Theoretical justification of the optimal parameters of the copying crop lifter of the combine harvester header

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Abstract. The article describes the efficient copying crop lifter of a combine header, which allows to significantly reduce grain losses during harvesting lodged crops. The article deals with mounting, adjustment of the proposed copying crop lifter and a method of experimental research to substantiate the optimal design and operating parameters of this device. The results of field experiment based on the method of a multifactorial experiment proved that the smallest grain losses are provided at the combine speed \( \nu = 1.5 \ldots 1.9 \) m/s, the thickness of the retainer plate \( h = 2.8 \ldots 3.1 \) mm and the length base of the copying crop lifter \( l = 405 \ldots 450 \) mm.

1. Introduction
Depending on the metrological, soil and agrotechnical conditions, the physical and mechanical properties of crops and other factors, in some years it is possible to have a great amount of lodged crops. Even in favorable years, lodging of crops during the harvesting period could reach 20% [1-5].

To reduce grain losses when harvesting lodged crops, it is necessary to design and mount special crop lifters or other devices on combine harvester headers to improve their quality parameters for efficient harvesting. Having analyzed the construction of the existing crop lifters, the authors came to the conclusion that these crop lifters poorly copy the rough field surface (lumps, hummocks, anthills, etc.), and could not completely adjust and lift the lodged crops to the cutting unit of the combine header [6,7].

2. Methods and materials
Description of the copying crop lifter construction. To reduce grain losses when harvesting lodged crops, the authors have developed a copying crop lifter, consisting of two base parts (Figure 1): front 1 and rear 2, connected by a hinge 3, lifting pen 4, made of a V-shaped profile of variable cross-section and welded to front 1 part of the base with the top of the profile up, and the lock 5 made of strip spring steel, and the front toe of the retainer 5 using rivets 6 is attached to the front 1 part of the base, and the rear one is fixed to the rear 2 part of the base.

The retainer 5 is bent so that, together with the front 1 and rear 2 parts of the base, a closed triangular figure is formed, in which the front side is located at an angle of not more than 45° against the field surface when the crop lifter is fixed at the working position, and the rear side is at right angles to the rear 2 part of the base. In the rear side of the retainer 5 there is a hole where the pointed toe of the retainer 7 of the cutting device should go through. The rear 2 part of the crop lifter base with a bolt connection 8 is attached to the pin bar of the header cutting device (positive decision on application No. 2021112501/10 for a utility model).
Crop lifter works as follows. When the header moves, the crop lifter constantly and without separation from the soil copies the relief of the field with the front 1 part of the base, the lifting pen 4 picks up the ledged crops and smoothly brings them to the cutting device. When the crop lifter runs over the rough field surface (lumps, bumps, anthills), the front 1 part of the base rises, copying them due to the hinge connection with the rear 2 part of the base, while the retainer 5 acts as a spring. After overcoming the rough field surface the crop lifter returns to its normal position.

Figure 1. Copying crop lifter of the combine header: 1 - front part of the base; 2 - the rear part of the base; 3 - hinge; 4 - lifting pen; 5 - retainer; 6 - rivets; 7 - toe of the retainer; 8 - bolted connection

Description of the mounting and adjusting the copying crop lifter. The optimal values of the design parameters and operating mode of the copying crop lifter were determined by several examinations carried out using the method of planning a multifactorial experiment on a laboratory setup consisting of the frame 1 (figure 2), where an infeed belt conveyor 2, a cutting device 3 and a copying crop lifter 4 should be mounted on.

Figure 2. Laboratory mounting: 1 - frame; 2 - belt conveyor; 3 - cutting device; 4 - copying crop lifter; 5 - gear motor; 6 - stems of grain crops; 7 - electric motor; 8 - V-belt transmission; 9 - swing washer mechanism; 10 - collection box; 11 - cut stems.

The drive of the infeed belt conveyor 2 is carried out from the gear motor 5 through a chain drive. The speed of the infeed belt 2 is controlled by a DELTA VFD-B frequency inverter. The stems 6 of the grain crop with a given lodging are attached to the conveyor belt 2. The height of the cutting device 3 is set in accordance to the requirements for harvesting lodged crops and is driven by an electric motor 7, a V-belt drive 8 and a swing washer mechanism 9. To collect the cut stems, a collection box is located under the cutting device 10. Experimental technique. The experimental technique is as follows. Preliminarily, on the conveyor belt 2, the stems 6 should be fixed with a given lodging, and on the frame the tested copying crop lifters should be mounted 4. Then select the required speed of the infeed belt conveyor 2. Sequentially it is important to turn on the drive of the cutting device 3 and the feeding conveyor 2. When the conveyor belt 2 moves, the lodged crops are lifted by copying crop lifters 4 and fed into the operating zone of the cutting device 3. The cut stems fall into the collection box 10 without any laying cut stems 11 on the conveyor belt 2.

As the optimization criterion was chosen the amount of losses (G,%) of grain crops [eight]. Uncut stems are considered lost.

\[ G = \frac{n_i - n_{cpi}}{n_i} \cdot 10^2, \]  

where \( n_i \) is the number of fixed stems before the experiment, pcs; 
\( n_{cpi} \) is the number of cut stems after the experiment, pcs.

When the crop lifter is in operation, more than 10 factors affect the process of lifting and supplying lodged crops to the cutting device [9]. It is impossible to determine the influence of all factors and their interactions on the process of lifting lodged crops and transferring them into the cutting zone with the cutting device. Guided by specific research objectives and on the basis of a priori information, the most significant factors were identified and the intervals and levels of their variation were selected (Table 1).
Table 1. Factors, levels and intervals.

| Factors                     | Symbol | Coded designation | Variation levels | Variation interval |
|-----------------------------|--------|-------------------|------------------|-------------------|
| Speed, m/s                  | θ      | x1                | 1.2              | 1.8               | 2.4               | 0.6               |
| Retainer plate thickness, mm| h      | x2                | 2.5              | 3                 | 3.5               | 0.5               |
| Crop lifter base length, mm | l      | x3                | 360              | 410               | 460               | 50                |

For these factors, a second-order orthogonal compositional design matrix was compiled [10].

3. Results

After processing the results of the three-factor experiment using the Microsoft Excel and Statistic programs on a PC, an adequate second-order mathematical model was obtained that describes the correlation $G(\upsilon, h, l)$ in coded form:

$$Y = 1,078 + 0,301 \times x_1 + 0,084 \times x_2 - 0,234 \times x_3 - 0,144 \times x_1 \times x_2 +$$
$$+ 0,094 \times x_2 \times x_3 + 0,505 \times x_1^2 + 0,440 \times x_2^2 + 0,350 \times x_3^2,$$

(2)

The study of the reaction surface was carried out using two-dimensional sections (Figure 3, Figure 4, Figure 5).

**Figure 3.** The surface of the grain losses reaction behind the header and its two-dimensional section from the speed $x_1$ and the thickness of the retainer plate $x_2$ at the optimal index of the length of the crop lifter base $x_3 = 0.359$

**Figure 4.** The surface of the grain losses reaction behind the header and its two-dimensional section from the speed $x_1$ and the length of the crop lifter base $x_3$ at the optimal index of the retainer plate thickness $x_2 = -0.187$
Figure 5. The surface of the grain losses reaction behind the header and its two-dimensional section of the retainer plate thickness $x_2$ and the length of the crop lifter base $x_3$ at the optimal operating speed $x_1 = -0.325$.

Conclusion
Analyzing graphic images of two-dimensional sections, it could be concluded that the optimal values of the factors under the current research are in the intervals: $\nu = 1.5 \ldots 1.9$ m/s; $h = 2.8 \ldots 3.1$ mm; $l = 405 \ldots 450$ mm. At the same time, grain losses do not exceed 1.0%.

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