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аграрний університет****УДК 631.3:633.2****DOI: 10.37128/2306-8744-2025-4-18****DETERMINATION OF RATIONAL
PARAMETERS AND OPERATION
MODES OF ROTARY RAKES**

In the feed production system, the harvesting of forage from leguminous grasses and leguminous mixtures plays a key role in achieving high levels of plant protein. However, the efficiency of using the biological potential of the crop is significantly limited by the imperfection of the technological processes of harvesting. The specificity of leguminous grasses arises from a significant difference in the strength of the connection with the stem of the most valuable vegetative organs - leaves and inflorescences, which in terms of nutritional value are 2...3 times greater than the stem fraction. It has been established that the main crop losses and reduction in feed quality occur during mechanical processing of the dried mass, in particular when performing the operations of stirring, raking into windrows and turning. Therefore, an objective assessment of the quality of the work of the relevant agricultural machines (tedders, rakes) is a critically important condition for improving technologies.

The main methodological problem in researching these processes is the difficulty of reliably determining quantitative loss indicators in field conditions. In real operating conditions, due to the fine size of lost particles and their tendency to shatter, complete collection is practically impossible. In this regard, the assessment of machine quality in the field is carried out mainly by indirect methods, the reliability of which raises well-grounded doubts.

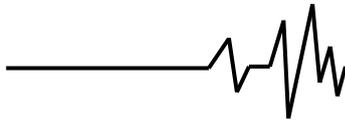
During mechanical action, two parallel processes occur: first, the loss of a portion of the free particles that already existed in the swath (due to scattering on the stubble); second, the active destruction of plants with the formation of new free fractions. A part of these newly formed particles is lost irretrievably, but a significant amount accumulates in the structure of the formed windrow, remaining in a "bound" state until the next mechanical impact. Thus, determining losses by a simple difference masks the real level of plant damage, as it does not account for the accumulation of free particles in the mass. This leads to the distortion of test results and complicates the constructive improvement of machinery. Solving this scientific problem requires the development of new theoretical approaches that would take into account the combined influence of scattering and accumulation factors of vegetative residues in the process of fodder harvesting.

Keywords: fodder production, fodder grasses, hay, technology, harvesting, physical and mechanical properties, rotary working bodies, tedding, rakes.

Introduction. According to the standard methodology [1], it is proposed to calculate losses from mechanical plant damage based on the difference between the content of free (detached) plant parts in the forage before the machine's pass and after the execution of this operation. However, a detailed analysis of the process dynamics indicates the methodological incorrectness of this approach.

During the execution of technological

operations (tedding, raking, turning), active detachment of vegetative organs occurs. A significant portion of these organs is irretrievably lost on the stubble, while another portion is retained within the windrow structure, shifting to the category of "free" but not lost. During subsequent processing (e.g., repeated tedding), these detached parts are no longer attached to plant stems and are subjected to additional mechanical impact. Consequently, during subsequent



operations (repeated tedding or raking), a certain quantity of these parts is lost, scattered on the stubble, or remains within the forage mass [2, 3].

Therefore, the real process is characterized by the simultaneous occurrence of two phenomena: the loss of previously accumulated free fractions and the formation of new ones. Therefore, the definition of losses as a simple difference of indicators does not reflect reality, since it masks the process of accumulation of separated parts inside the plant mass. The actual losses are the sum of the particles that fell out of the windrow from previous operations and those that were reflected directly during the current processing.

Analysis of recent research and publications. The significant diversity of forage harvesting equipment is the result of continuous efforts to enhance productivity and operational quality while simultaneously reducing the metal intensity of the machines [4, 5]. Fundamental studies by a number of authors [2-15] elucidate the theoretical foundations for designing working elements that ensure the execution of the full cycle of hay harvesting operations: from mowing and conditioning to tedding, windrowing, chopping, and baling.

The purpose of research. The purpose of this study is investigation the influence of the design parameters of rotary working bodies on the quality of hay harvesting.

Presentation of the main material.

According to [1], losses from leaf and inflorescence are calculated using the formula:

$$P = \frac{100(m_1 - m_2)}{m_3}, \quad (1)$$

where:

- P - losses from shattering, %;
- m_2 - mass of free (shattered) plant particles in the sample after the machine pass, g;
- m_1 - mass of free (shattered) plant particles in the sample before the machine pass, g;
- M - total mass of the grass (hay) sample, g.

In this case, the loss indicator calculated according to [1] may assume alternating values, indicating that the proposed evaluation criterion lacks clear physical meaning.

The dry matter content in the shattered plant parts is always higher than the dry matter content in the grass from which they are detached. Consequently, the value of the loss indicator calculated on a wet basis is underestimated compared to determinations based on dry matter; therefore, reliably assessing the performance of machines for tedding, raking, and turning based on shattering and losses of vegetative plant parts is practically difficult.

Thus, it is more expedient to assess the performance of machines for tedding, raking, and turning forage based on the quantity of shattered and lost vegetative plant parts [5].

The shattering of leaves and inflorescences

can be expressed in terms of the change in plant leafiness before and after the impact of the machine's working elements using the formula [10]:

$$\sigma = \frac{G_l + G_{inf}}{G}, \quad (2)$$

where: G_l i G_{inf} – mass of dry matter of leaves with inflorescences and stems, respectively, g;
 G – total mass of grass dry matter, kg.

The material balance of the grass tedding, raking, or turning process is expressed as follows [10]:

$$G_{l1} + G_{inf1} = G_{l2} + G_{inf2} + G_{shat} \quad (3)$$

where: G_{l1}, G_{l2} - dry matter mass of leaves and inflorescences before and after the machine pass;

G_{inf1}, G_{inf2} - mass of dry matter of stems before and after the machine pass;

G_{shat} - mass of dry matter of covered leaves and inflorescences.

The coefficient of covering leaves and inflorescences is calculated by the formula [10]:

$$C = \frac{G_{shat}}{G}, \quad (4)$$

$$C = \frac{\sigma_1 - \sigma_2}{1 - \sigma_2} \quad (5)$$

where: σ_1 - grass foliage before cultivation,

$$\sigma_1 = \frac{G_{l1}}{G};$$

σ_2 - leafiness of the grass after the action of the working bodies on it.

When the machine performs the operations of intensification of drying perfectly, when $\sigma_1 = \sigma_2$, leaf and inflorescence covering coefficient $C = 0$.

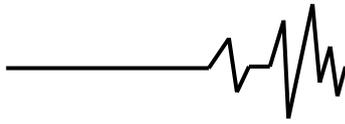
In the case when, as a result of the action of the working organs on the grass, absolute covering of leaves and inflorescences is observed, i.e. $\sigma_2 = 0$, shattering coefficient $C = \sigma_1$. The coefficient of leaf and inflorescence covering can reach such limit values.

The mass of covered leaves and inflorescences is calculated [10]:

$$G_{shat} = G_{shat1} + G_{shat2}, \quad (6)$$

where: G_{shat1}, G_{shat2} - consequently, the dry matter quantity of shattered leaves and inflorescences that are lost and remain in the forage mass after processing.

To determine grass dry matter losses resulting from the shattering of vegetative plant parts, it is necessary to determine plant leafiness before and after the operation, as well as the dry matter fraction of the shattered plant parts remaining in the grass after



processing.

Research on substantiating the rational parameters and operating modes of tedder-rakes was conducted using the multifactorial experiment planning method.

When selecting factors for conducting multifactorial experiments, they must meet the following requirements:

- the factors must be independent of one another;
- no contradictions should arise between the factors during the research;
- the factors must have a clear physical

meaning and be characterized by measurement accuracy and stability at a specific level.

To study the process, the following factors were selected: grass moisture (W , %), peripheral speed of the working bodies (R_w , m/s), forward speed of the unit (V , m/s), and grass feed rate (m , kg/s). The research was conducted by simulating the processing of wilted grass on a laboratory setup, the scheme of which is presented in Fig. 1. The leaf shattering coefficient (C_0 , %) was selected as the output variable, which was determined using the formula [5]:

$$C_0 = 10^4 G_{066} / \mu (100 - W) \quad (7)$$

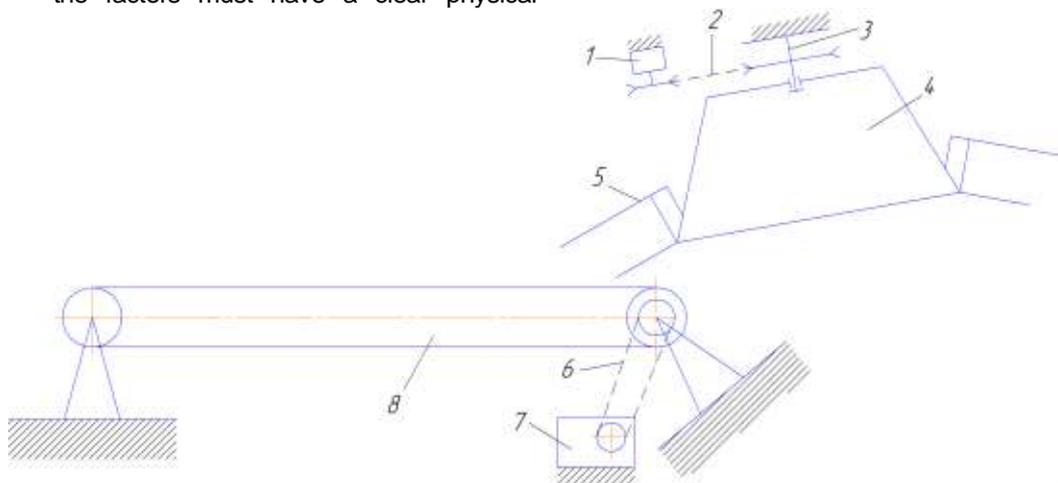


Fig. 1. Scheme of the installation for studying the process of covering vegetative parts of plants during stirring and raking grass: 1 - rotor drive mechanism; 2 - V-belt transmission; 3 - axle; 4 - rotor; 5 - rakes; 6 - chain transmission; 7 - motor-reducer; 8 - conveyor.

Conclusions. Total hay losses caused by unraked material and the shattering of vegetative plant parts during raking should not exceed 2.5%. Losses due to unraked material for rotary rakes with centrifugal working bodies are low and do not exceed 0.5%.

It has been established that the primary losses occur due to the shattering of vegetative plant parts. Although the majority of shattered parts remain within the forage mass after tedding and raking operations, these parts are free - that is not attached to plant stems, and are consequently lost during subsequent operations. Therefore, this specific loss indicator value should be selected as the permissible value for the shattering coefficient during optimization.

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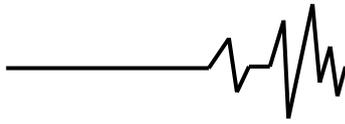
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ВИЗНАЧЕННЯ РАЦІОНАЛЬНИХ ПАРАМЕТРІВ І РЕЖИМІВ РОБОТИ ГРАБЛІВ-ВОРУШИЛОК

У системі кормовиробництва заготівля сіна з бобових трав та бобових сумішей займає пріоритетне місце завдяки високому вмісту рослинного білка. Проте ефективність використання біологічного потенціалу культур суттєво обмежується недосконалістю технологічних процесів збирання. Специфіка

бобових трав полягає у суттєвій відмінності міцності зв'язку зі стеблом найбільш цінних вегетативних органів - листя та суцвіть, які за поживністю у 2...3 рази переважають стеблову фракцію. Встановлено, що основні втрати врожаю та зниження якості корму відбуваються під час механічної обробки прив'язаної маси, зокрема при виконанні операцій ворущіння, згрібання у валки та перевертання. Тому об'єктивна оцінка якості роботи відповідних сільськогосподарських машин (ворушилок, граблів) є критично важливою умовою удосконалення технологій.

Головною методологічною проблемою при дослідженні цих процесів є складність достовірного визначення кількісних показників втрат у польових умовах. У реальних умовах експлуатації через дрібнодисперсність втрачених часток та їх схильність до кришіння повний збір є практично неможливим. У зв'язку з цим, оцінка якості роботи машин у полі здійснюється переважно непрямими методами, достовірність яких викликає обґрунтовані сумніви.

Під час механічної дії відбувається два паралельні процеси: по-перше, втрата частини вільних часток, що вже існували у прокосі (внаслідок розсіювання по стерні); по-друге - активне руйнування рослин із утворенням нових вільних фракцій. Частина цих новоутворених часток втрачається безповоротно, але значна їх кількість акумулюється у структурі сформованого валка, залишаючись у «зв'язаному» стані до наступного механічного впливу. Таким чином, визначення втрат за простою різницею маскує реальний рівень пошкодження рослин, оскільки не враховує накопичення вільних часток у масі. Це призводить до викривлення результатів випробувань та ускладнює конструктивне вдосконалення техніки. Вирішення цієї наукової проблеми вимагає розробки нових теоретичних підходів, які б враховували сукупний вплив факторів розсіювання та накопичення вегетативних решток у процесі заготівлі кормів.

Ключові слова: кормовиробництво, кормові трави, сіно, технологія, заготівля, фізичні та механічні властивості, ротаційні робочі органи, ворущіння, граблі.

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