Analysis of the cutting machine movement across the field when harvesting dead crops

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Abstract. The article is devoted to the analysis of various types of cutting machine movement across the field when harvesting dead crops. It is noted that despite improvements in the design of the cutting machine, the problem of grain loss remains unresolved. A classification of the types of cutting device movement according to the movement nature is proposed, which can serve as a basis for substantiating agrotechnical requirements for the quality of soil surface treatment.

1 Introduction

Improving the efficiency of machines and mechanisms used in the agricultural sector is an urgent problem considered in the agro-industrial complex. One of the most popular and profitable options in terms of energy consumption, so that the harvesting of dead crops takes place with the greatest efficiency, can be called improving the adaptability of the cutting apparatus of machines – mowers and harvesters – to the field irregularities. It is for this purpose, in particular, that the so-called copying and narrow-grip harvesters with support wheels, floating cutting machines and other mechanisms were created [1]. It is worth noting that, despite such improvements, the cutting machine, which operates at a high cut, carries high grain losses, and when working at a low cut, it becomes clogged with plants and dirt, that is, the quality and efficiency of harvesting equipment decreases.

The good adaptability of the cutting machine to field irregularities depends on many factors. As a result, it is determined by the type of cutting mechanism movement in the field. Nevertheless, this issue and the feasibility of choosing the optimal movement have been little studied. Therefore, the purpose of the work is to study the various types of movement of the cutting machine across the field when harvesting dead crops.

2 Materials and Methods

The cutting machine rests on the ground with wheels or skids during operation. When moving, these supports produce both copying and relative smoothing of irregularities [2, 3]. Thus, the types of movement of cutting machines can be divided into:

– copying;

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– smoothing;
– copy-smoothing.

Undoubtedly, it is worth noting that the degree of different movements in the field depends on various factors and conditions (for example, the shape and size of supports, soil moisture, the presence of irregularities, etc.). The first two movement types are, so to say, outer, and the third type is intermediate.

During the smoothing movement, the cutting device supports will pass through the tops of the highest irregularities of the field parallel to its median plane, as shown in Fig. 1a. Such a movement can be performed by supports in the form of flat skids or wheels of sufficiently large dimensions.

In the copying motion, the supports of the cutting device pass over the surface of the field soil and reproduce its profiles (Fig. 1b). Such movement can be carried out by supports in the form of small wheels or skids.

In the copying-smoothing motion, the supports of the cutting device copy the tops and slopes of the field ridges, can descend to different depths, but never reach the bottom (Fig. 1b). Such a movement can be performed by medium-sized wheels or skids enclosed between the sizes of copying and smoothing supports. It is worth noting that with a decrease in the size of the supports, the degree of copying of the field irregularities will increase, and the degree of smoothing will decrease [4, 5].

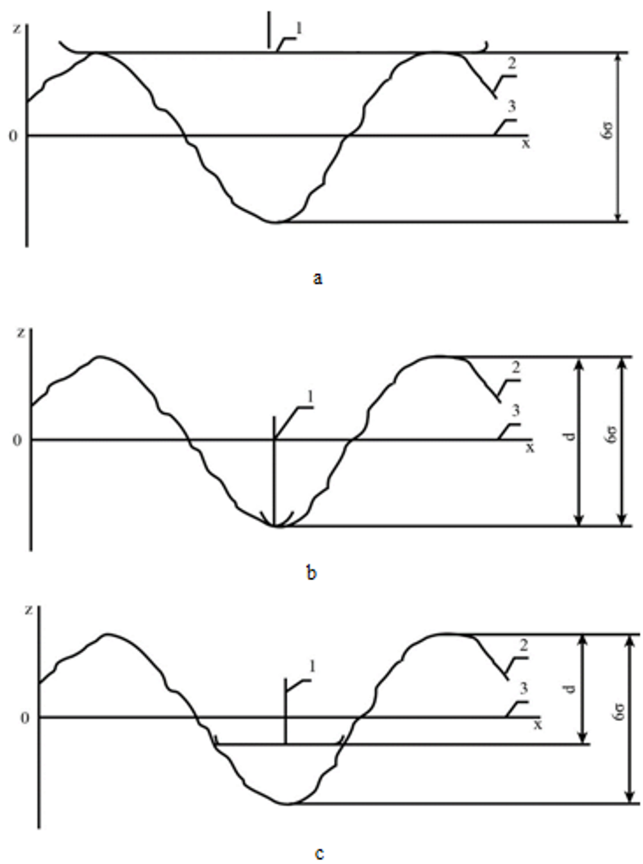

Fig. 1. The type of the cutting device support movement along the irregularities: a – smoothing, b – copying, c – copy-smoothing; 1 – cutting device support, 2 – field profile, 3 – trace of the middle plane of the field.

Definitely, the above representation of the types of movements of cutting machines in the field can be called ideal. Nevertheless, in reality, various defects of supports may occur, soil crumpling, sticking to the ground, etc., but with the optimal choice of a cutting device, a mechanism for soil characteristics, the result can be brought closer to ideal.

For brevity and certainty, the established types of movement of the cutting machine supports across the field can be represented by a number:

$$k_0 = \frac{d}{6\sigma} \tag{1}$$

or

$$c_0 = \frac{6\sigma - d}{6\sigma} = 1 - k_0,$$

where k_0 is an indicator of copying the field irregularities by a separate support of the cutting machine;

d is the range of this copying, mm;

σ is the average square deviation of the height of the field irregularities relative to its median plane, mm;

c_0 is an indicator of smoothing out the field irregularities by a separate support of the cutting device.

In this case, the range d is the maximum height of the support movement from its lowest position to its highest or back in the process of moving along the field irregularities. The value 6σ, in accordance with the law of normal distribution of the height of the field irregularities, determines the entire thickness of the layer of irregularities from the top of the highest ridges to the bottom of the deepest depressions or the practically possible range of copying these irregularities by the cutting device support. Then the indicator k_0, being the ratio of the actual copying range to its practically possible value, characterizes the degree of copying of the field irregularities by this support.

The difference 6σ—d is the maximum height of separation of a support part from the soil surface in the field depressions, and the value 6σ in this case determines the practically possible height of such separation. This means that the indicator c_0, as the ratio of the actual separation height to its practically possible value, characterizes the degree of smoothing of the field irregularities by a separate support of the cutting device. But since the indicators k_0 and c_0 are interrelated, one is enough to represent the types of movement of supports across the field. Let it be the exponent k_0.

In a smoothing motion, when the support, by definition, moves along the plane, the range d=0. Then from the equality (1) $k_0=0$.

Therefore, the value of the copying indicator, equal to zero, represents a smoothing view of the support movement across the field.

In the copying motion, when the cutting device support moves along the soil surface within the entire layer of field irregularities, the actual copying range is d=6σ. Then from the equality (1) $k_0 = 1$.

Therefore, the value of the copy indicator, equal to one, represents a copying view of the support movement across the field.

Finally, in the copying-smoothing motion, when the support copies the ridges to varying degrees and smoothes the field depressions, the copying range is $0< d <6\sigma$. Then from the equality (1) $0< k_0<1$.

Therefore, the value of the copy indicator is greater than zero, but less than one, represents the copying-smoothing support movement across the field.

Nevertheless, this inequality contains a certain set of values of the exponent k_0, which makes it vague. Therefore, as the main representative of the copying-smoothing movement of the support along the field, the value $k_0 = 0.5$ should be taken. Then all other values of the k_0 indicator will represent varieties of this type of movement. In the case when $k_0 = c_0$, the support copies only the field ridges to its middle plane, and it smooths out the field depressions.

As a result, all possible types and varieties of movement of the cutting device support across the field can be represented by the indicator $0 \leq k_0 \leq 1$. At the same time, with an increase in this indicator, the copying-smoothing movement of the support will move away from the smoothing and approach the copying one.

The cutting machine usually has two supports. But there are many more of them. These supports can be different and identical in shape, size and pressure on the soil. Moreover, each support can move along the field irregularities independently of other supports. As a result, possible types of joint movement of the same supports, as well as one support, are smoothing, copying, and copy-smoothing, and combinations of different supports, smoothing with copying, smoothing, with copy-smoothing, copying with copy-smoothing, and smoothing with copying and copy-smoothing. At the same time, the first three types should be classified as basic, forming the basis of all possible types of movement, and the remaining four types, as possible combinations of the main ones, should be classified as combined.

3 Results and Discussion

In the main types of joint movement, all supports of the cutting device perform either smoothing, copying, or copy-smoothing movement along the field irregularities. In this case:

$$k_1 = k_2 = \dots k_n = k,$$

where k_1, k_2, k_n are the indicators of copying the field irregularities by the corresponding supports of the cutting machine;

k is the general indicator of copying the field irregularities by all the cutting machine supports when they move together. Then when smoothing k=0, when copying k=1, and when copy-smoothing k=0.5.

In combined types of joint movement, some supports of the cutting device perform smoothing, others — copying, and others — copy-smoothing movement along the field irregularities. In this case:

$$k_i \neq k_j \neq k_k,$$

where k_i, k_j, and k_k are the indicators of copying the field irregularities by the corresponding groups of the cutting device supports. Then when smoothing with copying:

$$k = \begin{cases} k_i = 0 \\ k_j = 1, \end{cases}$$

when smoothing with copy-smoothing:

$$k = \begin{cases} k_i = 0 \\ k_j = 0{,}5, \end{cases}$$

when copying with copy-smoothing:

$$k = \begin{cases} k_i = 1 \\ k_j = 0{,}5, \end{cases}$$

and when smoothing with copying and copy-smoothing:

$$k = \begin{cases} k_i = 0 \\ k_j = 1 \\ k_k = 0{,}5. \end{cases}$$

As a result, all possible types and varieties of joint movement of the cutting machine supports across the field can be represented by the expression:

$$k = \begin{cases} 0 \leq k_i \leq 1 \\ 0 \leq k_j \leq 1, \text{at } k_i \lesseqgtr k_j \gtreqless k_k \\ 0 \leq k_k \leq 1 \end{cases} \quad (2)$$

At the same time, the varieties of basic and combined types of movement are associated not only with a change in the copying index of the copy-smoothing supports, but also with the rearrangement of different supports in places.

The cutting machine is mounted rigidly on the supports. At the same time, the knife bar to which they are attached is also quite rigid, which eliminates the possibility of its deflection on the inter-support span. As a result, any movement of the supports along the irregularities of the field is transmitted directly to the entire cutting machine [6]. This determines the nature or type of its movement on the field. Consequently, the possible types and varieties of cutting device movement in the field are all the established types and varieties of joint movement of its supports, represented by expression (2).

In addition, during operation, the cutting machine moves along the field with the machine. The latter can be a mower or a harvester in an aggregate with a tractor, as well as a self-propelled combine harvester. When moving across the field, these machines rely on the ground with tracks or wheels. Such supports can make and transmit to the machine the same movements as the cutting machine supports.

Nevertheless, the mounting of the supports to the machine can be rigid and sprung. With a rigid attachment, any movement of the supports along the irregularities of the field is transmitted to the machine directly, and with a sprung attachment — through springs, which can slightly change the movement of the machine, thereby introducing new varieties into the nature of its movement. As a result, all possible types and varieties of machine movement associated with field irregularities, by analogy with a cutting machine, can be represented by the following expression:

$$k_m = \begin{cases} 0 \leq k_u \leq 1 \\ 0 \leq k_v \leq 1, \text{at } k_u \lesseqgtr k_v \lesseqgtr k_w, c\ or\ s, \\ 0 \leq k_w \leq 1 \end{cases} \quad (3)$$

where k_m is the total index of copying the irregularities of the field by all the machine supports when they move together;

k_u, k_v, k_w are the indicators of copying the field irregularities by the corresponding groups of machine supports;

c, s is the designation of the rigid and sprung mounting of the machine supports, respectively.

All movements of the machine are transmitted to the cutting machine through the suspension [7]. The suspension can be movable and fixed. The movable suspension, in turn, can be radial and four-link, in particular, parallelogram.

With a fixed suspension, the cutting machine and the machine move across the field as one. In this case, the cutting machine supports on the soil are the supports of the machine and the types of their movement coincide. Then, considering (3), all possible types and varieties of movement of the cutting device across the field in this case can be represented by the expression:

$$k = k_m = \begin{cases} 0 \leq k_u \leq 1 \\ 0 \leq k_v \leq 1, at\ k_u \gtreqless k_v \lesseqgtr k_w, c\ or\ s\ and\ G, \\ 0 \leq k_w \leq 1 \end{cases} \quad (4)$$

where G is the designation of the fixed suspension of the cutting device to the machine.

With a movable suspension, the cutting device moves across the field on its own supports and can perform all types of movement represented by expression (2). Nevertheless, it receives additional movements from the machine through the suspension, which depend on the type of machine movement and the type of movable suspension and can be classified as varieties of its movement. Then, consdiering (2) and (3), all possible types and varieties of movement of the cutting device across the field in this case can be represented by the expression:

$$k = \begin{cases} 0 \le k_i \le 1 \\ 0 \le k_j \le 1 \\ 0 \le k_k \le 1 \end{cases}, \text{when } k_i \lesseqgtr k_j \lesseqgtr k_k, R \; or \; P \; and$$

$$k_m = \begin{cases} 0 \le k_u \le 1 \\ 0 \le k_v \le 1 \\ 0 \le k_w \le 1 \end{cases}, \text{at } k_u \lesseqgtr k_v \lesseqgtr k_w, c \; or \; s, \qquad (5)$$

where R, P — the designation of the radial and four-link (parallelogram) suspensions of the cutting apparatus to the machine, respectively.

The analysis made it possible to determine the possible types of the cutting device movement across the field when harvesting dead crops and present them with expressions (4) and (5).

4 Conclusions

Finally, the main conclusions of the analysis can be given:

1. The types of the cutting machine movement can be classified according to the movement nature.
2. The established types of movement are determined by the value of the index of copying (or smoothing) the irregularities of the field by the supports of the cutting device. This indicator ranges from 0 to 1 for each support or group.
3. The proposed classification of the types of the cutting machine movement across the field when harvesting dead crops can serve as a basis for substantiating agrotechnical requirements for the quality of soil surface treatment, as well as, undoubtedly, to the very design of the supports of harvesting machines.

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