DOI 10.22314/2073-7599-2018-12-3-45-52

Tendencies and Prospects for the Development of Domestic Machinery for Sowing Grain Crops

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Abstract. The design of domestic grain drills largely determines the quality of sowing and the effectiveness of technologies for cultivating farm grain and seed crops in general. (*Research purpose*) To consider the development stages of domestic industrial production of grain drills and, in the form of an analytical review, to present the main information a chronological order. (*Materials and Methods*) the authors have conducted an expert analysis of the results of domestic scientists' research on the effect of the surface distribution of seeds on the yield of grain crops and determined general trends in the development of sowing machines, which made it possible to implement various methods of sowing cereals. The authors have also identified the main trends and stages of industrial production of grain drills in the Soviet Union and the Russian Federation. (*Results and discussion*) The contribution of Russian and Soviet scientists to the improvement of grain drills and the issues of the optimization of structural and operational characteristics of sowing units have been analyzed in the paper. The authors have determined and examined the main directions of development of grain drill in the pre-perestroika period, as well as characterized the state of the domestic agricultural machinery industry at the present stage. (*Conclusions*) Basing on the results of the conducted research, the authors have found that the development of grain drill designs in the domestic agrarian market is influenced by various reasons and has several directions. Among the most obvious trends we can single out the following ones: the use of the best foreign samples as prototypes; a tendency to increase the area of plant nutrition; the use of operational experience and comparative test results; optimization of design and technological parameters of drills based on the results of targeted scientific research; the development of machines that ensure the rational utilization of the energy resources used; extending the functionality of sowing machines as a result of combining operations and carrying out sowing on stubble backgrounds.

Keywords: seed drills, seed-sowing units, coulters, seed grain tubes, cereals, row seeding, dispersion sowing, seeding-down, development of designs.

For citation: Nesmiyan A.Yu., Tsench Yu.S. Tendencies and prospects for the development of domestic machinery for sowing grain crops. *Sel'skokhozyaystvennyye mashiny i tekhnologii*. 2018. 13(3): 37-43. DOI 10.22314/2073-7599-2018-12-3-45-52. (In Russian)

The effectiveness of technologies for cultivating grain crops, which form the basis of agricultural production in most developed countries, largely depends on the agrotechnical indicators and the period of sowing. Therefore, the improvement of sowing technology, its constructive refinement, increasing operational and technological indicators has always been and still is an urgent task.

Research purpose is to consider the development stages of domestic industrial production of grain drills and, in the form of an analytical review, to present the main facts in a chronological order.

Materials and methods. For hundreds of years, the main method of sowing in Russia remained manual spreading. The situation changed little towards the beginning of Russia's capitalist development: individual, hand-crafted coulter drills were rare and expensive, so they were used only on large and well-off farms [1]. A more economical direction of seed mechanization was the use of seed spreaders (Fig. 1), which as compared to manual spreading allowed to increase productivity and the uniformity of seed distribution over the field surface and reduce their rate. At the end of the 19th century, the seed spreader of Grinevitsky was widely used and it was produced by several workshops [2]. Since 1900, a new Kiev plant of Filvert and Dedin started producing combined seed drills [3]. However,

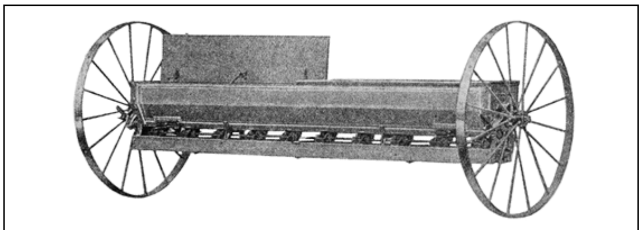

Fig. 1. A wide-track seed spreader

the unevenness of the depth of subsequent seeding significantly reduced the yields, so that their use, and, consequently, production, gradually ceased [4]. Further on, the remaining models were completely converted to fertilizer spreaders, although on some farms they were used as drills until the beginning of the Great Patriotic War.

The industrial production of coulter drills in our country and abroad began in the late 19th century. At that time, several plants were producing sowing machines in Russia, the largest of which was the Elisavetgrad plant (now Chervona Zirka, Kropivnitsky, Ukraine). The factory was founded in 1874 by British businessmen brothers Robert and Thomas Elvorti as a workshop for the repair of agricultural implements, which by the beginning of the 20th century had grown into a large enterprise for the production of horse-driven drills, threshers and oil mills. Light single-row 7-row drills with anchor coulters and a sling harness, a two-horse 11-row seeders with anchor coulters and 12-row seeders with double-disc coulters were in great demand [5].

A special place in the range of agricultural equipment produced at the enterprise was occupied by a wide-gauge seed spreader "Russia" (Fig. 1) with improved coulters and roller sowing machines, which was equipped with an improved device for plowing coulters into the soil. Thanks to its high technological properties, ensuring uniformity and high quality of seeding, the seeder was repeatedly awarded at major trade shows and invariably aroused great interest among both domestic and foreign producers and suppliers of agricultural implements and technical equipment. It was produced until 1927 [6].

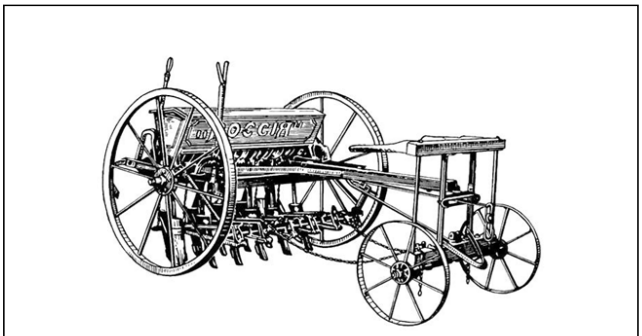

Fig. 2. 11-row coulter grain drill «Russia» (1895)

The drills were also produced by Kharkov Russian-German partnership "M. Gelferikh-Sade "(a serial model of the “Krestyanka” brand), the Bryansk locomotive plant (a model of the "Vernaya" brand), etc. At the First All-Russian Exhibition of seeds and seeding machines, in 1908, seeders from the above-mentioned manufacturers of agricultural machinery and other domestic enterprises were in high demand [7].

Even though Russia entered the phase of capitalist development later than other countries, its production of simple agricultural machines came the third in Europe and the fifth in the world by 1913. The amount of produced units was 59 thousand pcs. a year. Basically, these were horse-driven seed drills, providing an inter-row spacing with an interval of 125-150 mm [7-9].

However, by that time many well-known scientists and production workers (P.A. Kostychev, N.S. Sokolov, V.V. Wiener, and others) noted that the existing arrangement of coulters was not scientifically grounded and was caused, rather, by the need to reduce their possibility of being clogged with stubble residues (mortmass). At high seeding rates, this row spacing results in a decrease in plant productivity due to excessive thickening in rows, and the deviation of the plant nutrition shape from optimum. As early as in 1881, P.A. Kostychev noted that, according to the results of field experiments, the method of sowing with a row spacing of about 75 mm, at the same seeding rates is much more effective than a regular drill placement. Studies on different crops carried out at the Shatilovskaya Experimental Station (1902-1903 and 1910-1911), the Rostov Experimental Station (1913-1917) and later, ensured a significant increase in yield to 20-26% [10].

In the absence of special narrow-row drills, V.V. Wiener (Shatilovskaya Experimental Station) at the end of the XIX century proposed cross sowing as an effective replacement of narrow-drill placement. Numerous studies and production experience have confirmed its effectiveness, but also revealed significant shortcomings: significant energy and labor costs, the influence of the second run of the coulters on the depth of seeding of the first-run seeds and a prolonged sowing period [10].

During the First World War and the Civil War, most of the scientific research was practically stopped, and the production of seed drills stopped completely. Only by 1925 it was again possible to establish a stable level of their output, although it was 1.6 times lower than the pre-war level (35.8 thousand units/year) [7-9].

Machines of that time were distinguished by a wide variety of designs. On the territory of the country there were more than 110 different models of seed drills, which made it difficult to rationally operate them and restrained the establishment of large-scale industrial production. Thanks to the work of the special commission under the leadership of V.P. Goryachkin, the number of perspective seed drill models was reduced to 7. A considerable amount of data, on the basis of which the commission evaluated the drill models and gave an expert opinion, was obtained on the basis of an experimental model developed by V.P. Goryachkin and consisting of a fixed seed drill with a belt conveyor with a sticky surface underneath it [10].

In 1929, the production of tractor drills started at the Krasnaya Zvezda plant in Kirovograd (now Kropivnitsky, Ukraine). In 1931, the plant was completely transferred to the production of 11- and 13-row horse-driven and tractor drills. The second large enterprise specializing in the production of seed drills was the Kherson plant. Later large-scale production of seed drills was also deployed at the Rostov plant of agricultural machines named after I.V. Stalin (now JSC KZ "Rostselmash") [7].

It was planned to establish the production of a 22-row drill by the “Krasnaya Zvezda” plant in Rostov-on-Don. However, the commission of the People's Commissariat of the USSR made a choice in favor of a 24-row seeder with two-disc coulters, a prototype for which was the technical innovation of that time - a grain drill of direct sowing McCormick produced by American agricultural machinery manufacturers in 1927. This decision was due to the results of comparative tests of the models of domestic seed drills and European companies Praner, Melicher and Sakk, as well as American Moline and Massey Harris, which were conducted in Rostov. With a row spacing of 6 inches (152 mm), the McCormic’s direct seeding drill proved to be the most efficient. It was reliable and easy to manufacture and operate, and also featured high performance [11].

The seed drill SD-24 (Fig. 3) of the Rostselmash plant, modeled on the McCormic model, had cast boxes of seeding mechanisms with lower seeding and adjustable bottoms, individual emptying and double disc coulters. Later this model became the basis for the development of various types of seed drills: grain-cotton drill SZH-6, grain-grass drill NWT-47, linseed drill C-47, grain-combined drill SK-24, grain-vegetable drill SOD-24 and others [7, 11].

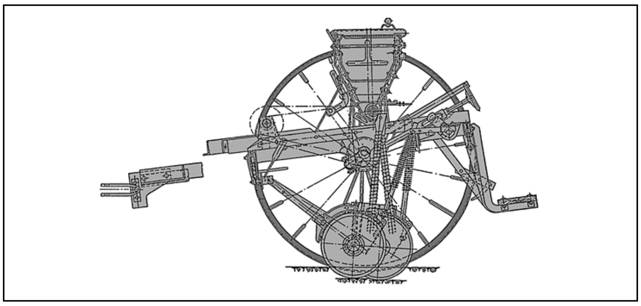

Fig. 3. The grain drill SD-24

Another family of unified seeders was developed on the basis of the seed drill SD-10. It included the grain-and-vegetable drill SOD-10, grain coulter drill SA-12, linen drill SL-17, grain-grass NWT-19, beetroot-grain combined drill SK-10, etc. [7].

Specialists of the “Krasnaya Zvezda” plant also adopted the McCormic drill as a prototype. However, taking into account the experience of designing sowing machines, they did not completely copy it, but made a number of significant changes: they translated the documentation into a metric system, changed individual parameters to those already tested by domestic practice, and made maximum use of specialized units of their own production. As a result, at the end of 1929 the plant produced a T-I series seed drill. By the spring sowing campaign of the following year, the plant produced 750 units of seed drills and sent them for testing in full-scale conditions in almost all soil-climatic zones of the country [11].

Gradually the seed drill was improved, designers developed transient models T-II and T-III on its basis, and by 1931 a model T-IV was prepared for serial production. According to the year plan the plant was to produce 58 thousand seed drills, of which 40 thousand units were of T-IV series [11].

Soon the designers were tasked to develop a seed drill for tractors of SKhTZ, with an engine power of about 30 hp and the S-60 - 60 *hp*. The designed seed drill T-V with a box holding up to 500 kg of grain was too heavy, and its serial production was not approved. Instead, a seed drill T-VII (Fig. 4) was adopted for production, which could be aggregated with the Fordzon-Putilovets tractor (20 hp), and in a double hitch it was possible to use more powerful tractors [11].

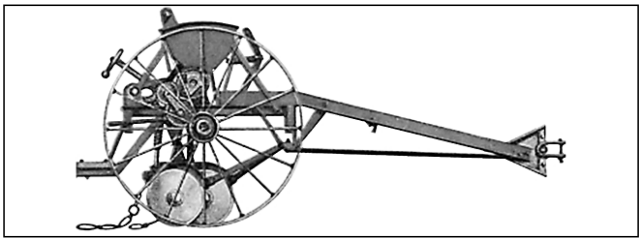

Fig. 4. Grain seed drill T-VII

This seed drill produced by the "Krasnaya Zvezda" plant had stamped sowing units with bottom and top seeding, 24 double-disc coulters with seed feed behind the axis and a seed hopper with a capacity of 240 *kg*. The total width of the seed drill was 3.6 *m*. The seed drill was produced before 1939 [11].

In those years, the research conducted by P.A. Nekrasov in the Moscow region, the specialists of Belarusian Agricultural Institute, Kiev Institute of Scientific Methods of Sowing, the Odessa Regional Experimental Station and other scientists made it possible to address the question of the irrational distribution of seeds on the field surface during drill seeding [10]. In this connection, on the initiative of the engineer and agronomist D.Y. Kamyshchenko, a SKT-52 narrow-row seed drill with two-row coulters (Fig. 5) was developed and in early 1937 the “Krasnaya Zvezda” plant mastered its production [11].

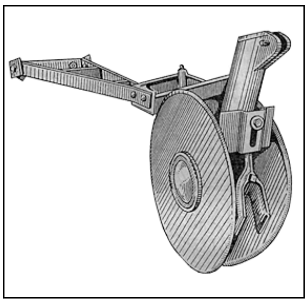

Fig. 5. Two-disc double-row coulter

Practical experience

has shown that the working process of a narrow-row seed drill is characterized by increased energy intensity, the depth of seeding is more uneven, the travel speed of the unit is lower (accordingly, the sowing time is increased) [10]. The use of narrow-row seeders was not completely canceled, but the level of their production and use was significantly reduced.

Results and discussion. By 1939, the country had 607.8 thousand horse-driven and 109.6 thousand tractor-driven seed drills. Moreover, the production of tractor-driven seed drills increased, while that of the horse-driven ones was reduced and completely stopped in the first post-war years [7, 9].

Brief technical characteristics of some seed drills produced in the pre-war years in the USSR [10] are given in Table 1.

Table 1

Technical characteristics of seed drills (the 1930-40s)

Seed drill make	Sowing width, mm	Row spacing, mm	Mass, kg	Traction effort	Sowing units	Coulters
SD-10A	1500	150	350	2, 3 horses	roller feed	double-disc
SA-12	1500	125	350	2 horses	roller feed	anchor-type
SZT-19	1350-1500	75-150	450	2, 3 horses	cast iron roller feed	keel-shaped
SK-10	1500	150	534	4000-5000 N (tractor)	cast iron roller feed	anchor mixed-type
СД-24 SD-24	3600	150	995	4000-5000 N (tractor)	cast iron roller feed	double-disc
T-VII	3600	150	1000	4000-5000 N (tractor)	iron roller feed	double-disc
SZKh-6B	3600-4200	150-654	1245	4000-4500 N (tractor)	special and roller feed	keel-shaped with slides
SK-24	3600	150	1018	4000-5000 N (tractor)	cast iron roller feed	anchor mixed-type
SZT-47	3450-3600	75	1250	4500-5500 N (tractor)	cast iron roller feed	double-disc or keel-shaped
SA-48B	3600	78	995	4500-5500 N (tractor)	steel narrow-typed	double-disc with dividers

At that time, the researchers paid close attention to the continuous (uncontrolled) method of sowing, which has the advantages of both seed spreading, narrow-row, and cross-ways methods, but partially without their shortcomings. Studies conducted in 1949-1957 in the conditions of the Kuban machine testing station, Kherson and Odessa Agricultural Institutes and other places confirmed the economic effect almost equal to the effect obtained with narrow-row sowing. However, it was noted that special paw coulters (Gurnitsky coulters) cannot be effectively applied to soils that are weedy, lumpy and wet (more than 20% moisture), as the energy intensity of the process increases substantially [10].

Since the 1930s, the improvement of grain seed drills was achieved by copying the best foreign samples and practically justified upgrades, and using a deep experimentally confirmed theoretical base. At this time, to the research results of V.P. Goryachkin, B.A. Kril' and others were supplemented by the data of many authors, which made it possible to substantially optimize the design of grain seed drills.

A.N. Karpenko, M.N. Letoshnev and A.N. Semenov, conducted an extensive analysis of the regularity of the volume supply of seeds by the sowing mechanism roller [10, 12]:

$$V_o = l_p\,(\beta z f + \pi d C_{пр}) \qquad (1)$$

where V_o – the amount of seeds fed by the sowing device to the receiving hopper per one revolution of the roller, m^3; l_p – working length of the roller, m; β – filling factor of the grooves; z – the number of grooves; f – cross-sectional area of grooves, *pcs*, m^2; d – external diameter of the sowing roller, m; $C_{пр}$ – reduced thickness of the active layer of seeds, m.

The reduced thickness of the active layer of seeds ($C_{пр}$) depends not only on their physicomechanical properties, but also on many other factors, including the length of the working part of the roller [10]. It was experimentally established that, for example, for wheat this dependence is described by a polynomial:

$$C_{пр} = 0{,}0065\, l_p^2 - 0{,}281\, l_p + 6{,}2075. \qquad (2)$$

Basing on the study results of the seed feeding process, we have proposed the dependences of the roller grooves, which make it possible to determine the working volume of the grooves, for example, according to M.N. Letoshnev's cross-sectional area of the roller grooves [12]:

$$f = \frac{r^2}{2}(\pi - \alpha - \sin(\pi - \alpha)) +$$

$$+ \frac{d^2}{8}(\alpha' - \sin\alpha') + \frac{b^2 - 4r^2(\cos 0.5\alpha)^2}{4\,\mathrm{tg}\,0.5\alpha}, \quad (3)$$

where r, α, α', b – geometric parameters of the roller

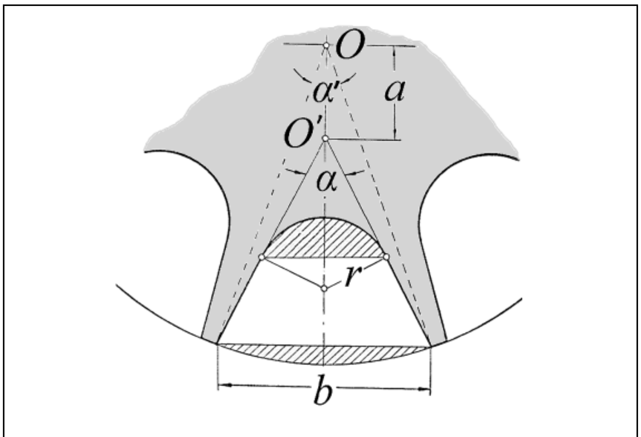

Fig. 6. Scheme for calculating the cross-sectional area of a groove of the seeding unit roller

(Fig. 6).

The performed calculations made it possible to determine the rational parameters of the sowing rollers and seed boxes (the unit casings), and optimize their mutual arrangement.

The influence of the design and parameters of a seed grain tube on seed dispersion has been studied as well, rational parameters of coulter groups, transmission line, and the hopper have been determined, and great attention having been paid to the uniformity of the seeding depth, the rational pressure of the various coulter types on the soil, and the optimization of the sowing units as a whole, with taking into account their kinematic and dynamic characteristics [13, 14].

In the 1950s, on the basis of research and development works, a new family of tractor seeders with improved performance indicators was designed. The basic model of the new family is the unified 24-row grain drill SU-24 (Fig. 7). Its modifications were SUK-24 seeders, narrow-row SUB-48 designs of the Stalin Prize laureate V.D. Bogatchev, SZT-47, SZTK-47, and others (Tab. 2), equipped with disk and tine point coulters [7, 9].

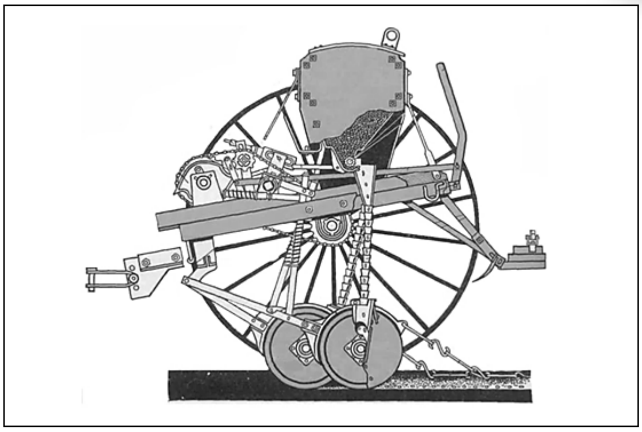

Fig. 7. The grain drill SU-24

In general, by the early 1950s, the prewar level of seed drill production was surpassed by more than 4 times. Thanks to this, mechanization of grain sowing significantly increased (Tab. 3) [7-9].

Table 3

Increase in the level of mechanization in sowing grain crops

Years	1933	1940	1950	1955	1965
Level of mechanization, %	7.0	56.0	74.0	94.0	100

The introduction after 1958 of hinged seed drills SZN-10, SZN-16, SZN-24, SZNK-24. SLN-20, SLM-32, SLN-48 proved to be insufficiently effective for a number of reasons, the main of which were: the impossibility of a simultaneous introduction of fertilizer and seeds and the presence of a hitch in wide-coverage units. The first had to be done to decrease the seed drill weight, the second circumstance nullified the saving of metal during its manufacture [7, 8].

For the areas prone to wind erosion of soil, special machines were developed: a seed drill LDS-4A (the Krasnoyarsk combine plant), a grain seed drill SZP-24 (Krasnaya Zvezda) and a stubble drill SZS-9 (Syzran combine plant) [7, 8, 15].

The development in a short time of machines differing in design and purpose required the implementation of works on the universalization and unification of seed drills on the basis of the latest achievements of science and advanced experience. As a result, there appeared

Table 2

Technical characteristics of some seeders (the 1950s)

Seed drill make	Sowing width, mm	Row spacing, mm	Mass, kg	Performance, ha/h	Traction effort, N	Sowing units	Coulters
SUK-24	3600	150	1014	1.62-2.68	5500	cast iron roller feed	double-disk
SUB-48	3550	68-80	1100	1.62	up to 6000	cast iron roller feed	double-disk with dividers
SZTK-47	3600	Grain 150 Total 75	1330	up to 2.6	up to 6000	roller feed	double-disk and keel-shaped

a family of combined seeders with a high degree of unification with pneumatic wheels, a hydraulic coulter lift, and an improved design of all working bodies. The basic model of this family is the S3-3,6 seeder (Fig. 8),

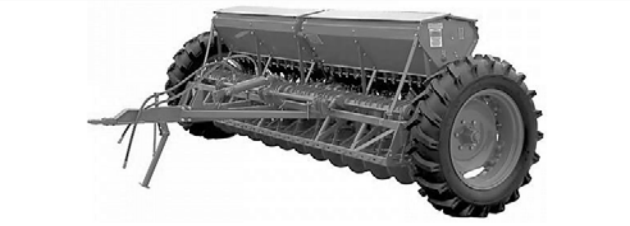

Fig. 8. Grain drill C3-3,6

launched in the production in 1971.

In the no-hitch version, it was aggregated with tractors of 50-82 *hp*.

Its modifications: SZU-3,6 – a narrow-row drill, SZP-3,6 – a press drill, SZA-3,6 – an anchor drill, SZO-3,6 – a single-disk drill SZL-3,6 – a flax drill, SZT-3,6 – a grain- (grassland) drill, SRN-3,6 – a rice drill, SZS-2,1 – a stubble drill, LDS-6 – a seed drill-stubble cleaner; SZG-2,4 – a mountain drill.

The Krasnaya Zvezda, Belinskkselmash and Sibselmash plants mastered the production of modernized grain drills equipped with seven types of working bodies, NWT-3,6A and SZP-3,6A for sowing cereals and other crops in various ways using intensive technologies [7, 9].

On the basis of the S3-3,6A seed drill, a combined seed drill SZK-3,6 was designed to apply the full rate of mineral fertilizers simultaneously with the sowing of grain crops. When a device for the application of a full rate of mineral fertilizers was disconnected, it was transformed into an ordinary C3-3.6A, and with a connected device for sowing grass seeds in NWT-3,6A [7, 9].

For seeders C3-3, 6A, feeding containers (seed boxes) were installed common to all the sowing machines and accommodating the amount of seeds sufficient for 1.5-2 hours of operation.

The volume of the feeding container can be determined by the formula:

$$V = \frac{LBQ}{10^4 \gamma \eta_e}.$$

L – length of the furrow from the filling, *m*;

B – width of machine grip (or row width), *m*;

Q – seeding rate, kg/m^3;

γ – density of seeds, kg/m^3;

η_e – utilization of tank capacity, equal to 0,85-0,9,

In the pre-perestroika years in the early 1980s, grain seed drills of new generations were developed in our country: wide-spread pneumatic stubble drills SZS-14 and SZS-8; wide-spread seed drills-cultivators SZS-12 and SZS-6; no-hitch grain seed -fertilizer drills SZP-8, SZP-12 and SZP-16 capable of being converted into ordinary ones: a combined seed drill SZK-3,3; a modernized rice seed drill SRN-3,6A; a modernized family of seed drills S3-3,6, providing convenient maintenance and increasing the reliability and quality of sowing. The sowing machines were operated with tractors with an engine power from 80 to 240 *hp*. [7-9].

Currently, along with ordinary monoblock seed drills, similar to the SZ and its modifications, sowing machines of centralized sowing and sowing complexes using pneumatic seed transportation are increasingly distributed on the domestic market. In general, in the absence of a planned economy, without a pronounced specialization of farm machinery building enterprises, the variety of manufactured machines has grown substantially. Taking into account the fact that many farms are still using Soviet equipment and various foreign sowing machines, it can be asserted that not a hundred different brands of grain seed drills are present on the market, as it used to be at the dawn of Soviet industrial development, but many hundreds.

Conclusion

Today, the following implements are widely applied in planting technology: systems of process automation and precision farming; multi-row placement of coulters and pneumatic conveying of seeds, which allows to obtain any reasonable row spacing; the use of powerful tractors (up to 530 *hp*) provides seedless sowing on untreated stubble soil, the use of single wide-spread soil cultivating and sowing complexes. But whatever a seed drill of the future might be, its design will be based on the knowledge obtained by many generations of engineers and agronomists living long before us.

In general, the analysis has shown that the development of the design of grain seed drills on the domestic agrarian market is influenced by various factors and it is multi-directional.

The most obvious trends include: the use of the best foreign samples as prototypes; a tendency to increase the area of plant nutrition; the use of operational experience and comparative test results; optimization of design and technological parameters of drills based on the results of targeted scientific research; the development of machines that ensure the rational utilization of the energy resources used; extending the functionality of sowing machines as a result of combining operations and carrying out sowing on stubble backgrounds.

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The paper was submitted to the Editorial Office on 20.03.2018   The paper was accepted for publication on 05.06.2018

Conflict of interest. The authors declare no conflict of interest.