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Revisiting the Choice of the Sowing System of Broad-Cut Seeders

Anatoly Gribanovsky, Askar Rzaliyev, Valeria Goloborodko, Shabden Bekmukhametov, Darkhan Karmanov and Akmaral Sagyndykova
Kazakh Scientific Research Institute of Mechanization and Electrification of Agriculture, LLP (KazSRIMEA), Rayimbek Avenue 312, 050005 Almaty, Kazakhstan

Abstract: The basic requirements for seeding grains when cultivating them in dry steppe areas of Kazakhstan are presented. The analysis of correspondence of different types of sowing systems for broad-cut seeders with these requirements is given. The main results of studies on the choice of pneumatic sowing systems are specified. The factors that do not allow the required uniformity of seed distribution between openers to be achieved are established. A combined pneumatic and mechanical sowing machine for distribution and conveying of seeds to openers is proposed for broad-cut seeders. The proposed sowing system was used in the development of SKBM-12 block-modular cultivator drill. The main results of acceptance tests of SKBM-12 which confirmed the high technological efficiency of the combined pneumatic and mechanical sowing system for broad-cut seeders are presented.

Key words: Seeding, agro-technological requirements, sowing rate, seed distribution, centralized sowing system, acceptable non-uniformity, common dispenser, individual coil dispenser, horizontal distributor, turbulator, pneumatic conveying line, compensating tank, openers

INTRODUCTION

A significant part of the grain area of Kazakhstan is located in zones characterized by the rough continental climate, strengthened wind conditions and low rainfall. The cultivation of grains without taking into account these features leads to wind erosion and as a result to a total loss of soil fertility. Therefore, machines and equipment performing a particular technological operation in the cultivation of grains should be adapted to these conditions. In the cultivation of grains, the most severe agro-technical requirements are applied to sowing machines which should provide the qualitative performance of the technological operation on seeding with no-tillage or minimum tillage seeding (Baker *et al*., 2007).

The purpose of seeding is to lay the basis for the optimum use of the potential yield of area-specific grains in specific soil and climatic conditions by means of uniform distribution of their seeds per area unit and at a predetermined depth to create equal opportunities for the development of each of them.

In order to determine numerical values of indicators of agro-technological requirements for grain seeding in the conditions of North Kazakhstan, the long-term studies were performed by the All-Union Scientific Research Institute of Agriculture (now Barayev Kazakh research institute of grain farming) which established the following (Suleimenov 1988; Akulov, 1976; Fogel, 1974).

The optimum period for grain seeding regardless of the degree of spring soil moistening is from May 15-24, since in the case of earlier sowing seedlings can be exposed to drought in June while in the case of later sowing seedlings can be exposed to frosts in August. When cultivating area-specific variety of grain legumes, the following sowing rates (kg/ha) should be provided: wheat, barley, Rye-50, 245; Oat 100-250; Pea 80-300; Buckwheat 30-80 as well as the subsurface application of granular fertilizers of 50-200. The deviation of the actual total sowing of seeds from predetermined rates should be >±4% for grains, ±10% for fertilizers.

As a result of studying the effect of sowing non-uniformity, it is found that due to non-uniform completeness of seedlings, the predetermined deviations of sowing density are subject to certain changes. A significant non-uniformity of productive plant stand density remained unchanged only at sowing non-uniformity of ±(12-15) and was ±(6.4-8.8)% (Table 1). In addition, the grain content and weight of 1000 grains appeared to be uniform.

Corresponding Author: Askar Rzaliyev, Kazakh Scientific Research Institute of Mechanization and Electrification of Agriculture, LLP (KazSRIMEA), Rayimbek Avenue 312 , 050005 Almaty, Kazakhstan

Table 1: Spring wheat yield non-uniformity depending on sowing non-uniformity

Sowing non-uniformity (%)	Yield (center/ha)	Yield non-uniformity (%)
0	21.2	1.8
3	21.0	2.8
6	21.3	5.8
9	20.9	6.4
12	20.5	8.8
15	20.7	6.4

The biological yield of spring wheat per row is non-uniform because of the difference of productive plant stand density but the total yield per area has a tendency to leveling. When sowing non-uniformity is <±6%, mean yield non-uniformity is 2 times lower than in the case of sowing non-uniformity of ±(9-15)%. For this reason, it was recommended to establish ±6% as an acceptable sowing non-uniformity limit which was approved in the development of agro-technical requirements for seeders.

In addition, seeders should provide: depth of grain legume seed placement within 4-8 cm. In this case, 80% of seeds should be in the layer corresponding to the mean predetermined depth and two adjacent horizons of 1 cm as a deviation from the predetermined depth of seed placement of >±10 mm results in the loss of about a quarter of the yield (Chernoivanov *et al*., 2012, Conceicao *et al*., 2016).

Optimum soil density (1.1-1.3 g/cm^3) in the area of seed placement (Fogel, 1974; Crabtree *et al*., 2014); Preservation of at least 70% of crop residues of the original amount on the surface of the field; Maintenance or decrease in the amount of erosion threatening soil particles to <1 mm in a layer of 0-5 cm from the initial level.

In the case of tight agro-technical deadlines of grain seeding on large areas, seeders should be of high productivity that is achieved by increasing its speed and sowing width. However, when the sowing width of the seeder with dispensing and distribution of seeds and fertilizers between openers through individual coil dispensers increases, the length of the tank is required to be approximately equal to the sowing width of the seeder. In this case, it is impossible to increase substantially the capacity of such tanks for obvious reasons. Consequently, the sowing width of seeders is reduced and the efficiency of the use of change-over time of such units due to the necessity to load their tanks with seeds and fertilizers decreases significantly.

In order to remove this defect of broad-cut seeders, high-capacity centralized tanks for seeds and fertilizers as well as pneumatic sowing systems (CSS) are widely used (Trends of the development of agricultural equipment abroad 2014; Based on materials of the international exhibition of “Agritechnika 2003”, Hannover, Germany, November 9-11, 2003 Moscow, FGBNU “Rosinformagrotech”, New equipment for an agro-industrial complex in 2005. Based on materials from the 6th Russian agro-industrial exhibition “golden autumn”, Moscow FGBNU “Rosinformagrotech”.

MATERIALS AND METHODS

From the above it follows that broad-cut seeders include two systems of dosing and feeding of seeds and fertilizers into openers: mechanical system using an individual coil dispenser for each opener; Centralized Sowing System (CSS) with pneumatic distribution and conveying of seeds and fertilizers to openers.

As shown by numerous studies (Kardashevsky, 1973; Buzenkov and Ma, 1976; Matyushkov and Bykhalov, 1987; Blednykh, 2007; Evchenko *et al*., 2007; Gribanovsky *et al*., 2007; Sharshukov, 2005) each of these systems has both advantages and disadvantages. Therefore, in order to choose the sowing system which would satisfy agro-technological requirements applied to the quality of seeding by broad-cut seeders, it is required to analyze the results of studies and tests of these systems and choose the most effective one.

When conducting theoretical studies of sowing systems, the authors used classical provisions of theoretical mechanics, the theory of machines and mechanisms, continuum mechanics, fluid mechanics, agricultural mechanics. Experimental studies of sowing systems were conducted using specifically developed laboratory or laboratory and field units or industrial samples of seeders with appropriate measuring instruments and equipment. For example, in the studies of two-component flows in pipelines, the radiometric method was used. Experimental data was processed by the authors using well-known methods of mathematical statistics.

The acceptance tests of SKBM-12 block-modular cultivator drill which uses the proposed combined pneumatic and mechanical sowing system, were carried out according to Interstate standard GOST 31 345-2007 tractor seeders, test methods. Therefore, the accuracy of results of these studies and tests is out of any doubt and they can be used when choosing the effective sowing system for broad-cut seeders and its assessment.

RESULTS AND DISCUSSION

Broad-cut seeders available in the world at present can be divided into three types: drills with individual mechanical sowing coil units. They provide not only a predetermined rate of seed sowing but also non-uniformity of seed distribution between openers accepted (±6%) by the agro-technological requirements (Kardashevsky, 1973; Buzenkov and Ma, 1976). For this reason, drills with individual coil dispensers and pneumatic conveying of seeds and fertilizers along openers were produced-Tive seeder (Sweden), SUP-48 seeder (Romania), etc. These drills provide non-uniform seed distribution between openers within ±(5-6)% (Matyushkov and Bykhalov, 1987). However, due to the large number of dispensers equal to the number of openers, they are difficult in terms of construction and have a limited sowing width-no more than 6 m.

Drills with the centralized sowing system with the group coil dispenser and single-stage pneumatic conveying and distribution of seeds and fertilizers between openers using Accord dividing heads "Morris-620" model (Canada), models of Accord and Horch (Germany), Ural tillage-sowing units PPA-5,4 and PPM-14.7 (Russia) (Blednykh *et al*., 2007), etc. Studies associated with the search of technical solutions in order to improve the uniformity of seed sowing using seeders of this type are in progress (Evchenko *et al*., 2007).

Drills with the centralized sowing system with one or two group dispensers and coil two-stage pneumatic distribution and conveying of seeds and fertilizers along openers using Accord dividing heads of first and second stages of distribution-models of Flexi-Coil (Canada), Connor-Shia (Australia) as well as SZS-14 direct grain drill developed by the Main Specialized Design Engineering Department for Erosion Control Equipment (Tselinograd).

In drills with the centralized sowing system of second and third types, materials are fed from tanks to the common coil dispenser and then to the feed chamber. In the chamber, they are picked up by the fan air flow and directed by reflecting from its cover (divider) to the head of the first stage of distribution through the tube installed vertically and distributed between seed tubes leading to openers or directly between openers (second type of drills) or to heads of the second stage of distribution and then to openers (third type of drills).

For the purpose of air-seed-fertilizer flow turbulence and feeding to the center of the dividing cone of the head, tabulators made in the form of rings or corrugations are placed on the inner surface of central supply tubes and conical dividers for flows of mixtures of different form are mounted on covers of heads which centers can be shifted against the vertical axis of the supply tube. Due to these devices, it is possible to reduce a little non-uniformity of seed distribution between openers in drills of such type (Matyushkov and Bykhalov, 1987). But in the case of planting of different crops and different sowing rates, the acceptable non-uniformity (±6%) was not achieved even in laboratory conditions (Table 2).

The reason is as follows. It is known (Zuyev, 1976) that the stable conveying of bulky materials through pipelines depends on the carrying air flow rate V and concentration factor of seed air flow μ, i.e., on the ratio of mass flow rate of the material transported to the mass flow rate of the carrier medium as well as on the suspension velocity of seeds and fertilizers. The effect of sowing rates for different crops and carrying flow for seed tubes with CSS on the conveying speed and concentration factor was established (Gribanovsky *et al*., 2007) (Table 3).

At accepted delivery rates of air flow (carrying flow rate V = 15.9-31.0 m/sec) and sowing material (sowing rate), values of concentration factors on the vertical part of the pipeline varied from 0.32-1.68 in the case of pea sowing and from 0.36-1.38 in the case of wheat sowing. On the horizontal part of the pipeline at the carrying flow rate V = 10.9-22.0 m/sec, concentration factors varied from 0.36-1.95 in the case of pea sowing and from 0.40-1.47 in the case of wheat sowing. At specific combinations of values of the carrying flow rate and

Table 2: Non-uniformity of seed distribution between openers by drills of second and third types at different sowing rates

	Seeders and crops sown								
	Connor shea			Flexi-coll			SZS-14		
Indicators	Wheat	Barley	Oat	Wheat	Barley	Oat	Wheat	Barley	Oat
Minimum sowing rate (kg/ha)									
Predetermined	50.0	-	80.0	50.00	50.00	50.00	50.0	50.0	50.0
Actual	48.8	-	79.2	54.10	51.00	49.30	52.7	50.4	47.7
Non-uniformity of seed distribution between openers (%)	7.4	-	7.6	10.91	10.37	19.13	10.0	12.7	14.0
Mean sowing rate (kg/ha)									
Predetermined	130.0	-	130.0	130.00	150.00	130.00	130.0	150.0	130.0
Actual	134.4	-	138.0	132.60	151.00	132.00	125.0	142.0	123.2
Non-uniformity of seed distribution between openers (%)	4.7	-	7.8	10.45	11.78	21.29	11.3	10.0	13.5
Maximum sowing rate (kg/ha)									
Predetermined	250.0	-	250.0	250.00	250.00	250.00	250.0	250.0	250.0
Actual	200.0	-	160.0	252.10	248.50	173.00	245.0	236.8	202.0
Non-uniformity of seed distribution between openers (%)	5.8	-	7.2	12.30	12.10	16.50	8.1	11.3	15.3

Table 3: Conveying speed for pea (V_p), wheat (V_w) seeds, concentration factors (μ_p and μ_w) at different sowing rates and carrying flow rates (V)

Pipeline/carrying flow rate V (M/C)	Pea: Conveying speeds and concentration factors (V_p/μ_p) at sowing rates (kg/ha) 100	200	300	Wheat: Conveying speeds and concentration factors (V_w/μ_w) at sowing rates (kg/ha) 110	180	250
Vertical Ø 120 mm						
31.0	9.56/0.32	8.10/0.64	7.84/0.96	13.68/0.36	12.25/0.58	11.90/0.80
29.0	9.00/0.34	7.59/0.68	7.27/1.02	13.20/0.39	11.37/0.62	11.06/0.85
27.0	8.70/0.37	6.93/0.72	6.65/1.09	12.7/0.410	10.20/0.67	9.74/0.93
25.0	7.06/0.40	6.50/0.80	6.00/1.20	11.7/0.440	8.90/0.72	8.64/1.00
21.5	5.58/0.43	4.80/0.86	4.50/1.29	9.80/0.51	8.40/0.84	8.18/1.17
20.0	4.81/0.48	4.26/0.96	4.03/1.44	8.40/0.55	7.60/0.90	7.50/1.25
19.0	-	-	3.09/1.68	7.0/0.580	6.50/0.95	6.26/1.32
18.0	3.94/0.58	3.46/1.16	*	-	5.56/1.00	*
16.4	2.59/0.61	2.98/1.22	*	5.20/0.67	*	*
15.9	2.10/0.63	*	*	4.70/0.69	*	*
Horizontal Ø 67 mm						
22.0	8.53/0.36	7.50/0.72	6.85/1.08	11.22/0.40	9.60/0.66	9.05/0.92
20.2	8.20/0.40	7.15/0.80	6.42/1.20	10.70/0.44	9.0/0.720	8.92/1.00
18.6	7.06/0.43	6.0/0.86	5.46/1.29	9.87/0.48	8.26/0.78	8.06/1.08
17.1	6.43/0.47	5.71/0.94	5.10/1.41	9.30/0.52	7.45/0.85	7.46/1.18
14.7	5.30/0.51	4.98/1.02	3.96/1.53	8.70/0.56	6.45/0.92	6.58/1.28
13.6	4.80/0.59	4.10/1.18	3.29/1.77	7.60/0.65	4.92/1.06	2.77/1.47
12.3	-	-	2.23/1.95	5.80/0.72	3.36/1.18	*
11.7	4.02/0.69	3.31/1.38	*	-	2.66/1.24	*
11.2	3.44/0.72	2.32/1.44	*	4.50/0.79	-	*
10.9	2.98/0.74	*	*	3.40/0.81	-	*

concentration factor, the conveying speed reduces which leads to the termination of the stable conveying process.

The concentration factor depends not only on the sowing rate and carrying flow rate but also on the speed of the unit. When increasing or decreasing the speed of the unit, the weight of seeds fed per time unit changes at the constant rate of carrying flow generated by the fan which speed is constant, since it is driven by the PTO shaft of the tractor. Calculations show that with increasing the speed of the unit from 3.6-10.8 km/h, the concentration factor increases by about three times. Therefore, the amount of seeds fed to distribution heads will change as well which leads to an increase in non-uniformity of seed distribution between openers.

It was established (Gribanovsky *et al*., 2007) that overall pressure losses in the pipeline of grain air flow also depend on the carrying flow rate and sowing rate (Table 4). In the vertical pipeline with increasing the air flow rate from 15.9-31.0 m/s and sowing rates for pea and wheat seeds from 100-300 and from 110-250 kg/ha, respectively, pressure losses ΔP/m of path increase by 1.5-2.0 times along with this losses increase most extensively at low sowing rates since in this case the conveying speed is greater and the concentration factor is less (Table 3). For this reason, the loss proportion of ΔP_p and ΔR_w reduces from 30-40 to 5-20% of overall pressure losses ΔP. If losses ΔP_p and ΔP_w reach 40-50% of overall pressure losses ΔP, stable conveying is terminated. At the same time, regardless of seed sowing rates, pressure losses ΔP_p and ΔP_w have a minimum value at the carrying medium rate V = 21, 5-27, 0 m/sec.

In the horizontal pipeline, with increasing the carrying flow rate from 10.9-22.0 m/sec and sowing rates for pea and wheat seeds within the above range, pressure losses ΔP per 2.5 m of path increase by 1.5-2, 5 times and losses increase most extensively at lower sowing rates. When the carrying flow rate increases, the loss proportion of ΔP_p and ΔP_w reduces from 7.0-10.0 to 0.6-1.0% but when sowing rates increase, it increases from 1.0-10.0-3.5 26.0%. In this case, if the proportion of pressure losses ΔP_p and ΔP_w is 22.0-40.0% of overall pressure losses, the process of seed conveying is terminated. Regardless of the sowing rate such ratios of $\Delta P_p/\Delta P$ and $\Delta P_w/\Delta P$ were obtained at the carrying flow rate V = 13.6 m/sec. Thus, in order to ensure the predetermined sowing rates for pea and wheat seeds and stable conveying of seeds to distribution heads of the second stage of distribution, the carrying medium rate should be within V = 21.5-27.0 m/sec in ⌀120 mm vertical pipelines and in ⌀67 mm horizontal pipelines for the delivery of seeds to openers it should be within V = 17.0-19.0 m/sec.

The length of pipelines from distribution heads to openers will be different for obvious structural reasons-the further the opener is from the distribution head, the longer the pipeline is. This increases the non-uniformity of sowing material distribution between openers as openers with shorter pipelines will receive more material.

Table 4: Specific pressure losses in pipelines of grain air flow (ΔP) associated with the presence of pea (ΔP_p) and wheat (ΔP_w) seeds in it at different carrying medium rates and seed sowing rates

	Pea			Wheat		
	Specific pressure losses $\Delta P/\Delta P_p$ (Pa) rates (kg/ha)			Specific pressure losses $\Delta P/\Delta P_w$ (Pa) at sowing rates (kg/ha)		
Pipeline/carrying flow rate V (m/sec)	100	200	300	110	180	250
Vertical Ø 120 mm						
31.0	248.6/30.5	288/58.6	303/81.3	252.6/13.8	276/42.9	288.6/60.6
29.0	230/21.7	263/48.3	286/70.5	243.5/10.4	257.4/4.35	271.4/46.5
27.0	204.5/16.3	243/40.0	267/58	212/6.2	230.3/29.7	248.8/35.7
25.0	182.6/15.5	221/37.4	247.3/49.0	187/3.6	213/29.3	228/33.6
21.5	145/16	183.2/46.0	216/73.2	167.8/6.8	192/31	205.2/39.3
20.0	125.4/19.4	170.4/53.6	204.7/83.1	137/6.0	163.5/40.5	179.3/54.7
19.0	120/26.7	-	212.3/97.4	126/10.8	149/47.7	188/74.9
18.0	-	162.4/68.5	*	-	152.3/57.8	*
16.4	116.3/35.0	166/82.7	*	*	*	*
15.9	117.2/39.6	*	*	*	*	*
Horizontal Ø 67 mm						
22.0	178.6/1.6	182.4/4.3	201.4/12.0	171.5/1.0	175.9/2.9	183.6/6.4
20.2	158.7/2.7	164/6.0	187/16	152.5/1.5	155/3.7	162/7.2
18.6	143/4.4	148/8.0	172.8/19	135/1.5	140.1/4.1	161.2/9.1
17.1	127.1/3.1	135.1/12.3	161.4/21.6	119.5/5/19	125.4/5.4	139/10.4
14.7	98.5/4.2	107.4/14.0	137.4/28.2	105.9/2.6	113/6.3	122.1/13.2
13.6	88/6.7	101.1/18.4	127.8/33.8	83.8/4.8	89.3/9.3	99/17
12.3	-	-	132/40.6	71.4/6.9	79/14	104/23.4
11.7	74.7/7.0	87.7/20.4	*	-	81.5/18.0	*
11.2	72/16.4	89/35.7	*	66.5/11.0	*	*
10.9	72.8/20.8	*	*	68/14	*	*

*Stable conveying is terminated

During the movement of the unit on uneven surfaces of the field, drill frames execute vibrations in different planes. Pipes delivering a multicomponent mixture to distribution heads having inner diameters of 70-120 mm and rigidly connected to the frame of drills deviate from the vertical position increasing the non-uniformity of flow distribution along their cross-sectional area. In order to reduce the negative effect of vertical deviation of the central pipe on non-uniformity of sowing material distribution along laterals of Accord heads, it is recommended (Sharshukov, 2005) to use the high-load horizontal dispenser, in which sowing material supplied by air flow is divided into two parts by the partition edge. In the first part made according to the principle of a diffusor, the preliminary distribution of flow is performed. Reflecting from front plates, the air-seed-fertilizer mixture is delivered to the upper and lower plates of the second part made according to the principle of a confusor and flows leaving them are mixed and fed to lateral pipelines. Sowing rates of grain and legume crops and fertilizers fall within the range of 50-300 kg/ha.

The pneumatic conveying of such amount of the material is carried out by air flow at a rate not <15-30 m/sec. At such amount of the feed material and air flow rate values, the concentration factor of a two-component flow of the mixture is within the range from 0.32-1.95. In such case, solid particles of a two-component flow in the horizontal conveying line of the horizontal divider are transferred on its bottom part of the cross-section area (Gribanovsky *et al*., 2007). Thus, the partition edge placed in the center of inlet pipe of the horizontal divider cannot divide the mixture flow equally which affects the uniformity of material distribution in outlet pipes. As mentioned above, the significant difference in 1.5-2 times of the air tube length conditioned upon the drill opener position in relation to each head of the second distribution stage as well as upon different value of pressure losses contributes to the distribution non-uniformity of sowing materials between openers. Elimination of the above mentioned deficiencies is practically impossible because it is necessary to regularly change the length and diameters of air tubes in the course of researches depending on the carrying flow rate, seed type and sowing rates, etc.

As the required uniformity of distribution on the feeding area cannot be reached by clearly pneumatic distribution of sowing seeds, the pneumatic seed-spacing units are developed for sowing of seeds of technical, vegetable and legume crops. These units are difficult in configuration and each is installed for seed feeding to only one or two openers (Yazgi and Degirmencioglu, 2014; Karayel, 2009). The application of such difficult sowing units during cultivation of the aforesaid crops is justified, because in comparison with grain crops they are cultivated on small areas and have higher yield and selling price per unit of products.

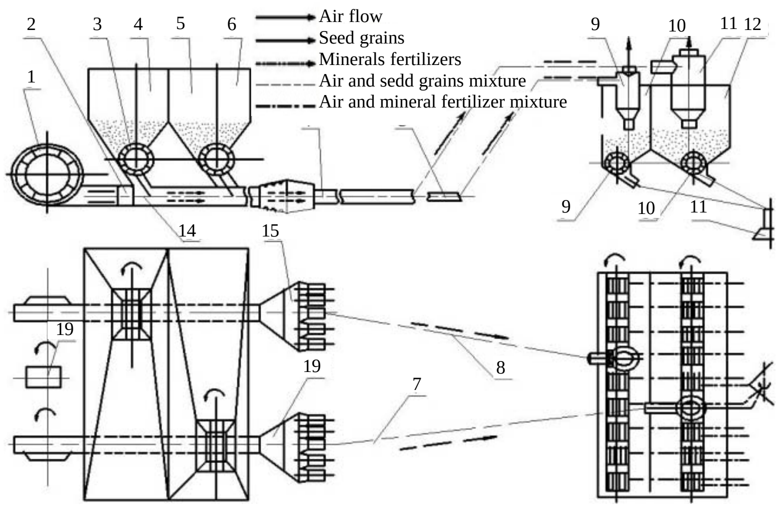

Fig. 1: Combined pneumomechanical seed feeding system: 1-fanner; 2-inlet chamber; 3-reel dispenser for seeds; 4-tank for seed; 5-tank for mineral fertilizers; 6-reel dispenser for mineral fertilizers; 7-seeds line: 8-mineral fertilizers line; 9-cyclone discharger for mineral fertilizers; 10-tank compensator for mineral fertilizers; 11-cyclone discharger for seeds; 12-tank compensator for seeds; 13-reduction gearbox; 14-air duct reducer unit and diffuser of inlet chamber; 15-horizontal distributor of seeds; 16-individual reel dispenser for mineral fertilizers; 17-individual reel dispenser for seeds; 18-opener and 19-mineral fertilizers horizontal distributor

Due to such fact that the elimination of defects in broad-cut seeders with centralized sowing systems is practically impossible for the reasons given above; it is proposed to use the combined pneumatic and mechanical sowing system in such drills.

The proposed combined pneumatic and mechanical sowing system (Fig. 1) includes: centralized seed Tank (4) and fertilizer Tank (5) where general coil dispensers (3) and (6) are installed; feed chambers (2), consisting of convergent tube and diffuser (14); two high-pressure fans (1) which are driven by PTO shaft and reduction gear of the tractor (13); two horizontal high-pressure seed spreader (15) and fertilizer spreader (19), feeding the sowing materials by conveying lines (7) and (8) to the second distribution stage. Horizontal seed and fertilizer spreaders have a number of outlet pipes equal to a number of narrow-cut till-plant section-modules.

Typical seed and fertilizer tanks (compensators) for seeds (12) and fertilizers (10) with individual coil dispensers (16) and (17) which number is equal to a number of openers of the section-module are used as the second distribution stage.

Unloading cyclones (9) and (11) of respective capacity are installed on seed and fertilizer tanks (compensators) of the second distribution stage in order to divide the air flow and sowing materials. Individual coil dispensers of seed and fertilizer tanks feed seeds and fertilizers to the seed tubes which come to the openers (18) by action of gravity.

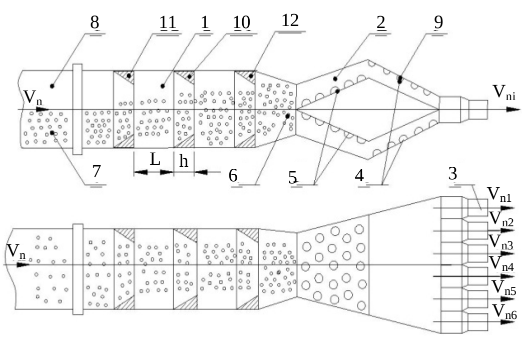

Fig. 2: Horizontal distributor of seeds and mineral fertilizers: 1-inlet elbow; 2-body; 3-outlet elbow; 4-distribution plate on air duct reducer unit; 5-distribution plate on diffuser; 6) rhombic baffle; 7-seeds (mineral fertilizers) airline; 8-pneumatic conveying line; 9-spherical reflector; 10-vortex generator; 11-input vortex generator; 12-output vortex generator

The following modifications are introduced into the spreader in comparison with the proposed one (Chernoivanov *et al*., 2012) in order to reduce the non-uniformity of mixture distribution between outlet pipes of the horizontal high-pressure seed and fertilizer spreader (Fig. 2).

The proposed horizontal spreader consists of the inlet pipe (1) and outlet pipes (3), body (2) and rhombic partition (6) installed at a height of 0.5 diameter of the inlet pipe and dividing the internal cavity into upper and lower parts. The distributing plates (4) and (5) with spherical reflectors (9) are installed on walls (7) of the body (2) and partition (6) which are directed to the flow of air-seed-fertilizer mixture. The feeding pneumatic conveying line (8) is connected to the inlet pipe (1).

The inlet pipe (1) is equipped with ring turbulators (10) which are in the shape of truncated hollow cone and are installed at specific intervals between each other. Thus turbulators are directed toward the mixture flow with large diameters of rings of the truncated cone which is equal to the internal diameter of the inlet pipe in order to reduce the risk of seed damage. The minimum diameter of truncated cone of the first inlet turbulator (11) (first from the side of direction of the mixture flow) has a greater value, than that of minimum diameter of the outlet turbulator (12).

The air-seed-fertilizer flow (7) which solid particles are transferred as described above on the bottom part of the pneumatic conveying line, is fed by the pneumatic conveying line (8) and comes to the inlet pipe (1) with turbulators (10) enhancing the flow turbulence. Due to such fact that the minimum diameter of truncated cone in the inlet ring turbulator (11) is greater than that of the outlet turbulator (12), solid particles of the multi-component mixture (7) are centered and more evenly distributed on a cross-section area of the outlet hole of the inlet pipe (1). So the rhombic partition (6) of the proposed horizontal spreader of bulk materials will divide the mixture flow into equal parts between upper and lower cavities of the spreader, thus creating practically equal conditions of the seed and fertilizer movement which makes it possible to reduce the non-uniformity of flow distribution between outlet pipes (3) as opposed to existing spreaders.

The proposed combined pneumatic and mechanical sowing system will operate properly, if the number of seeds and fertilizers fed by the central coil dispenser is equal to the number of material sowed by individual coil dispensers of technological modules.

It is well known (Kardashevsky, 1973; Buzenkov and Ma, 1976) that coil dispensers of drills ensure predetermined sowing rates of seeds with a variability of the general sowing of ±2%. The non-uniformity of distribution of sowing material between outlet channels of the horizontal divider as described above may reach ±10-15%. In this respect, there is a possibility that this condition may not be fulfilled. The tanks of technological modules of the proposed pneumatic and mechanical sowing system should play a role of compensators in order to reduce this possibility, i.e., they are filled with seeds to approximately 1/4 of its full capacity before operation. However, the difference in the number of feed and expendable materials during long-term operation of the unit may lead to the overflow or emptying of compensating tanks of several modules. Hence, it is reasonable to determine the time intervals, for which the early emptying or overflow of compensation tanks of modules occurs.

It is assumed that the broad-cut seeder consists of six technological section-modules. The capacity of seed compensation tank of the module is 276 dm^3 and the seed amount in the tank is to be equal to 220.8 kg with account for wheat density. If the one fourth of this amount of seeds (55.2 kg) is used as compensation amount, the "working" amount is to be 165.6 kg. If the sowing width of the technological module is 2 m and there are six section-modules, the sowing width of seeder is 12.0 m. It is assumed that the unit speed is 10 km/h and the seed sowing rate is 250 kg/ha.

Taking into account these accepted assumptions, the unit capacity per hour of net operating time is to be 12 ha h^{-1}. So the centralized coil dispenser should feed 3,000 kg/h to the horizontal divider or 2,940-3,060 kg/h with account for variability of the general sowing (±2%) and to each of six outlet pipes of the divider -490-510 kg/h.

It is assumed that 490 kg/h is supplied to one of outlet pipes of the horizontal divider and 510 kg/h is supplied to another one. Then in case of non-uniformity of seed distribution between outlet pipes in the amount of ±15%, 490±(490×0.15) may be supplied to one of tanks of the technological module, i.e., 416.5-563.5 kg/h and 510±(510×0.15) may be supplied to another one, i.e., 433.5-586.5 kg/h.

We assume the unfavorable combination of events: the minimum amount of seeds of 416.5 kg/h is to be regularly supplied to one compensating tank of the module and the maximum amount of 586.5 kg/h is to be supplied to another one. Taking into account the accepted unit speed of 10 km/h, sowing rate of 250 kg/h and sowing width of the section-module of 2.0 m, the number of expendable seeds per hour of net operating time of the unit is to be 500 kg/h or 500±(500×0.2), i.e., 490-510 kg/h with account for variability of the general sowing by coils.

In order to calculate the time necessary for occurrence of the situation of early emptying or overflow of the module tank, we should take the very unlikely combination of events: the minimum amount of seeds of 416.5 kg/h is supplied to one compensating tank and the maximum amount of 510 kg/h is expended, i.e., the deficient amount of seeds is 93.5 kg/h; the maximum amount of seeds of 586.5 kg/h is supplied to another tank and the minimum amount of 490 kg/h is expended, i.e., the deficient amount of seeds is 96.5 kg/h.

Taking into account the “working” amount of seeds in the compensating tank of the module, the early emptying occurs in 165.6: 416.5 = 0.4 h and the overflow-in 165.6: 586.5 = 0.28 h. So in the first case for 0.4 h of net operating time of the unit, the seed deficiency is to be 93.5×0.4 = 37.4 kg and in the second case the seed deficiency is to be 96.5×0.28 = 27.02 kg. If the “working” amount of seeds in the tank is 165.6 kg, then the early emptying occurs in 165.6: 37.4 = 4.43 h and the overflow-in 165.6: 27.2 = 6.13 h.

Having performed similar computations for application of a starting dose of fertilizers simultaneously with sowing, we obtain that the early emptying of the module fertilizer tank occurs in 3.8 h and the overflow-in 5.4 h. The coincidence of events accepted in the computation is unlikely because the variation of sowing rates of seeds and fertilizers by coil dispensers and the non-uniformity of distribution between outlet pipes of the horizontal divider are occasional processes in which the numerical values change in relation to the average value downward or upward. Consequently, it can be assumed with great probability that the early emptying or overflow of tanks of technological modules will not occur during the entire period of shift work (10 h).

The developed combined pneumatic and mechanical sowing system is used in the process of creation of series of block-modular cultivator drills to tractors of different classes, including SKBM-12 to class 5 tractor (Fig. 3). The novelty of technical solutions used during their creation is protected with five patents of invention of the Republic of Kazakhstan including 2 patents on combined pneumatic and mechanical sowing system.

Results of acceptance tests of SKBM-12 carried out by Kostanay Branch of “Research and Production Center of Mechanization and Electrification of Agriculture” LLP, an accredited testing center, (protocol No. 228-428-2011 dated October 10, 2011) have demonstrated the following. Seed and fertilizer dispensers of tanks of the Centralized Sowing system (CWS) ensure sowing rates of wheat seeds (variety “Omskaya 29”) and granulated mineral fertilizer (superphosphates). The maximum sowing capacity of wheat is 256.5 kg/ha, the minimum sowing capacity is 48.6 kg/ha and those of superphosphate are 206.3$kgha^{-1}$ and 4.48 kg/ha, respectively which fall within acceptable limits of deviations from predetermined sowing rates (±5%).

If the domestic sowing rate of wheat is 160 kg/ha, the deviation from actual sowing value is +2.4%. The non-uniformity of seed sowing by pipes of the horizontal divider is ±11.3%. The variability of general seed sowing by the dispenser of seed tank is ±1.7% that is lower than the acceptable one (±2.0%). If the domestic sowing rate of superphosphate is 80 kg/ha, the deviation of actual

Fig. 3: Modular cultivator drill SKBM-12 with tractor belarus 3022DV; a) General view; b) In operating position

sowing value from the predetermined one is +2.4%. The non-uniformity of fertilizer sowing between pipes of the horizontal divider is ±13.6%.

The variability of general sowing value is ±6.0% that is lower that the acceptable one (not more than ±10%). Coil sowing units of compensation tanks of the technological modules ensure the maximum sowing rate of wheat of 252.8 kg/ha (deviation of ±1.1%) and the minimum sowing rate of 47.8 kg/ha (deviation of -4.4%); the maximum application rate of superphosphate of 203.9 kg/ha (deviation of +1.9%) and the minimum application rate of 47.0 kg/ha (deviation of -6%). If the domestic sowing rate of wheat is 160 kg/ha, the actual sowing value is 162 kg/ha (deviation of +1.3%).

Taking into account such sowing rates, the non-uniformity of wheat sowing between coil sowing units of compensation tanks is ±2.5 that is more than twice as little as acceptable non-uniformity (±6.0). The variability of general sowing value is ±1.6% at acceptable variability of ±2.0%.

If the domestic sowing rate of superphosphate is 80 t/ha, the actual sowing value is 81.4 kg/ha (deviation of +1.8%). The non-uniformity of fertilizer sowing between units of compensation tanks is ±5.4% at acceptable non-uniformity of ±10%. The non-uniformity of general sowing is ±4.8% at acceptable non-uniformity of ±10%.

Therefore, the proposed combined pneumatic and mechanical system for broad-cut seeders makes it possible to eliminate the major defect of pneumatic sowing systems, a non-uniformity of seed distribution between openers from (10÷30)% to ÷2.5% at acceptable non-uniformity of ÷6%. It should be noted that implementation of other new technical solutions proposed by us during the development of SKBM-12 ensures qualitative performance of the drill and other technical indices of sowing process of grain crops in steppe arid regions of Kazakhstan.

At required running depth of openers of 4.0÷4.0 cm SKBM-12 ensures the minimum penetration depth of 4.21cm and the maximum penetration depth of 8.34 cm. If the established running depth of openers is 7.0 cm, the average depth of seed placement is 7.5 cm at mean square depth deviation of ÷0.7 cm. The number of seeds placed in the horizon corresponding to the average depth and two adjacent layers of 1 cm is 81.8%. Seeds not placed in the soil after passage of the seeder are absent.

The average height of field surface irregularities after passage of press wheels of technological modules is 4.8 cm at acceptable height of 5.0 cm. Star-wheeled rollers ensure the strip soil panning up to 1.18g/cm^3 in the layer of seed placement which corresponds to 1.1-1.2g/cm^3 for this type of soils. The content of erosion-hazardous particles in the upper soil layer of 0-5 cm after passage of SKBM-12 is decreased by 6.9% which corresponds to requirements (number of erosion-hazardous particles should not increase). SKBM-12 ensured 99.1% of weed undercutting at required cutting level not less than 97%. The early emptying or overflow of compensation tanks of technological modules have not been observed during tests.

CONCLUSION

The application of combined pneumatic and mechanical sowing system makes it possible: to ensure the non-uniformity of distribution of ±(3-6)% and ±10% between seed openers and fertilizer openers, respectively which is acceptable under agro-technological requirements. This uniformity (usually ±(10-30%)) cannot be ensured by foreign sowing machines which centralized sowing system is based on pneumatic distribution principle; to deliver SKBM under customer requests for operation with and without centralized sowing system by using only sowing systems of compensation tanks of technological modules.

The broad-cut seeder SKBM-12 ensures: 80% of seed placement in the layer of 2 cm to the predetermined depth; height of field surface irregularities that is less than the acceptable one of 5.0cm; predetermined soil panning in the layer of seed placement; reduction of erosion-hazardous particles of the soil in the layer of 0-5 cm and almost complete undercutting of weeds. The block-modular principle used in SKBM allows the manufacturing plant to produce seeders of different sowing width to class 2-5 tractors under customer requests as opposed to foreign sowing machines.

Under customer requests SKMB may be equipped by the manufacturing plant with hoe openers and press wheels in order to perform sowing in drills or strips. SKMB are equipped with the following: seed and fertilizer level sensors located in tanks of the centralized sowing system and in each compensation tank of technological modules; operation monitoring sensors of centralized coil dispensers of the centralized sowing system and monitoring sensors of seed and fertilizer feed to compensation tanks of technological modules; operation monitoring sensors of sowing units of compensation tanks of technological modules.

Indices of all sensors are displayed on the alarm panel installed in the tractor driver's cabin. The price of SKBM is 1.4-1.6 times lower than that of far-abroad sowing machines similar in the sowing width. The application of SKBM-12 in comparison with sowing unit SZTS-12 makes it possible to reduce operational expenses by 14.1% and obtain the annual economic effect of 416.9 thousand tenge.

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