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# COMPARISON OF TECHNOLOGICAL OPERATIONS IN PROCESSING ALFALUFER HAY IN TERMS OF THEIR IMPACT ON FORAGE QUALITY AND QUANTITY

*Haymaking is a key stage in feed production, as the choice of technological methods directly affects its quality, nutritional value, and digestibility by animals. One of the most significant challenges in this process is the mechanical loss of alfalfa leaves during harvesting and processing of the mown mass. It is well known that leaves contain the majority of protein, carotene, and other biologically active substances.*

*Research results have confirmed the significant impact of windrow processing frequency on dry matter losses and the nutritional value of the feed. It has been established that a single windrow treatment during drying reduces dry matter losses by 2.6–4.5 % compared to multiple tedding operations. This has a positive effect on the chemical composition of the hay and promotes the preservation of essential nutrients, particularly carotene. The carotene content in the natural mass with single windrow processing reached 32.4 mg/kg in the first experiment and 30.4 mg/kg in the second, which significantly exceeds the values for hay subjected to intensive mechanical processing.*

*Optimizing the haymaking process not only reduces nutrient losses but also shortens drying times, which is especially important under unfavorable weather conditions. Reducing the time that mown mass remains in the field minimizes the risk of feed quality deterioration due to precipitation and promotes uniform drying of stems and leaves.*

*Thus, improving the technological processes of alfalfa haymaking enables the production of high-quality feed with a high nutrient content and stable feed characteristics. Compared to traditional harvesting methods, the use of optimized technologies helps reduce dry matter losses, increase carotene and protein content, and improve the overall nutritional value of the hay. This contributes to a more efficient supply of high-quality roughage for livestock farming, which is a crucial factor in enhancing the productivity of agricultural animals and the profitability of the industry as a whole.*

**Keywords:** *drying, consortium, chemical composition, hay, mechanical losses, alfalfa seeds, drying, active ventilation.*

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## 1. Introduction

The main factor in the production of livestock products together with the improvement of the genetic potential of animals is the feed base, its structure, level and quality of feed. Ensuring a full-fledged scientifically sound fodder base involves the intensive use of agricultural resources, the use of energy and cost-effective technologies of harvesting, storage of fodder and their rational use.

Hay has a special role in providing farm animals with nutrients. Haymaking is one of the most common ways to preserve green grass. Hay of legumes, especially alfalfa, is an excellent source of protein, minerals, vitamins and is a mandatory component in animal diets [1]. It was and remains one of the main bulky feeds that have a direct impact on the digestibility of other feeds by ruminants. Hay is a source of coarse fiber needed for normal scar digestion. In addition, it is the only bulky food that contains a sufficient amount of vitamin D, which regulates mineral metabolism in animals, due to its dietary properties, it is widely used in the diets of not only adults but also young animals [1].

Feeding alfalfa hay increases the digestibility of the diet and the absorption of nutrients, resulting in improved animal productivity. When choosing the technology of harvesting hay from alfalfa take into account its biological characteristics [2].

Alfalfa is a very valuable fodder crop of the legume family. It is grown in more than 80 countries on all continents of the globe in an area exceeding 355 million hectares in various natural and economic areas and environmental conditions: from the temperate taiga to the tropics. Alfalfa is grown mostly in its pure form and as a component of grass mixtures on hayfields and to create cultivated pastures [3].

Scientific and technological progress in haymaking is aimed at intensifying its drying and reducing the time spent in the field. Slow drying of stems, especially legumes, increases the drying time and drying them in the field, which inevitably leads to increased nutrient losses, which in some cases reach 50 %.

The main problem when harvesting hay from legumes is the loss of leaves, the most valuable part of the feed. They occur during the processing of rolls and during the next technological operations for moving hay.

Therefore, in-depth study of accelerated drying of alfalfa grass in the field in order to maximize nutrient conservation at minimum cost of fuel and energy resources, ensuring high animal productivity and product quality is an urgent economic problem.

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Haymaking is associated with significant loss of nutrients due to falling leaves and inflorescences or significant energy consumption for artificial drying. Mechanical losses often exceed more than 40 %, and more than half of them occur during field operations: mowing, flattening, moving, raking and weight gain.

Artificial drying eliminates these losses, but energy costs are more than 680–900 kcal per 1 kg of evaporated water. To obtain a ton of hay with a moisture content of 15 %, it is necessary to remove 215 kg of water from the hay with a moisture content of 30 %. This requires an average of 711.65 MJ of energy, which in terms of gross energy content (15.5 MJ per 1 kg) corresponds to 45.9 kg of hay. For hay, 50 % of the moisture cost is 2317 MJ, which is equivalent to 149.5 kg of hay. The allowable drying time is 4 days, and when the humidity is more than 70 %, the air used for ventilation is heated to 4–5 °C to maintain a constant evaporating capacity of 1–2.5 g/m$^3$ air [2, 3].

The share of energy costs in the total cost of the technological process of dehydrated fodder procurement exceeds 35 %. Therefore, in production, despite significant mechanical, biological losses, as well as losses associated with hay in the rain, both in our country and abroad, field drying of hay is widely used.

The most common are technologies that provide drying of grass in mowing and rolling to a humidity of 20–22 %, or 25–30 %. In the first case, the grass from the rolls is selected and pressed into bales or rolls, which are laid for storage. Otherwise, the grass is pressed into bales, the density of which does not exceed 140 kg/m$^3$ and left in the field for 2–3 days for drying [4, 5].

The question of determining the influence of development phase, mowing time, weather conditions, harvesting technology on moisture intensity, chemical composition, digestibility and absorption of nutrients, as well as the efficiency of feeding alfalfa hay to farm animals has been studied extensively in Ukraine [6] and abroad.

The question of the influence of the frequency of tillage when drying alfalfa grass in the field on the rate of moisture and chemical composition of feed is insufficiently studied, and on the impact of this measure on the digestibility of hay nutrients and its effectiveness meat growing has not been studied at all, which prompts to ask this question to study.

*The aim of this research* is to identifying the impact of the number of technological operations for processing the swath of mown alfalfa during hay harvesting on the chemical composition and quality of the forage. Particular attention is given to determining the mechanical losses of alfalfa leaves, the relationship between moisture recovery rates and solar radiation exposure, and the effects of roll treatment frequency on nutrient preservation. The study aims to establish optimal hay harvesting technologies that minimize dry matter losses, enhance the retention of nutrients and carotene, and improve overall forage quality.

## 2. Materials and Methods

*The object of research* is the impact of agrotechnical and technological factors on the quality of roughage for animal husbandry, particularly the maximum content of nutrients and vitamins.

The research was conducted on the basis of the State Enterprise "Research Economy "Shevchenkivske" (SE RE "Shevchenkivske") Institute of Bioenergy Crops and Sugar Beets at NAAS of Ukraine (Kyiv, Ukraine), which is part of the training and research and production complex "All-Ukrainian Research and Training Consortium".

The study involved two field technological experiments conducted on pure crops of alfalfa blue variety Vinnychanka under different weather conditions. These experiments focused on assessing the impact of different frequencies of technological operations for processing the roll (stirring and rotating) on the quality and nutritional value of hay.

The first experiment, conducted from June 28 to July 1, 2020, was carried out on first-mowing alfalfa crops in their early flowering phase. The second experiment, conducted from July 21 to July 23, 2020, involved alfalfa harvested from the second mowing in the budding phase. Both experiments took place at the farm of SE RE "Shevchenkivske" during the 2020–2021 period, ensuring that different environmental conditions were accounted for in the assessment.

The experiments were designed to determine how the number of technological operations for roll processing influenced hay quality, particularly in terms of nutrient preservation, carotene content, and dry matter losses. The study examined the effects of single and multiple treatments of the roll during drying [7].

The mowing process was performed at the optimal growth phases of alfalfa: early flowering in the first experiment and budding in the second. After mowing, the alfalfa was left in swaths for the wilting phase. To accelerate drying and reduce nutrient losses, a multi-purpose forage harvester "MFH-F2" (Ukraine) was used. This machine is specifically designed to enhance the drying process in hay and haylage production, as well as for harvesting cereals and legumes. It facilitated controlled roll processing through stirring and rotating, enabling precise evaluation of how different frequencies of mechanical treatment influenced the quality of the final forage product.

Throughout the drying period, meteorological conditions were monitored to assess their effect on the rate of moisture loss. The impact of solar radiation on moisture recovery and nutrient retention was also analyzed. After the drying process, laboratory analyses were conducted to determine the chemical composition of the hay, including dry matter content, carotene levels, ash content, and mineral composition [8].

By completing the machine with replaceable working bodies, it can be used to perform the following technological operations: scattering grass from the rolls into swaths, stirring mowing and raking grass from swaths into rolls, turning (rotation). Execution of works on re-equipment of the car on various technological operations passes within 0.5–2 hours by installation of replaceable blocks of working bodies by means of the tool which goes complete with a tractor. MFH-F2 (Ukraine) with tractors of a class of 6–14 kN is aggregated.

In our experiments, when the humidity reached 20–22 %, the hay was pressed into rectangular bales with a density of 130–140 kg/m$^3$ with a PS-1.6 (Ukraine) baler with unloading in the field.

The experiments involve the use of a multipurpose forage harvester MFH-F2 with elastic working bodies (rubber fingers made of drive belt of the combine harvester SK-5 "Niva" (Ukraine); rubberized cone-shaped belt made of conveyor belt) for tillage in the process of drying alfalfa grass on hay.

In this case, the hay of different options was harvested using different multiplicity of tillage: in the first option (control) – no tillage was carried out, in the second – used single, in the third – twice, in the fourth – three times (only in the first experiment) tillage per day.

Samples of green alfalfa for research were taken during the entire period of hay harvest during the day every 2 hours after mowing. In the samples taken every 4 hours, were determined: dry and organic matter, protein, fat, fiber and ash. The experiment was performed on four groups of sheep (4 heads each) by the group method. Animals in groups are selected based on sex, live weight and age. The preparatory period of the experiment lasted 7 days, and the accounting period lasted 10 days.

Technological field and laboratory experiments were conducted in accordance with Industry and State standards: (morphological composition of the mass); (humidity and moisture removal of the dried mass); DSTU 4674:2006 [9, 10].

The yield of alfalfa green mass was determined on the day of its mowing on 5 accounting plots of 1 m$^2$, located on the diagonals of the total area. From each accounting area, the entire mass of plants was cut at the height required by agronomic requirements, and weighed [10].

The intensity of moisture removal was set according to the State Standard by drying to constant weight at a temperature of 105 °C, followed by calculation of the percentage of water.

The rate of moisture removal was determined by:

$$\frac{dW}{dt}=\frac{W_1-W_{i-1}}{t_1-t_{i-1}}, \tag{1}$$

where $dW/dt$ – moisture transfer rate, %/hours; $W_1$ – actual humidity of mass, %; $t_i$ – drying time, hours; $W_1$–$W_{i-1}$ – humidity measurements during drying, %; $t_1$–$t_{i-1}$ – interval between measurements, hours.

Based on the humidity data, a schedule of drying dynamics was compiled. The mathematical dependence is calculated using the method [11].

The botanical composition of the forage was determined by collecting and analyzing grass samples weighing 1 kg. Each plant species within the sample was separated and weighed individually to establish its proportional content in the total mass. This approach allowed for an accurate assessment of the species composition, which is crucial for evaluating forage quality and its nutritional value for livestock.

The harvested forage consisted primarily of alfalfa (*Medicago sativa L.*), which formed the basis of the hay. As a leguminous plant, alfalfa is highly valued for its high protein content, rich mineral composition, and ability to fix atmospheric nitrogen, improving soil fertility. The presence of grasses such as timothy grass (*Phleum pratense L.*), fescue (*Festuca pratensis Huds.*), and orchard grass (*Dactylis glomerata L.*) was also noted. These species contribute fiber and structural carbohydrates, essential for proper digestion in ruminants.

Additionally, the forage contained a certain proportion of weed species, including representatives of the Compositae (*Asteraceae*), Brassicaceae, and Plantaginaceae families. While some of these plants may have minor nutritional value, their presence in large quantities can reduce the overall quality of the forage and affect its palatability.

To assess the losses of leaves and inflorescences of legumes, which significantly impact the final nutritional composition of the hay, morphological analysis was conducted. During the drying process in the field, mechanical losses occur due to natural detachment of leaves and flower structures, particularly in leguminous species such as alfalfa. A 1 kg sample of the drying forage was collected, and the separated leaf and inflorescence fragments were weighed to determine their proportion of total dry matter loss.

Complete zootechnical analysis of selected alfalfa samples was performed in the laboratory of mass analysis according to generally accepted methods [12, 13] on the basis of which the nutritional value of the received fodder and the actual loss of their nutritional value is calculated depending on the application of the planned technological operations.

During the experiments also investigated the indicators that characterize the quality of the machine MFH-F2, namely: width, height, profile of the roll, its power, weight loss from non-capture by the working bodies of the machine.

The width of the roll was measured along its edges at 10 points of the accounting area. Height – from the ground to the top of the roll.

The mass of one running meter of the roll was taken as the power of the roll (weighing was carried out in five places).

Weight loss from non-capture by the working bodies of the machine was determined on the accounting sections with a length of 10 m and a width equal to the width of the capture of the machine. All remnants of hay, raked by hand, weighed to the nearest 0.1 kg, counted per hectare as a percentage of harvest.

In order to determine leaf losses during technological operations for processing rolls (moving, rotating) in the process of drying alfalfa in field conditions, its leafiness was determined using the method [13].

Foliage is the ratio of the dry matter mass of leaves and inflorescences to the dry matter mass of grass.

The mass of dry matter before its processing can be determined based on the following:

$$G=M\cdot\frac{(100-W)}{100}, \tag{2}$$

where $G$ – mass of dry matter of grass, g; $M$ – mass of grass, g; $W$ – relative humidity of grass, %.

Losses of dry matter as a result of upholstery of vegetative parts of plants were calculated by determining the foliage of plants before and after the operation, as well as the proportion of dry matter of upholstered parts of plants that remain in the grass after its treatment.

Meteorological conditions during the first experiment during haymaking were not very favorable Table 1. During June and in the first decade of July 2020, unstable weather with rains and thunderstorms persisted.

Losses of dry matter due to the detachment of vegetative plant parts were calculated by determining the proportion of leaves before and after processing, as well as measuring the amount of dry matter lost quintals per hectare (q/ha) from the detached plant parts remaining in the forage mass after treatment. The assessment of dry matter losses was crucial for evaluating the impact of different technological operations on the final quality of the harvested hay. To comprehensively assess the quality of the harvested hay, several key nutritional indicators were analyzed. One of the fundamental parameters was the dry matter content (% DM), which was determined by drying forage samples in a thermostatic drying cabinet at 105 °C until a constant weight was achieved. This measurement allowed for an accurate evaluation of the moisture content in the hay, which is essential for determining its stability during storage and preventing spoilage.

The crude protein content (% CP) was analyzed using the Kjeldahl method, which measures the total nitrogen content in the forage and converts it into crude protein. This indicator is particularly significant as it reflects the ability of the feed to support livestock growth, muscle development, and milk production. Since alfalfa hay is known for its high protein concentration, optimizing harvesting conditions was crucial to preserving this nutrient.

Another important parameter was the crude fiber content (% CF), which was determined through the Weende analysis method. This test quantifies structural carbohydrates, which play a vital role in ruminant digestion by promoting proper gut function and regulating energy availability. The proportion of crude fiber is essential in balancing the diet, as excessive fiber can reduce feed intake, while insufficient levels may lead to digestive disorders.

The crude ash content (% Ash) was evaluated by burning forage samples in a muffle furnace at 550–600 °C, leaving behind only the mineral components. This measurement provides insight into the total mineral supply available in the feed, as minerals play a crucial role in bone formation, metabolic processes, and overall animal health.

A key factor influencing the nutritional value of hay is its carotene content (mg/kg), which was determined using spectrophotometric analysis. Carotene is the precursor of vitamin A, essential for immune function, reproduction, and vision in livestock. Since carotene is primarily found in the leaves of legumes like alfalfa, minimizing leaf loss during drying and processing was vital for maintaining high-quality hay. To assess the mineral balance of the forage, the calcium (Ca) and phosphorus (P) content was measured using atomic absorption spectrophotometry. These minerals are particularly important for bone strength, enzyme activation, and metabolic regulation. An optimal Ca-to-P ratio is necessary to prevent deficiencies that could lead to developmental and reproductive issues in animals.

Finally, the overall nutritional value and digestibility of the forage were assessed using the Relative Feed Value (RFV) and Digestibility Coefficients. These values were calculated based on Neutral Detergent Fiber (NDF) and Acid Detergent Fiber (ADF) analysis, which help estimate forage digestibility and voluntary intake potential by livestock. Lower NDF levels indicate higher digestibility and greater feed intake, while ADF levels provide insight into the amount of indigestible fiber in the hay.

The first experiment was conducted under unfavorable weather conditions during the haymaking period (Table 1). Throughout June and the first decade of July 2020, unstable weather persisted, with frequent rains and thunderstorms, leading to increased risks of nutrient loss due to delayed drying and potential leaching of soluble compounds from the forage.

**Table 1**

Meteorological conditions during experiments on alfalfa

| Days | Temperature, °C | | | | | Relative humidity, % | | Precipi-tation, mm |
|---|---|---|---|---|---|---|---|---|
| | air | | | on the soil surface | | aver-age | min | |
| | average | max | min | max | min | | | |
| The first experiment | | | | | | | | |
| 28.06.20 | 20.5 | 25.3 | 13.5 | 37.6 | 11.0 | 82 | 51 | – |
| 29.06.20 | 22.4 | 27.2 | 16.3 | 45.3 | 13.1 | 69 | 52 | – |
| 30.06.20 | 22.8 | 27.2 | 16.6 | 47.4 | 14.0 | 71 | 50 | – |
| 01.07.20 | 21.8 | 29.2 | 17.5 | 49.7 | 17.0 | 78 | 57 | – |
| The second experiment | | | | | | | | |
| 21.07.21 | 26.7 | 31.2 | 17.6 | 59.4 | 16.4 | 49 | 38 | – |
| 22.07.21 | 32.3 | 37.4 | 18.2 | 61.0 | 17.5 | 56 | 37 | – |
| 23.07.21 | 34.1 | 38.2 | 20.1 | 61.7 | 18.7 | 51 | 35 | – |

During the experiment, air temperature ranged from 13.5 to 29.2 °C, while the relative humidity fluctuated between 69 % and 82 % (Table 1). These conditions significantly influenced the rate of moisture loss in the drying hay, affecting the effectiveness of roll processing operations. High humidity and precipitation prolonged the drying period, increasing the risk of mold development, nutrient leaching, and degradation of protein and carotene levels.

## 3. Results and Discussion

Studies have shown that the amount of loss of dry matter of alfalfa in the process of harvesting it for hay depends on weather conditions, moisture content and the frequency of rolling. The profile of the roll in 1 variant (2nd experiment), which is shown in Fig. 1. Under adverse weather conditions (the first experiment), the mechanical losses of dry matter according to the variants of the experiment were: 1 – 12.7; 2 – 11.8; 3 – 14.2 and 4 – 14.9 %, or 16.26, respectively; 15.12; 18.18 and 19.08 c/ha. As a result of the agitation and rotation of the roll, the amount of mechanical losses ranged from 5.4 % in the second variant to 7.3 % in the fourth variant of the experiment. The greatest losses were observed due to the selection and pressing of hay at a humidity of 21–22 % press sorter PS-1.6.

In the second experiment, the loss of dry matter was much smaller than in the first, which is considered natural when harvesting hay in favorable weather conditions.

Total mechanical losses were 8.9 % in the first, 8.3 % in the second, 9.8 % in the third version of the experiment, or 6.1; 5.69; 6.72 q/ha [14].

Biochemical losses of dry matter were relatively smaller than mechanical and depended mainly on the duration of the mass in the field. Since the control variant hay was not subjected to technological processing and dried in the first experiment for 82 hours and in the second experiment for 58 hours, the biochemical losses of dry matter were the largest and amounted to 8.2 % in the first and 5.6 % in the second experiments.

Total losses (biochemical + mechanical) of dry matter ranged from 16.4 to 20.9 % in the first and 11.9 to 14.5 % in the second experiments in Table 2.

In both experiments, relatively lower losses of dry matter were determined in the second variant, where haymaking was carried out using a single roll treatment. The general regularity of growth of losses of dry substances with increase in quantity of technological operations on processing of a roll and decrease in humidity of weight is confirmed.

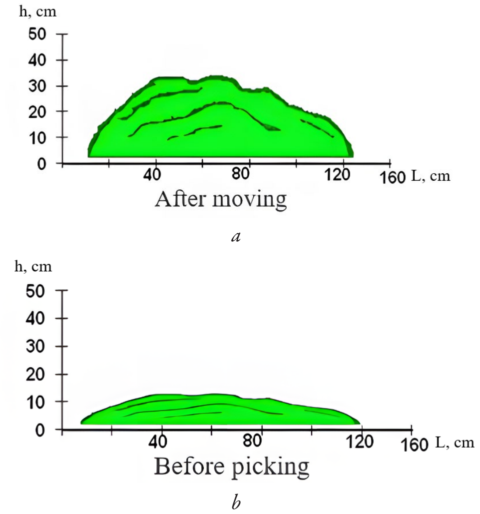


**Fig. 1.** The profile of the roll: *a* – after moving; *b* – before picking

It is known that the mechanical losses during the harvesting of alfalfa for hay are mainly related to the leaves – the most valuable part of the feed [15].

The loss of leaves during field drying of alfalfa in our experiments is characterized by the dynamics of foliage – the ratio of dry matter of leaves with petioles and inflorescences to the dry matter of grass (Table 3).

The data in Table 3 show that in all variants of both experiments in the process of drying green alfalfa there was a decrease in its foliage. The most noticeable were the changes in foliage after the technological operations of agitation, rotation of the roll and during the final operations of selection and pressing of hay.

Studies have shown that the loss of leaves was also observed in the control versions of both experiments, where the treatment of the roll in the drying process was not carried out. The main losses of leaves in these variants are recorded at the final stage of hay harvesting, during selection and pressing.

This is due to the fact that prolonged stay of the mass in the field under the open sky in order to bring it to a humidity suitable for pressing hay (20–22 %), leads to significant overdrying of the upper layer and decomposition of the lower layer of the roll directly on the surface soil, especially at high power rollers.

The total amount of leaf loss in the control version of the first experiment was 11.6, and in the second experiment – 8.2 % of their initial level.

The lowest leaf losses were found in 2 variants with the minimum amount of tillage: 10.1 % in the first and 7.4 % in the second experiment. More intensive treatment of the roll in 3 and 4 versions of the first experiment caused a relatively greater decrease in foliage, which were lower by 13.2 and 12.4 %, respectively, from their initial level.

In the third version of the second experiment, where the roller was subjected to two treatments during the day, the foliage in the process of harvesting alfalfa hay decreased from 51.7 % after mowing to 42.6 % after harvesting, leaf loss was 9.1 %.

It is worth noting the study of the dynamics of foliage and in the laboratory experiment on upholstery of alfalfa leaves on a model installation with a spring working body. The experiment was carried out on alfalfa blue second slope in the budding phase – the beginning of flowering.

According to the morphological composition of the mass, stems accounted for 50.92 %, leaves and inflorescences – 49.08 %. In order to model the technological process of selection of the dried mass for haylage and hay, the experiment was performed at a humidity of 58.32–1.23 % and 25.08–0.67 %. The linear velocity of the spring rake was 5.3 m/s. Indicators of reduction in foliage depending on the number of strokes are presented in Table 4.

**Table 2**

Loss of alfalfa dry matter during field drying

| Version | Indicator | Crop capacity | | Losses | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | mechanical | | | | biochemical | total |
| | | initial mass | hay | after agitation | after rotation | after the baler | total | | |
| The first experiment | | | | | | | | | |
| 1 | Mass, q/ha | 544.0 | 130.87 | – | – | 21.02 | – | – | – |
| | including dry matter: q/ha | 128.05 | 101.23 | – | – | 16.26 | 16.26 | 10.5 | 26.76 |
| | % | 100 | – | – | – | 12.7 | 12.7 | 8.2 | 20.9 |
| 2 | Mass, q/ha | 544 | 137.45 | 6.28 | 9.45 | 10.52 | – | – | – |
| | including dry matter: q/ha | 128.05 | 107.05 | 1.79 | 5.12 | 8.19 | 15.12 | 5.89 | 21.00 |
| | % | 100 | – | 1.4 | 4.0 | 6.4 | 11.8 | 4.6 | 16.4 |
| 3 | Mass, q/ha | 544.0 | 131.16 | 7.90 | 10.33 | 11.85 | – | – | – |
| | including dry matter: q/ha | 128.05 | 103.47 | 2.94 | 5.89 | 9.35 | 18.18 | 6.40 | 24.58 |
| | % | 100 | – | 2.3 | 4.6 | 7.3 | 14.2 | 5.0 | 19.2 |
| 4 | Mass, q/ha | 544.0 | 130.55 | 9.43 | 11.85 | 12.43 | – | – | – |
| | including dry matter: q/ha | 128.05 | 102.18 | 3.33 | 6.02 | 9.73 | 19.08 | 6.79 | 25.87 |
| | % | 100 | – | 2.6 | 4.7 | 7.6 | 14.9 | 5.3 | 20.2 |
| The second experiment | | | | | | | | | |
| 1 | Mass, q/ha | 327.0 | 73.70 | – | – | 7.66 | – | – | – |
| | including dry matter: q/ha | 68.6 | 58.65 | – | – | 6.10 | 6.10 | 3.85 | 9.95 |
| | % | 100 | – | – | – | 8.9 | 8.9 | 5.6 | 14.5 |
| 2 | Mass, q/ha | 327.0 | 78.53 | 2.08 | 2.88 | 4.27 | – | – | – |
| | including dry matter: q/ha | 68.6 | 60.44 | 0.62 | 1.78 | 3.29 | 5.69 | 2.47 | 8.16 |
| | % | 100 | – | 0.9 | 2.6 | 4.8 | 8.3 | 3.6 | 11.9 |
| 3 | Mass, q/ha | 327.0 | 76.35 | 3.2 | 3.02 | 4.4 | – | – | – |
| | including dry matter: q/ha | 68.6 | 59.54 | 0.96 | 1.99 | 3.43 | 6.72 | 2.33 | 9.05 |
| | % | 100 | – | 1.4 | 2.9 | 5.0 | 9.8 | 3.4 | 13.2 |

**Table 3**

Changes in alfalfa foliage in the process field wilting, %

| Technological operation | The first experiment | | | | The second experiment | | |
|---|---|---|---|---|---|---|---|
| | version | | | | version | | |
| | 1 | 2 | 3 | 4 | 1 | 2 | 3 |
| When mowing | 49.1 | 49.1 | 49.1 | 49.1 | 51.7 | 51.7 | 51.7 |
| Before picking | 47.5 | 46.8 | 43.4 | 43.7 | 50.6 | 49.3 | 47.4 |
| After pressing | 37.5 | 39.0 | 35.9 | 36.7 | 43.5 | 44.3 | 42.6 |
| Decrease from the initial level | 11.6 | 10.1 | 13.2 | 12.4 | 8.2 | 7.4 | 9.1 |

**Table 4**

Losses in the process of upholstering alfalfa leaves on a model installation with a spring working body

| Humidity, % $M \pm m$ | Indicator | Foliage to impact, % | Foliage after impact by a spring working body | | | | | | | | Leaf loss, % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1st | | 2nd | | 3rd | | 4th | | |
| | | | foliage rate, % | upholstered, % | foliage rate, % | upholstered, % | foliage rate, % | upholstered, % | foliage rate, % | upholstered, % | |
| 58.32±1.23 | $n$ | 9 | 9 | 9 | 9 | 9 | 8 | 8 | 8 | 8 | 9 |
| | $M$ | 49.08 | 46.47 | 2.64 | 43.83 | 2.65 | 42.53 | 1.30 | 41.41 | 1.14 | 7.70 |
| | σ | 3.45 | 3.34 | – | 3.78 | – | 3.53 | – | 2.28 | – | 1.84 |
| | $m$ | 1.15 | 1.11 | – | 1.26 | – | 1.17 | – | 1.05 | – | 0.61 |
| | $Cv$ | 7.04 | 7.19 | – | 8.64 | – | 8.30 | – | 7.62 | – | 23.99 |
| | $Cm$ | 2.34 | 2.39 | – | 2.88 | – | 2.76 | – | 1.80 | – | 7.99 |
| 28.08±0.67 | $n$ | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| | $M$ | 48.91 | 45.10 | 3.83 | 41.96 | 3.14 | 39.92 | 2.04 | 38.72 | 1.20 | 10.21 |
| | σ | 3.49 | 3.57 | – | 4.08 | – | 3.88 | – | 3.56 | – | 2.56 |
| | $m$ | 1.23 | 1.26 | – | 1.44 | – | 1.37 | – | 1.25 | – | 0.90 |
| | $Cv$ | 7.13 | 7.93 | – | 9.73 | – | 9.72 | – | 9.19 | – | 25.0 |
| | $Cm$ | 2.52 | 2.80 | – | 3.44 | – | 3.43 | – | 3.24 | – | 8.87 |

It has been experimentally established that the humidity of the sample significantly affects the number of upholstered leaves (only isolated cases of breakage off the top of stems and side shoots). With almost equal foliage of the original mass (48.98–49.11 %), the first collision with the working body of the spring type is accompanied by a loss of 2.64 % of the leaves. Reducing the humidity to the parameters of haymaking ($W_k$ = 25.08 %), increases the number of upholstered leaves to 3.48 % (or 45.4 %).

The application of subsequent blows (but not more than four) was accompanied by a gradual decrease in the number of upholstered leaves, and foliage decreased from 49.11 to 41.41 %, i. e. lost 7.73 % of leaves. When simulating the selection of hay (agitation, rotation in the final stages of wilting), the total loss of leaves was much greater and amounted to 10.21 %, and the relative foliage decreased from 48.93 to 38.72 %, respectively.

The dependence of the number of upholstered leaves on the initial humidity of the sample and the number of strokes is characterized by the regression equation:

$$\beta = 10.0 \cdot W^{-367} \cdot m^{0.93}, \qquad (3)$$

where $\beta$ – loss of leaves from upholstery, %; $W$ – humidity of samples, %; $m$ – the number of blows inflicted by the working bodies.

This regression equation corresponds to the experimental data at the 5 percent level of significance ($P \geq 0.95$).

The analysis of the regression equation shows that the factor $m$ (number of strokes) has a much stronger effect on the degree of leaf upholstery (pair correlation coefficient $r_{m\beta} = 0.89$) than the humidity of the samples (pair correlation coefficient $r_{m\beta} = -0.41$). Among all roughage, a special place is given to alfalfa hay, which is a desirable and indispensable component of the diet of farm animals.

The chemical composition and nutritional value of alfalfa hay are influenced by: climatic conditions, soils, development phase during the mowing period, variety, technology of cultivation and harvesting, etc. Haymaking is associated with large losses of nutrients due to loss of leaves and inflorescences or significant energy consumption for artificial drying. Mechanical losses often exceed 40 % or more, and more than half of them occur during field operations: mowing, flattening, moving, raking and weight gain.

According to [15] legume hay can be classified as class I under the following conditions: the content of legumes – not less than 90 %, moisture – not more than 17 %, crude protein – not less than 14 %, carotene – not less than 30 mg/kg, fiber – no more than 27 %, mineral impurities – no more than 0.3 %.

The results obtained in field technological experiments in 2020–2021 show that the frequency of tillage in the process of harvesting alfalfa for hay and weather conditions to some extent affect its quality and nutrient content in Tables 5, 6.

Thus, the protein content in the original mass (the first experiment) was 15.61, in hay harvested without the use of roll treatment – 13.43, with a single treatment – 14.81, double – 13.69 and triple 13.65 % in dry matter. Therefore, according to the content of crude protein in the first experiment, only the hay of the 2nd variant, harvested using a single treatment of the roll, according to the requirements of the State Standard can be classified as quality to class I.

In other variants (1, 3, 4) hay was somewhat inferior to the requirements of the State Standard and in terms of protein content occupied an intermediate place between I and II class.

When analyzing the results obtained on the protein content in hay, it is easy to see that in the process of drying alfalfa there was a decrease in the amount of protein, which is characterized in the first experiment by the following indicators: in control (first option) – by 2.18 %; 0.8 %, i. e. almost 3 times less than in the control, in the 3rd variant – by 1.92 and in the 4th variant – by 1.96 % less in comparison with green alfalfa (Table 7, Fig. 2, 3).

**Table 5**

Chemical composition of alfalfa hay

| Option and multiplicity roll processing | Dry substance, g/kg | Contained in dry matter, % | | | | |
|---|---|---|---|---|---|---|
| | | protein | fat | cell-guilt | ashes | BER |
| The first experiment | | | | | | |
| Initial mass | 235.4 | 15.61 | 3.20 | 34.07 | 7.05 | 40.07 |
| 1 – without cultivation | 807.8 | 13.43 | 1.52 | 39.89 | 6.87 | 38.29 |
| 2 – single | 845.5 | 14.81 | 2.05 | 35.95 | 6.35 | 40.84 |
| 3 – double | 854.6 | 13.69 | 1.80 | 40.23 | 6.56 | 37.72 |
| 4 – triple | 857.4 | 13.65 | 1.65 | 38.92 | 6.72 | 39.06 |
| The second experiment | | | | | | |
| Initial mass | 209.9 | 16.57 | 3.35 | 27.48 | 7.21 | 45.39 |
| 1– without cultivation | 837.4 | 13.84 | 2.05 | 33.74 | 7.0 | 43.37 |
| 2 – single | 828.2 | 15.71 | 2.66 | 30.38 | 7.46 | 43.79 |
| 3 – double | 829.6 | 15.06 | 2.61 | 30.55 | 7.62 | 44.16 |

**Table 6**

Chemical composition of alfalfa hay, % in natural mass

| Version | Water | Dry matter | Organic matter | Protein | Fat | Cellulose | Ash | BER |
|---|---|---|---|---|---|---|---|---|
| 1st experiment | | | | | | | | |
| Initial mass | 76.46 | 23.54 | 21.88 | 3.67 | 0.75 | 8.02 | 1.66 | 9.44 |
| 1 | 19.22 | 80.78 | 75.23 | 10.85 | 1.23 | 32.22 | 5.55 | 30.93 |
| 2 | 15.45 | 84.55 | 79.18 | 12.52 | 1.73 | 30.39 | 5.37 | 34.54 |
| 3 | 14.54 | 85.46 | 79.85 | 11.70 | 1.54 | 34.48 | 5.61 | 32.13 |
| 4 | 14.26 | 85.74 | 79.98 | 11.70 | 1.41 | 33.37 | 5.76 | 33.5 |
| 2nd experiment | | | | | | | | |
| Initial mass | 79.01 | 20.99 | 19.48 | 3.48 | 0.70 | 5.77 | 1.51 | 9.53 |
| 1 | 16.26 | 83.74 | 77.88 | 11.59 | 1.72 | 28.25 | 5.86 | 36.32 |
| 2 | 17.18 | 82.82 | 76.64 | 13.01 | 2.20 | 25.16 | 6.18 | 36.27 |
| 3 | 17.04 | 82.96 | 76.64 | 12.49 | 2.16 | 25.34 | 6.32 | 36.63 |

**Table 7**

Changes in the content of nutrients in the dry matter alfalfa hay in the harvesting process

| Version | The magnitude of changes compared to the original mass, ± % | | | |
|---|---|---|---|---|
| | protein | fat | fiber | BER |
| 1st experiment | | | | |
| 1 | –2.18 | –1.68 | +5.82 | –1.78 |
| 2 | –0.8 | –1.15 | +1.88 | +0.77 |
| 3 | –1.92 | –1.4 | +6.16 | –2.35 |
| 4 | –1.96 | –1.55 | +4.85 | –1.01 |
| 2nd experiment | | | | |
| 1 | –2.75 | –1.3 | +6.26 | –2.02 |
| 2 | –0.86 | –0.69 | +2.5 | –1.6 |
| 3 | –1.51 | –0.74 | +3.07 | –1.23 |

It should be noted that the hay harvested in the best weather conditions in 2021, in the second experiment, the protein content was better in all variants of the experiment compared to the corresponding versions of the first experiment. The hay harvested during a single treatment of the roll contained the largest amount of protein – 15.71 in dry matter, which was 0.86 % inferior to the original mass. According to the protein content in the dry matter of hay 2 and 3 options can be classified as class I.

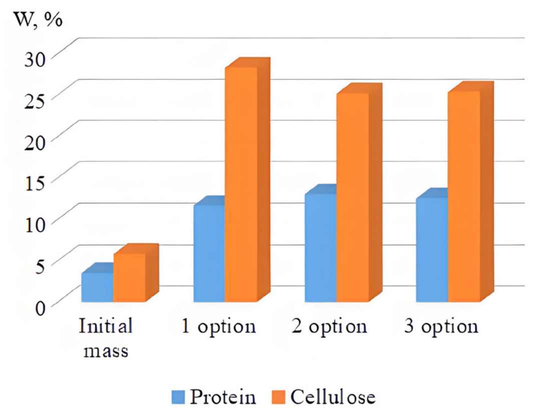


**Fig. 2.** Protein and fiber content in alfalfa hay of the first experiment, W, % in dry matter

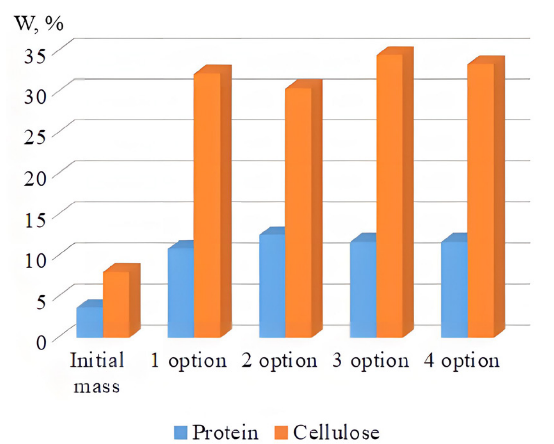


**Fig. 3.** Protein and fiber content in alfalfa hay of the second experiment, W, % in dry matter

The data in Table 1 show that along with the decrease in protein content during drying in alfalfa, an increase in the amount of fiber was observed (Fig. 2, 3). In the first experiment, the growth of fiber according to the variants of the experiment was observed in the following sizes: 1 – by 5.82 %; 2 – by 1.88; 3 – by 6.16; 4 – by 4.85 % compared to baseline.

In the second experiment, the fiber content in the hay of all variants was lower than in the first experiment and was 33.74 (1st variant), 30.38 (2nd variant), 30.55 % (3rd variant) in dry substance.

The results obtained in our experiments confirm the fact that the increase in fiber content in hay in the process of its procurement was more intense than the decrease in protein levels per hour of wilting mass. Thus, in the 1st experiment on average for 1 hour of drying the protein content is reduced by 0.015–0.026 %, and in the 2nd – by 0.025–0.047 %. At the same time, the increase in fiber content was 0.036–0.085 and 0.073–0.107 % in dry matter, respectively, for 1 hour of grass drying.

Interesting data were obtained in our experiments on the ratio of protein to fiber, which in 1 experiment was: in 1 variant – 0.337, in the second – 0.412, in the third – 0.340, in the fourth variant – 0.350, and in the initial mass – 0.458.

In the second experiment, these figures were slightly higher than in the first with the same pattern: 0.410 – in 1 variant, 0.517 – in 2 variant and 0.492 in 3 variants, in the initial mass – 0.602.

As can be seen from the above data, the advantage of the 2nd experimental option in the harvesting of hay with a single treatment of the roll over other options can be traced to all major indicators of quality composition.

The decrease in protein content and increase in the amount of fiber in the process of drying alfalfa was not only due to biochemical processes occurring in the dried mass, but also due to leaf loss, in which protein content is much higher and fiber – lower than in plant stems.

Crude fat in the hay was low, but compared to the original weight it was less in options (1, 2, 3, 4), respectively, 1.68, 1.15, 1.4, 1.55 % in the first and 1, 3, 0.68, 0.74 % less, respectively, in the second experiments (Table 8).

**Table 8**

Carotene, calcium and phosphorus content in the studied hay of alfalfa, mg/kg of natural weight

| Version | Moisture content, % | Carotene | Calcium | Phosphorus |
|---|---|---|---|---|
| 1st experiment | | | | |
| Initial mass | 76.46 | 52.3 | 6.90 | 0.85 |
| 1 | 19.22 | 18.8 | 15.3 | 1.71 |
| 2 | 15.45 | 32.4 | 15.93 | 1.73 |
| 3 | 14.54 | 29.8 | 14.81 | 1.49 |
| 4 | 14.26 | 28.9 | 15.34 | 1.53 |
| 2nd experiment | | | | |
| Initial mass | 79.01 | 47.8 | 6.67 | 0.91 |
| 1 | 16.26 | 18.7 | 13.27 | 1.83 |
| 2 | 17.18 | 30.4 | 12.86 | 1.95 |
| 3 | 17.04 | 28.3 | 13.31 | 1.88 |

A similar pattern was observed in the content of BER. In the process of harvesting hay there was a decrease in the content of BER in the amount of 1.01 to 2.35 % in the first and 1.23–2.02 % in the second experiments compared to the initial mass (except for the second option in the first experiment). Hay of different variants also differed in the content of carotene, calcium and phosphorus (Table 8).

The hay harvested using a single roll treatment had the highest content of carotene in the natural mass – 32.4 mg/kg in the first and 30.4 mg/kg in the second experiments. Undoubtedly, the loss of carotene in both experiments was significant. In control variants 1 and 2 of the experiments, they were 64.1 and 60.9 %, respectively, in 2 variants – 38.1 and 36.4 %, in 3 variants – 43.1 and 40.8 % to baseline [16–18].

There was no significant difference in the content of ash and minerals, calcium and phosphorus in the experimental variants.

The rate of moisture recovery of cut alfalfa grass and the nutritional value of hay are closely related to the action of solar radiation and the frequency of treatment of the roll during drying.

At one-time processing of a roll in the period of drying of an alfalfa grass provides decrease in losses of dry substances by 2.6–4.5 %, positively influences chemical composition of hay and creates the best conditions for preservation of nutrients and carotene.

On the basis of the conducted researches the technology of harvesting of alfalfa hay with one-time processing of a roll is offered to production. This makes it possible to reduce nutrient losses during the field drying of alfalfa on hay, increase the efficiency of its use in the diets of farm animals.

The data of the experiments give grounds to claim that the hay harvested using a single treatment of the roll had the highest content of carotene in natural weight – 32.4 mg/kg in the first and 30.4 mg/kg in the second experiments. The loss of carotene in the control variants of the experiments was 64.1 and 60.9 %, in the 2nd variant – 38.1 and 36.4 %, in the 3rd variant – 43.1 and 40.8 % to baseline.

According to all indicators of nutrient content, the technology of hay harvesting was the best, which corresponds to the second experimental variant, i. e. with the use of a single treatment of the roll per day.

The results obtained in the study are of great importance for agriculture, particularly for improving the technology of alfalfa hay harvesting. The proposed technology with a single swath treatment allows minimizing nutrient losses, including carotene, protein, and dry matter. This contributes to increasing the nutritional value of hay, which is especially relevant for dairy and meat livestock farming. The obtained data can be used in farming enterprises, agricultural companies, as well as in scientific and educational institutions to optimize the forage harvesting process.

Among the main limitations of the study, it is important to note the dependence of the hay drying process on weather conditions. Under unfavorable climatic conditions, drying efficiency may vary, requiring additional adjustments in the technological process. Additionally, the study was conducted using specific types of equipment (MFH-F2, PS-1.6), which may limit its applicability to other machinery. To fully implement the obtained results in production, additional research is needed under different climatic conditions and with the use of various agricultural equipment.

The martial law in Ukraine has significantly impacted the research process. Due to restricted access to certain scientific institutions and agricultural enterprises, some experimental studies were conducted under limited financial and material-technical conditions. Changes in the education and scientific activity system, associated with the transition to distance learning, also complicated communication between research groups and access to specialized laboratories. At the same time, the obtained results are particularly relevant for the agricultural sector under martial law, as increasing the efficiency of forage harvesting contributes to ensuring the country's food security.

Further research may focus on improving hay harvesting technologies, particularly optimizing the drying process and swath treatment considering different weather conditions. Additionally, it is advisable to study the impact of alternative methods for preserving nutrients in hay and the use of modern materials to enhance drying efficiency. Moreover, an important direction is the development of adaptive forage harvesting technologies for extreme conditions, which will help reduce the impact of climate change and other external factors on forage quality.

## 4. Conclusions

During the research, it was established that the frequency of windrow processing during alfalfa drying has a significant impact on the quality and chemical composition of the hay. The conducted experiments allowed for the determination of the optimal technology for alfalfa hay harvesting with minimal nutrient and carotene losses.

Main research results:

– With a single windrow processing during drying, dry matter losses decreased by 2.6–4.5 % compared to multiple tedding.

– The crude protein content in the dry matter of the hay during single windrow processing was 14.81 % (in the first experiment) and 15.71 % (in the second experiment), meeting the requirements of the national standard (DSTU) for first-class hay.

– The carotene content in the natural hay mass with single windrow processing reached 32.4 mg/kg in the first experiment and 30.4 mg/kg in the second, significantly higher than with other drying methods.

– The fiber content in the dried mass increased due to leaf losses during drying. The smallest increase in fiber content was observed with single windrow processing (+1.88 % in the first experiment and +2.5 % in the second).

– Carotene losses in the control variants were 64.1 % and 60.9 %, whereas with single windrow processing, they were 38.1 % and 36.4 %, respectively.

– The best hay quality indicators in terms of protein, carotene, and other nutrients were obtained in the second experimental variant (single windrow processing).

The research results can be used by agricultural enterprises, scientific institutions, and educational establishments to improve forage harvesting technology. The proposed technology reduces nutrient losses, enhances hay quality, and improves its efficiency in livestock diets.

## Conflict of interest

The authors declare that they have no conflict of interest in relation to this study, including financial, personal, authorship or other, which could affect the study and its results presented in this article.

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The study was performed without financial support.

## Data availability

The manuscript has no associated data.

## Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the presented work.

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