. Widespread use of lapping compounds began in 1942 in the United States to eliminate defects in the transmission of all-terrain army vehicles. Successful testing initiated the use of triboengineering in NATO since the 70s of the last century, and in the Navy and armored troops of the USSR since the 80s. Since then, the Soviet Union has gained popularity of non-disassembly repair by introduction the serpentine compounds in the lubrication of aggregates in order to partially restore worn surfaces and operability of aggregates (Dunaev, A. V., 2018).

Even partial restoration is advisable, since a large proportion of failures occur due to wear of 0.1-0.3 mm. As shown by 30-year practice, such treatment of non-failure objects is an alternative to repair: pre-repair life of units is extended to 3 years, significantly reduced the cost of service and operation while increased the performance of machines.

During studying the un-disassembly repair with the use of friction geomodifiers, there were made 3 discoveries, developments on the tribotheory of minerals were awarded with diplomas and medals of international exhibitions. Friction geomodifiers are protected by more than 160 patents of the Russian Federation and other countries, and have conclusions from foreign certification commissions. It is proved that this innovation makes it possible to significantly smooth out the problem of wear of machinery and equipment around the world (Lazarev, S. Yu., 2016).

In addition to the Russian Federation, friction geomodifiers are widely implemented in Finland (RVS Tec Oy), China, Japan (Fe-Do), Vietnam (TFT, “Blue jade”), Germany (REWITEC), Sweden (RESTAL), Ukraine (HADO). “Suprotek” scientific and technical company in the Russian Federation and in the Czech Republic monthly produces 47 brands of compounds for different units of machines, supplying 50 thousand bottles of friction geomodifiers in 30 countries. Large-scale production and use of friction geomodifiers is in car service in Finland.

“Ruspromremont” scientific and technical company has supplying friction geomodifiers to Japan since 2000. In 2002, at the University of Tokyo named after Vasseda, Russian engineer Pustovoy, I. F. together with Furuya Kazuhide has developed friction geomodifier on local raw materials: the island of Hokkaido is a solid piece of serpentine. Under the brands of RVS Technology and MRS Technology, there are created next friction geomodifiers: METARIZER EX; Metallion Power chip P250; Metarizer professional service; Fe-Do. With the support of automakers, local friction geomodifiers is used in 26 service centers in Japan (Dunaev, A. V., 2018). The composition of Fe-do is used in the repair of internal combustion engines for all of Indochina. Running-in of internal combustion engines with serpentine friction geomodifiers has been tested in Russia (Shabanov, A. Yu., 2016).

Friction geomodifiers have features and differ from additives to oils (**Table 1**) (Dunaev, A. V., 2018).

Friction geomodifiers includes mineral powders of the serpentine group of similar chemical composition:

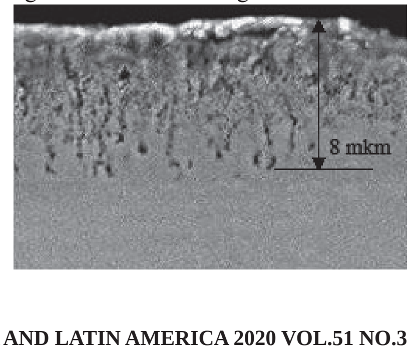
- $Mg_6[Si_4O_{10}](OH)_8$;
- $(MgOH)_6[Si_4O_{11}]H_{20}$;
- $3(MgO)_4[SiO_2]2H_2O$.

Silicon in friction geomodifier molecules can be replaced by aluminum and magnesium by aluminum, manganese, nickel, iron.

Here are the features of the friction geomodifiers:

- Work only on friction surfaces;
- Work mainly on steel parts, but there are laboratory confirmations of friction geomodifier coatings on non-ferrous alloy parts;
- Friction geomodifier coatings are formed firstly in zones of high contact temperature and pressure, in the zone of shock loads; after their stabilizing, the build-up of the coating slows down;
- It is considered that serpentine particles (if they are large or a lot of them) clean the friction surfaces, which can contaminate the oil filters and drop the oil pressure in the engine;
- The optimal size of the friction geomodifier particles must exceed the total thickness of the lubricant film and the total roughness of the contacting surfaces. For the cylinder-piston group and crank mechanism of the internal combustion engine, this value is from 7-8 to 25 microns, and for the coarser parts of transmissions with more viscous oil it is up to 50 microns;
- Friction geomodifiers increase the wear resistance of surfaces and the resource of aggregates by 2-3 times; the mileage of passenger cars after friction geomodifier treatment reached 1.2 million km

Fig. 1 Cylinder cutoff of 16V280Z diesel of DF-11 Chinese locomotive with a run of 150 thousand km after two processing by serpentine compounds: visible boundary between a metal and geomodificator coating of 8 microns



(Dunaev, A. V., 2018);

- The friction geomodifier coating has a resistance of 10-300 Ohms/cm, mirror cleanliness (Ra = 0.03-0.05 μm) monomolecular layering, high hardness (HV ≈ 1100 kgf/cm^2), it is transparent in a thin layer (traces of mechanical processing are visible), color is golden yellow, golden lilac or light grey (**Fig. 2**);
- Friction geomodifier coating is destroyed by the impact of electricity (from the point of contact with the electrodes of the tester, the combustion craters grow on the entire surface of the part);
- Coating is not etched by 2% nitric acid solution (proposed by engineer Podchufarov, S. N.);
- The substrate of the friction geomodifier coating (proposed by Ph. D. Lyubimov) is a stalagmite structure on which the polymerization of the lubricant components occurs

Table 1 Comparison of oil additives and friction geomodifiers

Indicator	Oil additives	Friction geomodifiers
Improved performance of lubricating oils	anti-seize, anti-wear, antifriction, detergent-dispersing, anticorrosive	anti-seize, anti-wear, antifriction,
Improved constitutional properties of lubricating oils	viscous, anti-oxidation, separation, low-temperature	doesn't improve
The object of impact	the base oil is a hydrocarbon liquid	friction surfaces when applying oils and lubricants to them
Concentration	Up to 20%	0.01-3.00%
The interaction with the lubricant oil	They are dissolving in oils and lubricants and are spent on maintaining their working and constitutional properties	they form oil suspensions and are spent on modifying the friction surfaces, the excess is removed with a change of oil
Thickness of the layer formed on the surfaces	Up to 40 Å	up to 650 microns in nanodiamonds; serpentine compositions in different nodes are 20, 100, 600 and up to 1000 microns
Temperature limit	up to 150ºC for surfactants, 150-350°C for chemisorption	150-500°C and within the temperature resistance of structural materials
Duration of action	Up to changing the oil	up to 3-5 terms of oil change or 30-50 and 100 thousand km of mileage of cars, a year or two of MTP units
Work without oil	Prohibited	guaranteed failure-free mileage up to 200 km without oil
Hardening of the original surfaces	minor and not for all additives	Significant, up to 1.2-1.5 times
Alignment of the microrelief of friction surfaces	small	Significant, up to 0.06 um
Expansion of the reduction layer and optimization of gaps in the contact surface	No	up to 1 mm; repeated treatment is required for heavy wear
Increasing the resource of friction pairs in comparison with the resource of standard parts	occurs, but less effectively	for new parts is up to 2.5 times, after repair is up to 150%
Reduction of vibration and noise of units	insignificant for many, good for some	significant, a maximum of 6 dB
Corrosion resistance	regular, high for special additives	high, reduction of corrosive wear
Heat resistance of the reconstructed surface	–	High, up to 500ºC
Friction losses, mechanical losses in the unit	Reduced, but to a lesser extent	Reduced to 0.025, mechanical losses are reduced up to 20%
Lowering the temperature of the friction units and lubricants	visible, but work without lubrication is not allowed	significant; the unit can work long time without lubrication
Protection of the unit from failures during the loss of lubrication	Small	Full
Reduction of starting wear in the engine when working with all-season oils	with additives that form a durable protective film	significant
Compatibility with lubricants and work fluids	individual for different additive package for different types of oils	with oils, hydraulic mediums, diesel fuel, kerosene, gasoline, alcohol, lubricant-coolants
Increasing of oil life	one need to follow the grade and the work life of the oil	Noticeable, requirements for the quality of the oil is reduced
Frequency of use	until the depletion of oil resource	up to 2500 h
Selectivity	balanced additive packages are versatile	mainly for steel and cast iron parts
Technical and economic effect	improving the resource and separate indicators	aggregates that depend on friction ensure the profitability of 500-800%

(Dunaev, A. V., 2018);
- There is the optimal duration of treatment; if not remove the oil in time, triboprocessing will be worse, it is possible failure of the particle coatings with increasing of friction; it is suitable suspending triboprocessing to harden the coating and strengthen its adhesion to metal (Shabanov, A. Yu., 2016);
- Effectiveness of even a thin coating is explained by the closing of the risks on the parts of the CPG and the oil-fillness, which provides semi-liquid friction (Shabanov, A. Yu., 2016);
- Introduction of blacksmith's soot (proposed by Pavlov, O. G.), magnesium or its oil-soluble compounds into the friction geomodifier powder (according to Podchufarov, S. N.) intensifies the formation of the coating;
- Friction geomodifier processing is appears in an hour, but the build-up of the coating occurs mainly in operation; the growth of coatings occurs also at a significant distance from the metal friction surfaces from tens to 1000 microns, continues after the removal of friction geomodifier in the presence of oil, and according to the "Eion-Baltika" scientific and production company and the Naval Academy of G. G. Kuznetsova - and after complete removal of grease;
- Friction geomodifier process is more intensive on the worked oils and is expedient if the operating time exceeds 50-100 h, for 500 km of run before oil change (Dunaev, A. V., 2018);
- In cold oil and hydrodynamic lubrication, the friction geomodifier process does not occurs;
- At the beginning of friction geomodifier treatment, the engine temperature and fuel consumption may increase, but at the end they become less than the original 5-8%;
- After the geomodifier treatment and cleaning of the CPG, the compression may increase or decrease, but after increasing the coating it increases;
- When cleaning the CPG and removing its contaminants to the oil filters, the oil pressure in the engine may decrease, but after changing the filters and coating formation, it increases significantly in comparison with the original;
- When friction geomodifier processing, the internal combustion engines work unstable, after 5-30 minutes from the input of the friction geomodifiers from the exhaust pipe of the engine may be released gray smoke, steam, drops and splashes, up to 1.5 liters of contaminated water; vapor release a few days after treatment is not uncommon;
- The volume of coatings is more than 25 times the amount of friction geomodifiers injected into oils;
- After friction geomodifier processing, the zone of rotation frequency of the crankshaft with a high and constant torque value of the internal combustion engine expands.

Topography of the surface after a short friction of the "finger-disk" steel pair under pressure of 0.5 MPa and a sliding speed of 1 m/s showed that the coating thickness of 1000 nm consists of two layers: mineral cellular "skeleton" of 400-600 nm and a layer of tribopolymer of 200-400 nm (Lyubimov, D. N., 2013).

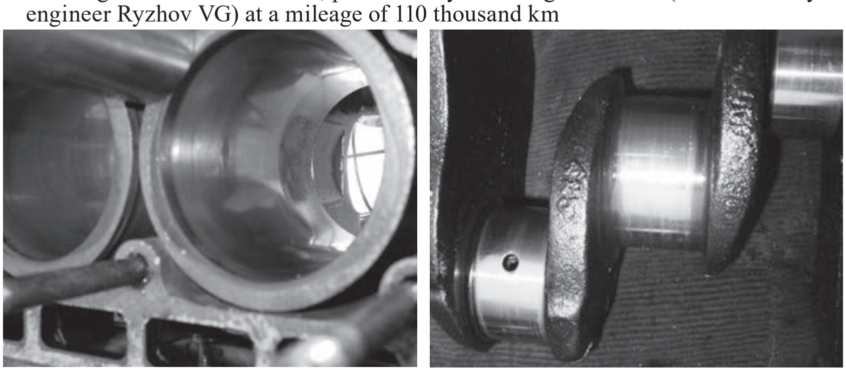
Friction geomodifier particles during friction form a mineral framework on the faces of metal crystals of friction surfaces. Tribopolymerization of the medium components occurs on it and forms a microporous coating (**Fig. 3**) (Lyubimov, D. N., 2009).

On the other hand, according to Beijing Tsinhua University, friction geomodifier coatings with a complex, but mostly carbon, composition are characterized by high hardness and elasticity, weak hydrogen bonds of conjugated friction surfaces and mirror purity (Dunaev, A. V., 2018). Here, the high antifriction properties of diamond-like friction geomodifier coatings were explained in a completely new way. The Beijing results are also confirmed by research in the French laboratory.

The second innovation for activation of oils and lubricants by electric impact, more practical in comparison with the processing of high voltage fields in the Kharkiv Academy of railway transport, has been created by Ph. D. Lyubimov D. N. (patent RF № 59198). Its unexpected effectiveness was first confirmed by laboratory tests at the University of Tallinn, twice by bench tests at the Helsinki diagnostic center, and especially deeply and widely at the St. Petersburg Polytechnic University by bench tests of the VAZ-2108 engine with measurements of 276 engine performance indicators and exhaust gas parameters.

At the heart of the third innovation, associated with an unexpected and significant increase in the calorific value of motor fuels, there are prewar magnetic activators. These are in the Scientific Center of nonlinear

Fig. 2 Cylinder liners and crankshaft neck of ZMZ-402 engine of GAZ-31029 with a mileage of 690 thousand km, processed by friction geomodifier (brand RVD by engineer Ryzhov VG) at a mileage of 110 thousand km



wave mechanics and technology at the Institute of mechanical engineering of Russian Academy of Sciences, Moscow economic Institute and Tambov state technical University has other mechanical and chemical nature (Vorobev, Yu. V., 2019).

Operational and bench tests in the Military Air Academy named after N. E. Zhukovsky and Yuri Gagarin showed a reduction in the consumption of motor fuels up to 20-32%.

The research purpose is to analyze and confirm the effectiveness of three low-labor-intensive innovative service methods for improving the performance of machines in agriculture and automobiles.

Materials and Methods

We have used the literature data, serpentine powder of "Saranovskaya" mine, studied on the XRD 6000 diffractometer and TRB-S-DE tribometer. Tests were carried out to supply the engine oil with charges from copper, aluminum, tin, zinc, iron and coal electrodes. We have studied the results of operational testing of charge emission in engine and transmission oils on 28 cars. There was made bench tests of the activator according to Russian patent No. 2411074, operational tests on a dozen cars, compared the chromatograms of the initial and activated fuels with the changed fractional composition.

Results and Discussion

In the GOSNITI Nanocenter, there conducted comparative tests of tribocompounds, including "Saranovsky", one of the best serpentine one (**Fig. 4**) (Dunaev, A. V., 2018).

"Saranovsky" friction geomodifier is one of the best serpentine, brings the properties of M-10G2k motor oil of CC class according API to the indicators of high-quality Mobil oil, reducing the coefficient of friction from 0.09 to 0.04. The Fe-do friction geomodifier developed by the engineer Pustov I. V. (the coefficient of friction is less than 0.04) was slightly more effective, and the friction geomodifier of the engineer Sokol S. A. from Pyatigorsk was recognized as the best (the coefficient of friction was reduced to 0.027).

The second innovation in technical service is the activation of oils by electrical methods. The simplest of them is the emission of charges into the oil from the electronic friction regulator created by D. N. Lyubimov, Ph. D. (Russian patent no. 559198) (**Fig. 5**).

Electronic friction controller causes the emission of electric charges in the oil from parts washed with oil and isolated from the body. Electronic friction controller increases the oil film strength in friction parts, its load capacity, reduces friction and wear, purifies combustion chamber of the internal combustion engine, initially increases but then rapidly decreases the exhaust gases opacity of diesel engines, increases pollution of oil filter, but purifies oil. These devices are used in many regions of Russia; they can be used on different equipment of the countries of Asia, Africa and America.

In 2012, the Helsinki diagnostic center conducted tests with the electronic friction controller on the Audi A4 diesel car on a running drum stand in stationary load with speed of 85 and 142 km/h. It was found that the specific fuel consumption in the tests at first speed decreased from 517.6 to 416.7 g/kWh (by 24.2%), and at the second speed it decreases from 538.9 to 513.7 g/kWh (4.9%). Fuel economy was 3.2% in bench tests of diesel in forced modes (Dunaev, A. V., 2018).

In 2013, electronic friction controller was tested at the Tallinn University of technology on a stand simulating the operation of a diesel engine. The most detailed efficiency of electronic friction controller was recorded by bench tests of the VAZ-2108 engine at the St. Petersburg Polytechnic University: mechanical losses decreased by 5.5%, fuel consumption by 4.3%, exhaust gas

Fig. 3 Topography of the surface after friction in a lubricant composition with friction geomodifier: a spatial stalagmite structure is visible that has grown along the faces of metal crystals, on which an anti-friction friction geomodifier coating is formed

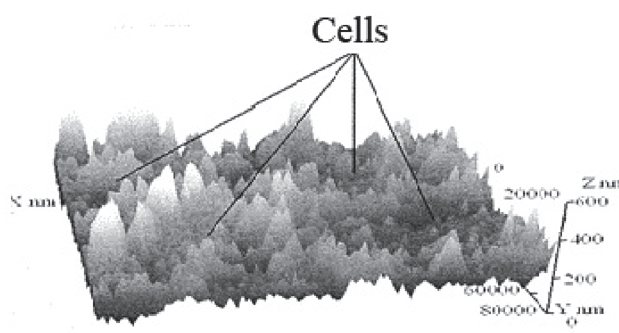
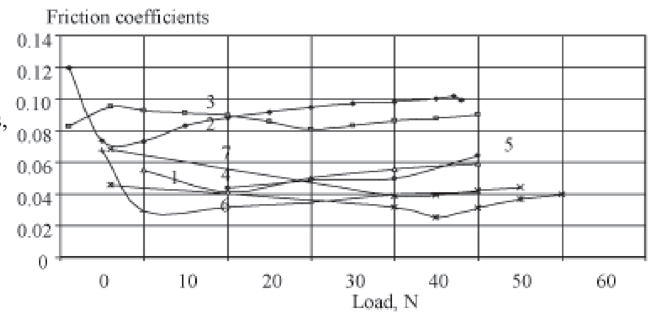


Fig. 4 Friction coefficients of the finger–disk steel pair on the TRB-S-DE tribometer in pure motor oils and with tribocompounds



1 - in pure Mobil SJ/SL SAE 05W-30 oil; 2 - in M-10G2k oil; 3 - in M-10G2k oil with 1% of the KAMP preventive composition (Saint Petersburg.); 4 - in M-10G2k oil with 1% of CNT f riction geomodifier (Moscow); 5 - in M-10G2k oil with 1% of MS-2 friction geomodifier (St. Petersburg and Moscow); 6 - in M-10G2k oil with 1% of "Saranovsky" friction geomodifier (GOSNITI); 7 - in M-10G2k oil with 1% of KARAT-5 nanodiamond composition (Krasnoyarsk)

temperature by 6-10°C, CO and CH content by 19%. However, the NOx content increased by 6.53%. The effective efficiency of the internal combustion engine increased by 4.62% and the power capacity by 1% (Dunaev, A.V., 2018). The greatest efficiency of the electronic friction controller is seen after a few hours of operation of the unit, but after it is turned off, the efficiency of the unit return to their original values.

According to operational data, the lowering of fuel consumption in gasoline, gas and diesel engines reaches 10-12% (Dunaev, A. V., 2018). In 2019, more than 330 domestic and imported cars worked with electronic friction controller in Russia. Their owners noted better acceleration.

For 15 years, electronic friction controller has been tested in different regions on the internal combustion engines of various cars and locomotives, on the gearboxes of lifting machines and in oil production, in household appliances. It is a simplest voltage converter +12 V/+ 50 V (Lyubimov, D. N. et al., 2009).

The effectiveness of friction controller is increasing when introducing into the oil an insulated zinc, tin, copper or aluminum oil dipstick with a developed surface instead of steel one. In this case, soft metal ions are also emitted into the oil (Gvozdev, A. A., 2016).

Power consumption of the device is less than 1 W. Economic efficiency of friction controller with reducing wear and friction, fuel consumption and lubricating oils in internal combustion engines increases considerably with installing them on all units of machinery and equipment: for example, one on the engine and another one on the transmission and drive axle.

According to engineer Ryzhov V. G., after 2 years of operation of his Audi A4 car, he found that friction controller is more effective with old oils. Moreover, the effect is greater, the thinner the oil; with insufficient temperature of the engine and high moving speed there is no fuel economy.

Instead of friction controller, it is possible to use industrial DC voltage converters for +50-70 V. The efficiency of increasing the voltage up to 100 V is being tested.

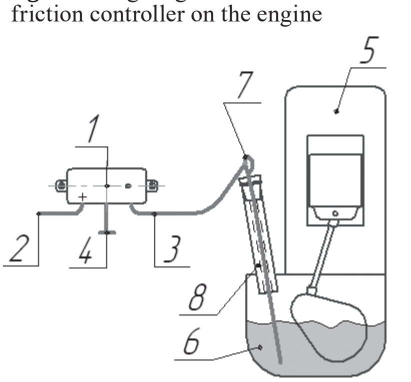
In the GOSNITI Nanocenter, the efficiency of oil polarization in improving the friction characteristics of conjugations was confirmed (**Fig. 6**). On the TRB-S-DE tribometer in the mode of step loading it has been tested “finger-disk” steel friction pair when entering into the M-10G2k oil behind the finger of electric charges from copper, aluminum, tin, zinc, steel and coal electrodes from various converters and from the serial friction controller (TU 3415-003-62012172-2010, certificate: ROSS No. 0841721-U. AG83. N00562). With a zinc electrode at a load of 10 N, the friction coefficient decreased from 0.050 to 0.037.

Oil control after the processing with friction controller showed that in the zone of its influence between the electrodes of the tester there was a voltage of up to 3.2 mV.

Performance testing of friction controller made on 26 cars by the engineer Postavim I. F. on the route Saint Petersburg - Petrozavodsk (450 km) and back, engineer Zeleznick A. I. on the VAZ-2131M in Moscow in 8 circles straight highway with a length of 2 km in one direction (Dunaev, A. V., 2018), and engineer Ryzhov V. G. on the route Moscow - Ekaterinburg at 2200 km as well as the biennial operating them personal car Audi. All these summer tests showed a decrease in gasoline consumption by 3.2-17%. Dr. Sharifullin S. N. in the summer of 2015 tested the friction controller with the Hyundai AX35 on the Chistopol - Kazan highway (140 km) and back. In this case, the consumption of gasoline from 11 l / 100 km with the use of friction controller decreased to 8.5 l/100 km (Dunaev, A. V., 2018).

The third innovation in the technical service is the activation of motor fuels. To improve fuel efficiency and environmental friendliness of automotive engines, high-tech modernization of their fuel systems is performed. At the same time, this issue can be solved by modifying fuels that change their properties and increase their calorific value, for example, by magnetic activation. However, magnetic fields act only in

Fig. 5 Wiring diagram of the electronic friction controller on the engine



1 - electronic friction controller; 2 - power supply input; 3 - output to the oil dipstick; 4 - output to the unit body; 5 - unit; 6 - oil; 7 - oil dipstick; 8 - insulator

Fig. 6 Tests of serial friction controller with different electrodes

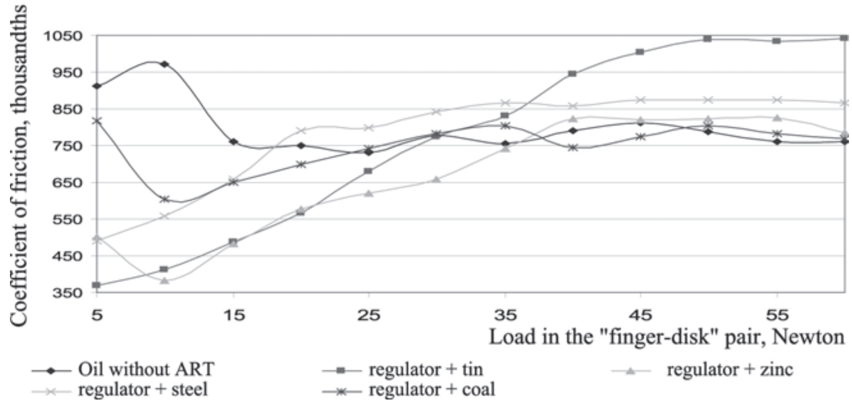


Table 2 Structure transformation of hydrocarbons under the influence of complex effects

Initial fraction, calorific value	The fraction composition in stages of transformation		Final fractions	Calorific value of processed fuel	Increase in calorific value
	first phase	second phase			
C_8H_{18} Q = 5470 kJ/ mole	2 C_2H2	2 C_2H_2	2 C_2H_2	Q = 7001 − 8367 kJ/mole	≥ 28%
	0.5 C_2H_4	0.5 C_2H_3	0.5 C_2H_3		
		0.5 C_2H_3	0.5 C_2H_3		
	3 CH_4	3 CH3	3 CH_3		

their zone, and outside of them, fuel changes are reversible.

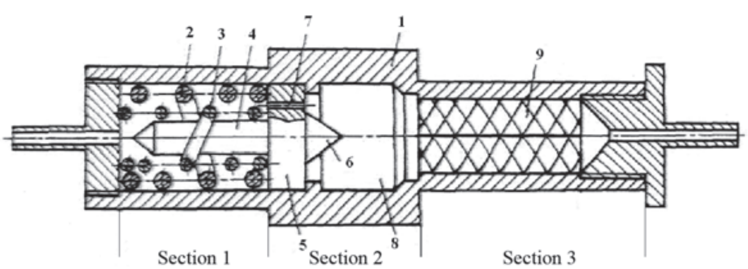
A new mechanical and chemical activator (RF patent no. 2411074) increases the calorific value of motor fuels and reduces their consumption by 20.0-31.9%, significantly reduces the content of harmful substances in exhaust gases, cleanses diesel fuel from sulfur and resins and reduces its freezing point below minus 45 °C (**Fig. 7**). Since 2009 the results of the activator test were confirmed by five official tests on diesel engines (KAMAZ-740, YAMZ-236) and three times on a ZMZ-406 gasoline engine, operational tests on a dozen cars and more than 150 comparative chromatograms of gasoline and diesel fuel of dozens brands, jet fuel and rapeseed oil (Vorobev, Yu. V., 2019).

The activator is the cylinder with a length of up to 150 mm and a diameter of 30-50 mm. It has three serial cameras, built in fuel system engine, does not require driving, contains no chemical substances in contrast to the activators of NACHI and others, increases the caloric content of gasoline, diesel fuel, aviation kerosene, does not reduce the resource engine.

The activator has been tested on diesel fuels from dozens suppliers. Chromatograms of activated diesel fuel showed a noticeable reduction in the share of heavy hydrocarbons and the formation of light gases that are not presented in commercial fuel: hexane, heptane, 3-methylpentane up to 37%. In gasoline, the content of octane-defining toluene increased to 16%, in aviation kerosene the share of nonane and decane is increased to 21%. Testing in the US (Rochester Institute of Technology) identified the reduction of sulfur in diesel fuel to 50%, resins up to 7-9 times, NO emissions by 17%, NO_2 by 14% CO by 49%, the natural increase in volume (not mass) of light diesel fuel after the activation is of 2.49% (Vorobev, Yu. V., 2019).

In addition to bench and road author tests of the activator, where the reduction in the consumption of activated gasoline reached 31.9%, in July 2014, an improved activator (Vorobev, Yu. V., 2019) was tested with the YAMZ-236 diesel. Tests were carried out on three different fuels when installing the activator both in the fuel supply line to the high-pressure (injection) fuel pump and in the drain line. In all cases, the fuel intake for the fuel injection pump was carried out from a laboratory measuring cylinder of 1000 ml. Controlled consumption with an error of not more than 1.25 ml during the operation of the diesel engine for 5 minutes that was controlled by Sospr-2A stopwatch with the accuracy of 0.2 s. At this idling mode of a diesel engine with engine speed of 900-1300 min^{-1}, eleven tests with a single repetition revealed a reduction in fuel consumption on average by 26.3%.

Fig. 7 Scheme of the activator



1 - body; 2 and 3 - screw elements; 4 - cylindrical rod; 5 - disk with microchannels; 6 - cone; 7 - microchannels; 8 - cavitation chamber; 9 - mixer with criss-crossing grids

The decrease of fuel consumption by activator can explain the example of structure conversion of hydrocarbons using a comprehensive exposure in the Scientific Center of Nonlinear wave mechanics and technology at the Institute of mechanical engineering of Russian Academy of Sciences. It has been recorded an increase of the calorific value of gasoline at 28% (**Table 2**). According to A. Shabanov, the St. Petersburg Polytechnic University, the use of other activators saved at least 15% of gasoline. In addition, the reduction in motor fuel consumption is confirmed by the testing of a variety of magnetic fuel activators from Europe, Russia, and the United States since pre-war times.

The uniqueness of the activator is also in the fact that the modification of fuels by it is irreversible, inexplicably enhanced when they are stored. Adding a small amount of activated fuel to the non-activated fuel increases the proportion of the latter in the mixture to its initial level.

Activated fuel slightly reduces the smokiness of diesels, can increase their resource due to easier start-up at low temperatures and reduce carbon formation in the CPG. The activator can be installed on many internal combustion engines and used at gas stations.

Summary

The analysis of own tests, authors of innovations and their followers convincingly shows the presence of new low-cost techniques in the technical service of machines and equipment.

Serpentine compounds can reduce the friction coefficient of steel friction pairs in engine oil from 0.09 to 0.027, bringing the anti-friction properties of average quality oils to the best world results and extending the service life of worn components by 2-3 times.

Emission of electric charges and metal ions into motor and transmission oils reduces the friction coefficient at low loads from 0.096 to 0.037. This allows reducing the consumption of motor fuels by at least 3.2%, in some cases it is up to 17-24.2%. According to operational data, the reduction in the consumption of gasoline, diesel and gas fuel reaches 10-12%. There was slightly improved performance of internal combustion engines and their environmental impact.

Irreversible mechanical and chemical modification with an activator facilitates the fractional composition of motor fuels, creates new hydrocarbons in them up to 37%, reduces their consumption in the internal combustion engine by 2031.9%; purifies fuels from sulfur by 50% and from resins by 7-9 times. Emissions in exhaust gases are reduced: NO by 17%, NO_2 by 14%, CO by 49%, diesel smoke by 7.8%; the freezing point of diesel fuel reaches minus 45 °C.

Proven techniques increase the resource, efficiency and environmental friendliness of machine part containing worn-out machines.

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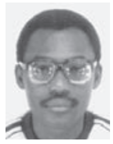
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