Soybean harvesting using current dedicated headers and adapters

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Abstract. The article describes the basic agrotechnical requirements for soybean combine harvesting. The current model range of adapters and headers used by agricultural producers for harvesting is analyzed. The design features and purpose of the headers and adapters to be used are studied. The results of experimental studies using dedicated soybean harvesting headers manufactured by Rostselmash in the real economic conditions of the Southern Federal District of the Russian Federation and a theoretical calculation of the optimal length of the header table are presented. Studies of combine harvesters from Rostselmash (Nova 340, Vector, TORUM) having various designs of threshers (single-drum; axial-flow) have shown that RSM-181 TORUM 750+ZhSU-900 and RSM-181 TORUM 740+ZhSU-700 combine harvesters have high productivity per hour of the main period equal to 5.20 and 4.80 ha / h respectively. This can be explained by the presence of a large working width header, a high speed of movement and an axial-flow thresher used on the combine. When harvesting long-stalked soybeans, the length of the header table is of great importance, which determines the reliability of the header auger, the uniformity of the plant mass supply to the combine thresher. As a result of theoretical calculations, it was established that the header table length should be \( L_{ht} \geq 0.81 \text{ m} \). Manufacturers of current headers recommend replacing a serial length table with a table having an extended length when harvesting long-stalked soybeans.

1. Introduction

Soybeans are fourth in world agriculture after such crops as wheat, corn and rice, and the first ones among leguminous crops. The total protein and fat content in the seeds reaches 70%, while the protein content exceeds the FAO standard. Soybean grain contains up to 43% of protein, 18 to 20% of carbohydrates, and up to 25% of oil, while soy protein belongs to complete proteins in terms of composition and quantitative content of essential amino acids and is close to meat proteins in terms of biological value [1]. Due to the biological features of the root system, soybean accumulates up to 100 kg of nitrogen per hectare in the soil, improves the phytosanitary condition of the soil and is a good precursor in the field crop rotation system. High yields of soybeans can only be obtained by cultivating it using the principles of zonal farming, i.e. when the issues of selecting varieties and places in crop rotation are optimally resolved. Varietal agricultural technology, a fertilizer system in combination with a set of measures to combat pests, diseases and weeds have been developed; and most importantly, dedicated equipment designed for harvesting crops with minimal losses is available.
Harvesting soybeans in production crops begins in the phase of full ripeness (when leaves fall, the stalks and all the beans are dried out and browned; the seeds acquire their characteristic lightness, the color becomes characteristic of the variety, and beans easily separate from the bean leaves and “rattle” when shaken). The moisture content of the grains during harvesting should be at least 14 to 16%, because at a smaller moisture content (11 to 12%) beans become fragile and are easily crushed (an increase in grain loss), and cracks form in their shell (a decrease in germination), through which pathogens penetrate. At a high moisture content (more than 20%), the seeds are deformed, and the embryo is damaged. Depending on the moisture content of the grain, the threshing drum speed is set within 450–800 rpm. When ripening, soybeans exfoliate and, as a rule, does not lodge, therefore, harvesting is performed by direct combining in the phase of full ripeness using combine harvesters fitted with headers converted to a low cut (6 to 8 cm) or with special adapters hung on the grain header. Since harvesting is often complicated by the presence of bumps and stones on the field, the soybean combine harvesters must have a reliable system for copying the field relief. The optimum operating speed of the harvesting unit is 3 to 4 km / h and up to 5 km / h in areas with a planned microlief.

The use of a combine harvester without a special adapter or header during harvesting results in a loss of about 10 to 15% of the crop, while according to GOST 17109-88 “Soy. Requirements for procurement and supply,” grain loss should not exceed 2 to 3%, grain crushing should be maximum 3%, the presence of weed impurities and soil in the seeds should be maximum 4 to 5%. To avoid losses during soybean harvesting, agricultural producers must have new technologies and equipment adapted to this sensible crop.

This article analyzes current dedicated adapters and headers used in soybean harvesting and theoretically calculates the optimal length of the header table.
with a rack, a reel, a cutterbar, an auger, dividers (left and right), a hydraulic system for driving the working bodies and electrical equipment for controlling the header functions.

The Maxflex header (figure 1c) having a working width of 7.5 to 10.5 m is designed for aggregation with a Claas self-propelled combine harvester for direct combining soybeans, spiked cereals, legumes, and cereal crops on flat fields. The bending range of the floating blade is 18.0 cm; the cutting height is adjusted from 3 to 14 cm above the soil surface. The header consists of a frame with a rack, a reel, a cutterbar, an auger, dividers (left and right), a hydraulic system for driving the working bodies and electrical equipment for controlling the header functions.

The SuperFlex header (figure 1d) having a working width of 6.7 to 11.2 m is designed for direct combining soybeans, spiked cereals, legumes, and cereal crops on flat fields in combination with a New Holland self-propelled combine harvester. The bending range of the floating blade is 11.0 cm, the maximum cutting height is 38 cm. The header consists of a frame with a rack, a reel, a cutterbar, an auger, dividers (left and right), a hydraulic drive for working bodies and electrical equipment for controlling the header functions.

The 600F HydraFlex header (figure 1e) having a working width of 6.0 to 10.7 m is designed for direct combining soybeans, spiked cereals, legumes, and cereal crops on flat fields in conjunction with a John Deere self-propelled combine harvester. The bending range of the floating blade is 15.0 cm, the maximum cutting height is 38 cm. The header consists of a frame with a rack, a reel, a cutterbar, an auger, dividers (left and right), a hydraulic system for driving the working bodies and electrical equipment for controlling the header functions.

John Greaves produces soybean headers (figures 1f) having a working width of 7.5 to 9.0 m, which is also intended for harvesting soybeans, spiked cereals, legumes, and cereal crops on flat fields with a slope of maximum 8 degrees. The header has the ability to be aggregated with any brand of the combine harvester. The bending range of the floating blade is 11.0 cm, the cutting height is from 3 to 20 cm. The reel vertical and horizontal positions can be hydraulically adjusted from the harvester cab. Reel speed is adjusted using a hydraulic motor or variator (depending on the model of the combine).

A structural and technological analysis has showed that all soya headers have one common design feature: the header being in the working position practically lies on the ground supported only by gage shoes located in the lower part of the cutterbar along the entire working width (figure 2a). If one of these gage shoes gets on an unevenness (earth, stones), then it starts to lift up that part of the flexible cutterbar that is above it. If there is a recess on the way, then the shoe lowers a part of the cutterbar

![Figure 1](image-url)
down. Depending on the manufacturer and model of the header, the cutterbar in such situations can sometimes deviate to a height of up to 30 cm in both directions. The degree of flexibility depends on the degree of pretension of the cutterbar.

![Figure 2. Header operation diagram: a – “with a fixed blade”; b – “with a floating blade” (1 – reel; 2 – cutterbar; 3 – spring bottom plate; 4, 5 – lever; 6 – cutterbar gage shoes; 7 – auger; 8 – auger pins; 9 – header body).](image)

Thus, the current soya headers are able to cut the stalk almost “to zero” at a height of only 2.5 cm from the field surface and along the entire working width while enveloping all the irregularities of the microrelief (reduction of grain loss). In addition, a header equipped with a “floating” cutterbar can be used not only for soybean harvesting, but also for harvesting peas and other down crops. When harvesting traditional crops, the soya header cutterbar is fixed (manually or using hydraulics controlled from the harvester cabin depending on the model or manufacturer), after which the header is practically no different from ordinary headers with a fixed cutterbar design (figure 2b). The “flexible” header own weight is important, unlike ordinary ones: the lighter the header, the more sensitive the gage shoes and the better the field microrelief is followed.

To harvest soybeans with minimal losses, dedicated adapters mounted on grain headers are also common. The Soja-Flex adapter from Biso Schratteneker (figure 3a) is known, which is intended for harvesting soybeans, peas, legumes, and cereal crops through re-equipping grain headers of foreign manufacturers of combine harvesters, such as Claas, New Holland, John Deere. Sanfloromash manufactures the RSM Ettaro adapter, which is designed to harvest soybeans, peas, legumes, and cereals through re-equipping any grain headers from Russian and foreign combine harvester manufacturers. The bending range of the floating blade is 10 cm, the cutting height is adjusted from 2 cm above the soil surface.

![Figure 3. Current adapters for soybean harvesting: a – Soja-Flex (Biso Schratteneker); b – RSM Ettaro (Sanfloromash).](image)

Studies have shown that the current headers and dedicated adapters from various manufacturers differ in detail: the presence or absence of an electronic terrain relief following system (for example, Claas AutoContour system); the possibility of folding into a transport position and changes in the level
of cut height. Unlike European manufacturers, some American firms optionally offer a conveyor belt as an alternative to the auger, which contributes to a more even flow of the mowed mass, facilitates threshing of soy, reduces injury to beans, increases the throughput of the threshing system, however, it has a higher cost, more parts are subject to operational wear, and there is a greater required drive power.

A segmented-pin type cutterbar to be used on all considered headers and special adapters designed for soybean harvesting (figure 4) is a flexible bar, to which press and welded pins, a blade, friction plates and stone guards are attached using fixing bolts. The cutterbar is mounted on the header body using articulated spring-loaded levers. Flexible bottom plates made of spring steel serve as springs. In addition, there are two springs on the left side of the header for hanging the blade drive gearbox.

![Figure 4. Cutterbar: a – bar assembly; b – standard factory-made stone guards (1, 2 – stone guard; 3 – bar; 4 – cutting segment; 5 – outer pin; 6 – holding pin; 7 – stone guard; 8 – fixing bolts; 9 – friction plate; 10 – outer pin; 11 – blade head).]

According to ASM Holding, a Russian analytical company, the ZhSU 500, ZhSU 700, ZhSU-700 EGR headers are the most widespread on the Russian market. They are manufactured by Klever JSC, which produces over 100 modifications of trailers and attachments under the world-famous Rostselmash brand (table 1) [3, 4].

| Manufacturer, model          | 2016 | 2017 | 2018 | 2019 | 2019/2018 [%] |
|------------------------------|------|------|------|------|---------------|
| ZhSU 500, ZhSU 700, ZhSU -700 EGR | 339  | 599  | 542  | 620  | 114.4         |
| RSM SS 750                   | -    | -    | 37   | 150  | 223.9         |

To analyze the performance of combine harvesters fitted with headers from Rostselmash and to identify crop losses during soybean harvesting, experimental studies have been carried out in accordance with GOST 20915-2011 “Testing of agricultural tractors and machines. Procedure for determination of test conditions” in the real economic conditions of agricultural enterprises located in the zone of the Southern Federal District. Table 2 shows the harvesting conditions for Vilana soybean varieties that correspond to the standard agrotechnical indicators for this zone.

The studies were conducted using combine harvesters that had a wide range of engine power from 180 hp up to 425 hp and various designs of the threshers: they were single-drum rotary and axialflow threshers. Table 2 shows the combine harvester performance.

Under the current working conditions, the speed of movement of the soybean combine harvesters was in the range of 4.0 to 6.9 km / h, which caused their throughput per hour of shift period of 1.52 to 4.20 ha at a specific fuel consumption for direct soybean harvesting of 8.3 to 12.9 kg / ha. The reliability coefficient of the soybean harvesting process for all combines was 1.0.
### Table 2. Key indicators of testing conditions for soybean harvesting using combines

| Indicator                                | Unit                  | Average indicator value |
|------------------------------------------|-----------------------|-------------------------|
| Ripeness                                 | %                     | 100                     |
| Crop yield                               | Hundredweight / ha    | 22.8                    |
| Down crop rating                         | %                     | 10.2                    |
| Weediness                                | %                     | 2.15                    |
| Plant density                            | ‘000 pcs. / ha        | 346                     |
| Plant height                             | cm                    | 110                     |
| Stalk diameter                           | mm                    | 8.3                     |
| Lower bean height                        | cm                    | 20.8                    |
| Ratio of grain weight to tailings weight |                      | 1:2.3                   |
| Moisture content:                        |                       |                         |
| grain                                    | %                     | 12.0                    |
| tailings                                 |                       | 32.4                    |
| Loss of grain from self-shedding         | %                     | 1.3                     |
| Row spacing                              | cm                    | 70                      |
| Field slope                              | Degrees               | 0                       |
| Soil moisture in a layer from 0 to 10 cm  | %                     | 9.0                     |
| Hardness of soil in a layer from 0 to 10 cm | MPa                | 1.7                     |

### Table 3. Experimental performance of the soybean combine harvesters

| Parameter                        | Nova 340 + Float Stream 500 | RSM-101 + Vector 420 | RSM-142 + ACROS 580 + ZhSU 600 | RSM-181 + TORUM 740 + ZhSU 700 | RSM-181 + TORUM 750 + ZhSU 900 |
|----------------------------------|------------------------------|----------------------|--------------------------------|--------------------------------|--------------------------------|
| Engine power [hp]                | 180                          | 220                  | 300                            | 425                            | 425                            |
| Working width [m]                | 5.0                          | 6.0                  | 7.0                            | 7.0                            | 9.0                            |
| Actual cut height [mm]           | 56                           | 60                   | 60                             | 58                             | 57.2                           |
| Motion speed [km / h]            | 4.0                          | 4.8                  | 5.8                            | 6.9                            | 6.2                            |
| Throughput [ha / h]:             |                              |                      |                                |                                |                                |
| - main period                    | 2.00                         | 2.80                 | 4.06                           | 4.80                           | 5.20                           |
| - shift period                   | 1.52                         | 2.21                 | 2.96                           | 3.76                           | 4.20                           |
| Specific fuel consumption [kg / ha]| 8.3                          | 9.8                  | 11.3                           | 12.3                           | 12.9                           |

#### Performance quality parameters

| Total grain loss [%]              |                              |                      |                                |                                |                                |
|                                  | including:                   |                      |                                |                                |                                |
| - downstream the thresher        | 2.37                         | 2.52                 | 2.90                           | 1.42                           | 1.84                           |
| - downstream the header          | 1.75                         | 1.32                 | 1.97                           | 0.96                           | 1.12                           |
| Hopper grain quality [%]:        |                              |                      |                                |                                |                                |
| - cracked grain                  | 1.41                         | 2.32                 | 2.65                           | 0.80                           | 0.96                           |
| - impurities                     | 1.72                         | 2.60                 | 1.68                           | 1.56                           | 1.20                           |
All combines to be studied were equipped with dedicated headers designed for soybean harvesting and providing a low cut of harvested plants. The RSM-181 TORUM 750 + ZhSU-900 and RSM-181 TORUM 740 + ZhSU-700 combine harvesters had a high throughput per hour of main period of 5.20 and 4.80 ha/h, respectively. This can be explained by using a large working width header, high speed of movement and the axial-flow combine [5, 6]. However, during the study, it was found that when harvesting long-stalked soybeans, the length of the header table was of great importance, which determined the reliability of the header auger and the uniformity of the supply of vegetable mass to the combine thresher. A serial header has the cut soybean stalks rested with one end against the cutterbar and with the other end against the auger cylinder. From this position, the helical tape cannot immediately grab the stalk in order to direct it under the auger to the bottom of the header rack for further transportation. When the reel feeds the next layers, the soybean mass accumulates on the header table in the form of an uneven portion and enters the thresher unevenly, which leads to the threshing process failure and reduces the combine performance.

To eliminate these shortcomings, the authors have performed a theoretical calculation of the optimal length of the header table, which will ensure full and layer-by-layer laying of cut soybean stalks before they fall into the gap between the auger and the bottom of the header rack, will not increase the distance between the header auger and reel (a “dead” zone), as well as will not cause the formation of uneven portions of soy on the header table.

When considering the process of laying upright long stalks of soybeans on the header table, the following assumptions were made [7, 8]:

- the stalks are fed not in a continuous stream, but in layers, while the frequency of arrival of the layers is determined by the number of reel bars \(K_{rb}\) and reel rpm \(n_{reel}\). The time interval during which the reel \(I\) (figure 5) feeds a layer of soybean stalks is equal to the period \(t_0\), in seconds, of impact of the neighboring reel bars on the stalks, and is calculated by the formula:

\[
t_0 = \frac{60}{n_{reel}K_{rb}}.
\]

In the header auger position I, the stalks that are laid in the inter-turn space a–b (figure 5), sequentially turn in the zone c–d along the movement of the helical tape 4. When the helical tape 4 reaches a certain position II, the last stalk of this layer, while turning around, descends from the surface of cylinder 3. In order to exclude the overlay of the next layer on the previous one, the last stalk turned around by the auger must come off the surface of the auger cylinder.

The movement of \(X_1\), in meters, of the helical type 4 from the position I to the position II (figure 5) corresponding to the descent of the last stalk of the layer from the surface of the auger cylinder can be determined by the formula:

\[
X_1 = \sqrt{L_{st}^2 - (R + \delta)^2 - L_{ht}^2},
\]

where \(L_{st}\) is a soybean stalk length, m; \(R\) is a radius of the auger helical part, m; \(\delta\) is a gap between the auger turn and header table, m; \(L_{ht}\) is a header table length, m.

The time \(t_1\), in seconds, of motion of the helical type 4 from the position I to the position II (figure 5) is equal to:

\[
t_1 = \frac{X_1}{v_{av}} = \frac{60X_1}{n_{aug}S},
\]

where \(X_1\) is a movement of the helical type 4 from the position I to the position II, m; \(v_{av}\) is an axial velocity of the helix line, m/s; \(n_{aug}\) is an auger rpm; \(S\) is an auger pitch, m.
Figure 5. Diagram for determining the optimal length of the header table, where: \( L_{ht} \) is a table length; \( L_{st} \) is a soybean stalk length, m; \( \omega_{reel} \) is an angular speed of the reel; \( \omega_{ac} \) is an angular velocity of the auger cylinder; \( v_{av} \) is an axial speed of the helical tape; \( R \) is a radius of the helical part of the auger, m; \( r \) is a radius of the auger tube; \( \delta \) is a gap between the auger turn and the bottom of the header rack, m; \( X_1 \) is movement of the helical tape from the position I to the position II; 1 – reel; 2 – rack; 3 – cylinder; 4 – helical tape; 5 – header table; 6 – cutterbar; 7 – stalk separator.

To fulfill the condition of turning around of the last stalk by the auger without laying the next layer on the previous one, the \( t_0 \geq t_1 \) condition must be satisfied, then taking into account expressions (1) - (3), we have the inequality:

\[
\frac{n_{aug}}{n_{reel}K_{rb}} \geq \frac{1}{S} \sqrt{\frac{L_{st}^2 - (R + \delta)^2 - L_{ht}^2}{}}. \tag{4}
\]

The inequality (4) makes it possible to determine the header table length, if the structural and kinematic parameters of the reel and auger are known and the length of the soybean stalk is also specified. Since the reel rpm \( n_{reel} \) and auger rpm \( n_{aug} \) of the current headers vary depending on the harvesting conditions, the header table length \( L_{ht} \), accordingly, as shown by the analysis of inequality (4), should increase with increasing soybean stalk length \( L_{st} \). Taking into account the most common values, such as \( n_{reel} = 32 \text{ rpm}, K_{rb} = 5, L_{st} = 1.1 \text{ m}, R = 0.3 \text{ m}, \delta = 0.02 \text{ m}, n_{aug} = 180 \text{ rpm}, S = 0.6 \text{ m} \) in accordance with inequality (4), we obtain that the header table length should be \( L_{ht} \geq 0.81 \text{ m} \).

An analysis of existing headers has showed that when harvesting long stalks, header manufacturers propose to replace the serial length table with an extended table.

4. Conclusion
After the studies have been performed using a method of comprehensive structural-dynamic analysis and expert-analytical method of processing information, we can conclude that there is a wide range of current dedicated headers and adapters for soybean harvesting. The current dedicated headers and
adapters from various manufacturers differ in details: the presence or absence of an electronic terrain relief following system (for example, Claas AutoContour system); the possibility of folding into a transport position and changes in the level of cut height. Unlike European manufacturers, some American firms optionally offer a conveyor belt as an alternative to the auger (a more even flow of the mowed mass, threshing of soy is facilitated, injury to beans is reduced, the throughput of the threshing system is increased, however, it has a higher cost, more parts are subject to operational wear, and there is a greater required drive power.)

Studies of combine harvesters from Rostselmash (Nova 340, Vector, TORUM) having various designs of threshers (single-drum; axial-flow) have shown that RSM-181 TORUM 750+ZhSU-900 and RSM-181 TORUM 740+ZhSU-700 combine harvesters have high productivity per hour of the main period equal to 5.20 and 4.80 ha/h respectively. This can be explained by the presence of a large working width header, a high speed of movement and an axial-flow thresher used on the combine.

When harvesting long-stalked soybeans, the length of the header table is of great importance, which determines the reliability of the header auger, the uniformity of the plant mass supply to the combine thresher. As a result of theoretical calculations, it was established that the header table length should be \( L_{ht} \geq 0.81 \) m. Manufacturers of current headers recommend replacing a serial length table with a table having an extended length when harvesting long-stalked soybeans.

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