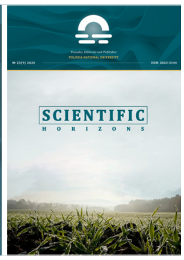
ISSN 2663-2144 e-ISSN 2709-8877

SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua

Scientific Horizons, 29(1), 9-19

UDC 633.2.03:631.8 DOI: 10.48077/scihor1.2026.09



Assessment of the impact of the component composition of grass mixtures on the productivity of sown agrocenoses in the Precarpathian region

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Article's History:

Received: 12.11.2025

Revised: 26.02.2026

Accepted: 25.03.2026

Published: 06.04.2026

Abstract. This study aimed to determine the effect of the component composition of perennial grass mixtures on the productivity of sown agrocenoses under the soil and climatic conditions of the Precarpathian region. Field experiments were conducted in 2020-2024 on sod-podzolic soils, using a summer sowing method without a cover crop and applying mineral fertilisers at a rate of $N_{30}P_{60}K_{90}$, following the methodological recommendations of the National Academy of Agrarian Sciences of Ukraine. Yield was assessed using the plot-by-weight method; the content of absolutely dry matter was

Suggested Citation:

Karasevych, N., Martsinko, T., Buhryn, L., Dzubaylo, A., & Begey, S. (2026). Assessment of the impact of the component composition of grass mixtures on the productivity of sown agrocenoses in the Precarpathian region. *Scientific Horizons*, 29(1), 9-19. doi: 10.48077/scihor1.2026.09.

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determined by drying samples at 105°C; and the botanical composition of the stands was analysed based on selective samples of green mass. The results showed that the highest productivity was achieved with multi-component grass mixtures comprising both grass and legume species. An optimal balance of components in the mixtures had a positive effect on dry matter yield, energy efficiency, and stand resilience. The generalised findings indicated that the inclusion of legumes – particularly red clover (*Trifolium pratense*), alfalfa (*Medicago sativa*), and common bird's-foot trefoil (*Lotus corniculatus*) – increased yield by 30%-45% compared with monoculture sowings. The dynamics of changes in botanical composition over three cuts were analysed. It was found that multi-component mixtures formed a more stable stand structure and ensured a higher proportion of legume components in the second and third cuts. An energy assessment confirmed the feasibility of using mixed sowings due to their higher energy return ratio. The findings can be applied by agronomists, fodder production specialists, and practitioners of ecosystem-based farming to establish highly productive and stable stands in the Precarpathian region

Keywords: crop yield; dry matter content; botanical composition of grass stand; grass mixtures; energy efficiency

INTRODUCTION

Ukrainian agriculture, like most other sectors of the economy, has been affected by the financial crisis and the country's challenging economic situation. Fodder is one of the key resources for livestock farming, making it essential to establish cultivated meadows capable of providing highquality, affordable, and readily available feed, as noted by H. Panakhyd *et al.* (2020). This necessity encourages the search for alternative methods of increasing crop productivity, such as the use of low rates of mineral fertilisers and the fullest exploitation of their biological potential. Particular attention is given to selecting the optimal composition of grass mixtures and applying fertilisers that stimulate plant growth and development, thereby enhancing both yield and quality. According to the research of T. Martsinko (2020), it is especially important to study the formation processes of sown legume-grass stands, particularly their development patterns, and to subsequently design methods aimed at improving their resilience and productivity. This can be achieved by improving the composition of grass mixtures and optimising the fertilisation system for sown meadow ecosystems. Since mineral fertilisers are seldom applied to meadows, or not used at all, due to their high cost, a key factor in increasing hayfield productivity is biological nitrogen fixed by leguminous grasses. Its utilisation significantly improves the environmental situation, as it does not leach into groundwater, accumulate in water bodies, pollute the air, or disrupt the soil's biological balance. According to U. Karbivska *et al.* (2020), incorporating legumes into legume-grass mixtures can increase the yield of sown meadowlands considerably – by 1.5-2 times. Moreover, it contributes to improved fodder quality and enhanced soil fertility.

In fodder production, various approaches and principles are used to select species for grass mixtures. However, under current conditions, these methods do not always align with practical requirements, as they often overlook allelopathic interactions between plants. This means that one species may inhibit the growth and development of another, which can affect the objectivity of species selection for mixtures. The competitiveness of different perennial grass species may vary considerably depending on environmental factors and management regimes. As noted by M. Komainda *et al.* (2019), the establishment of productive meadows is best achieved using perennial grass mixtures that provide higher and more stable yields compared with monocultures of grass or legumes. Through the careful selection of grass mixtures, it is possible to maintain high land productivity over an extended period. According to V. Petrychenko *et al.* (2020), the proper choice of grasses is a key factor in forming mixtures, as it determines not only the species composition but also the chemical characteristics and nutritional value of the fodder. Plants continuously influence the environment in which they grow, leading to interactions between them. The main factors driving these interactions are competition for nutrients, moisture, and light, as well as the decomposition of dead plant residues – a process that can be accelerated through liming and fertilisation. The impact of plants and the correction of the botanical composition of plant communities can be managed by purposefully altering environmental conditions.

The Precarpathian zone, where the research was conducted, is characterised by adequate moisture levels and an undulating landscape, creating favourable conditions for the development of meadow-based fodder production. High stand productivity is achievable with the correct selection of species composition, adherence to appropriate utilisation periods, and proper maintenance. However, the interactions between individual grass species in the process of nutrient uptake have not been fully studied. In particular, competition and the viability of certain species in mixed sowings remain insufficiently explored. This is especially relevant for grass and legume grasses in sown cenoses, where their interrelations require further investigation. In light of the above, it is important to identify the patterns of formation of highly productive sown stands with legume-grass components under varying proportions of perennial legumes in the grass mixtures, as well as to develop effective measures for maintaining legume species in the meadow phytocoenoses of the Precarpathian region. This study aimed, therefore, to analyse the effect of grass mixture components on the productivity of sown agrocenoses in the foothills of the Precarpathian region, and to develop effective methods for forming balanced stands with due consideration of the proportion of legume components.

LITERATURE REVIEW

In the early stages of field cultivation, perennial grasses were largely sown as monocultures. However, it was later established that mixtures containing three or four components have advantages over single-species sowings. V. Petrychenko *et al.* (2020) report that grass-legume mixtures produce yields 19%-20% higher than those of monocultures of grasses. Increasing the area under perennial legume crops not only optimises livestock rations during the transitional period but also ensures the production of high-protein winter fodder in the form of hay and silage. To achieve high productivity, it is essential to select grass species suited to the soil and climatic conditions of the specific growing zone. Research by B. de Haas *et al.* (2019) demonstrated that legume-grass mixtures utilise solar energy more efficiently and contribute to improving soil quality. Grass plants mainly absorb nutrients from the upper soil layers, requiring less phosphorus, potassium, and calcium than legumes, which take up these elements primarily from the arable and subsoil layers. Grass-legume mixtures also have a more efficient leaf arrangement and a greater total leaf area, which enhances the uptake of carbon dioxide from the air through the use of solar energy.

A grass mixture is a purposefully selected combination of different populations, species, and varieties of grasses that develop according to principles different from those of monocultures. Each population within such a sowing supports the existence of the others. Changes in the abundance or biomass of one population lead to adjustments in the other components of the mixture. A. Dziubailo & N. Pylypiv (2022) noted that each population must be provided with conditions that will ensure the highest possible yield of the entire mixture throughout its period of use. The most common species in the stand of meadows and pastures are grasses of the family *Poaceae* (*Graminae*). Timothy is regarded as one of the most productive and nutritious grasses. It is widely used in the formation of cultivated pastures, both in mixtures and as a sole crop. It thrives on meadows and in arable crop rotations, with hay yields reaching up to 8 t/ha. Another highly productive species is tall fescue, noted for its high frost resistance and tolerance to drought. In terms of both fodder quality and yield, tall fescue is among the most productive cultivated perennial grasses, producing 6-10 t/ha of hay. For fodder purposes, it is sown in mixtures with legumes and other grasses when used for cutting.

M. Monjardino *et al.* (2022), H. Zhang *et al.* (2022), and others have reported that perennial legume crops have a positive effect on the physico-chemical properties of the soil, contributing to structural restoration, preventing erosion, and strengthening the fodder base. They also play an important role in stabilising agricultural production. Y. Zhang *et al.* (2024) noted that the careful selection of grass crops for cultivation in combination with alfalfa, red clover, and other legumes enables the optimal use of their biological traits while taking account of soil and climatic conditions. Alfalfa is considered an essential component of grass mixtures intended for use in hayfields and pastures. According to P. Patra & T. Paul (2021), Y. Feng *et al.* (2022), it is the most versatile forage crop, characterised by high yield, multiple cutting potential, longevity, and adaptability to a wide range of growing conditions. It provides a consistent yield of green biomass and is widely utilised in the agricultural sector. Its lifespan in cropping can reach 10-25 years, with economic use typically lasting up to eight years. Due to its rapid regrowth, alfalfa can produce three to four cuts per season. From the second or third year of growth, the nitrogen accumulation in the soil is equivalent to applying 40-60 t/ha of manure. The decomposition of alfalfa's organic residues contributes to humus formation, improving soil fertility, reducing acidity, and enhancing both water and air permeability. Its deep root system aids in improving soil structure, increasing humus content, and serving as a natural phytosanitary barrier due to its resistance to pests and diseases.

V. Kurhak & U. Karbivska (2020) note that clover and alfalfa are the leading leguminous forage crops in Ukraine. Red clover is distinguished by its high content of protein, vitamins (E, B1, B2, B3, C, D, K), carotene, and micronutrients (molybdenum, copper, manganese, cobalt, boron). It is used for the production of hay, silage, and grass meal. For example, 100 kg of silage contains 3,842 feed units and up to 5.5 kg of digestible protein, while grass meal contains twice as much digestible protein as hay. From 1 ha of soil (0-30 cm), 6.02 t of air-dry residues are produced. Clover tolerates cold well, germinating at just 2°C, with optimal emergence at 10°C-15°C. The best time for hay harvesting is at the onset of flowering, when protein and vitamin levels are at their peak. Delayed harvesting results in leaf loss and reduced nutritive value. Thus, as reported in numerous studies, multi-component grass mixtures based on grasses and legumes offer significant agronomic and fodder advantages over monocultures. Their effectiveness largely depends on the careful selection of species suited to the soil and climatic conditions, which not only increases productivity but also enhances the ecological sustainability of agroecosystems.

MATERIALS AND METHODS

The experimental work was carried out in 2021-2024 at the Precarpathian Department of Scientific Research of the Institute of Agriculture in the Carpathian region, National Academy of Agrarian Sciences of Ukraine (NAAS), in the village of Lishnia, Drohobych District, Lviv Region. The trial was established using a coverless sowing method on 16 July 2020 on sod-podzolic, surface-gleyed, moderately acidic loamy soils. Agronomic practices followed generally accepted standards (Ushkarenko *et al.,* 2014), with the exception of the experimental variables under investigation. Three cuts were taken each year at the beginning of the flowering stage of the grasses, except in the establishment year, when crop formation was incomplete and only one cut was possible. The experimental design included the following treatments: Variant 1 – timothy; Variant 2 – timothy + red clover; Variant 3 – timothy + alfalfa; Variant 4 – timothy + common bird's-foot trefoil; Variant 5 – timothy + red clover + alfalfa + common bird's-foot trefoil; Variant 6 – timothy + perennial ryegrass + tall fescue+ red clover + common bird's-foot trefoil+ alfalfa.

The study used varieties of perennial grasses listed in the State Register of Plant Varieties Suitable for Distribution in Ukraine (2025), namely: timothy (Podhiryanka), tall fescue (Smerichka), perennial ryegrass (Drohobytskyi 16), red clover (Precarpathian 6), alfalfa (Syniukha), and common bird's-foot trefoil (Ajax). The proportion of leguminous to grass crops was 40% to 60%, respectively. Each spring, prior to the start of growth, all experimental variants received mineral fertilisers at a rate of $N_{30}P_{60}K_{90}$. All research activities were conducted per the methodological guidelines of the Institute of Feed Research of NAAS (Babych *et al.,* 1998). Figures 1 and 2 present the meteorological data for the growing seasons of 2021-2024, based on observations from the Drohobych meteorological station. Comparing the average monthly air temperatures and total precipitation with long-term averages allows the identification of trends and anomalies affecting vegetation conditions.

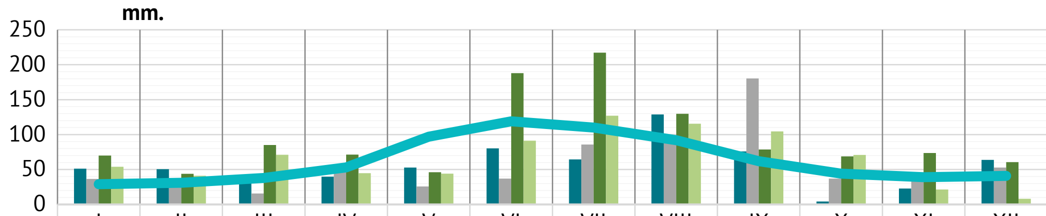
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
2021	-0.3	-1.4	2.8	6.6	13.4	18.2	21.5	17.6	13	7.8	4.7	-1.2
2022	0.2	3.1	2.3	7.3	15.1	19.5	20.3	20	12.7	11.1	4.5	1.7
2023	3.3	-2.3	5.5	7.9	13.5	17.1	20.1	20.9	17.1	12.6	5	2.5
2024	0.1	6.8	6.1	11.5	14.5	19.4	20.9	19.9	15.9	9.3	2.9	1.2
long-term average	-5.7	-2.2	1.8	7.9	13.2	16.2	17.6	17	13.4	9.3	2.9	1.2

Figure 1*. Monthly temperature distribution during the growing seasons of 2021-2024*
Source: *developed by the authors*

During 2021-2024, air temperatures in all months of the growing season were, on average, higher than long-term average values. In 2021, for instance, June and July recorded temperatures exceeding the norm by 2°C-4°C. The average temperature in July 2021 reached 21.5°C, considerably above the long-term average. In 2022, temperatures were also elevated, particularly in May, when the average value was 1.9°C higher than the norm. The year 2023 was marked by certain temperature fluctuations, yet overall values remained above the long-term average, especially in March and May. In 2024, the temperature in April (11.5°C) was 3.6°C higher than the long-term average, indicating a continuing warming trend. July 2024 also experienced elevated temperatures, reaching 20.9°C, which is 3.3°C above the long-term average.

Precipitation totals showed considerable annual variation. In 2021, June and July recorded significantly higher rainfall than the long-term averages, with 119 mm in June and 110 mm in July. In 2022, the greatest deviation occurred in May, when total rainfall was only 25.8 mm, well below the norm of 97 mm. August 2022, however, received more precipitation than the long-term average, at 98.2 mm. In 2023, July was the wettest month across all years considered, with rainfall reaching 217.3 mm, nearly twice the average. July 2024 also saw high precipitation (127 mm), while August remained closer to the long-term average (115.5 mm). During the autumn-winter period (September-December) from 2021 to 2024, notable fluctuations were observed in both temperature and rainfall. In September, average temperatures ranged from 13.0°C to 17.1°C, exceeding the long-term average values. In October, temperatures ranged from 7.8°C to 12.6°C, in November from 2.9°C to 4.7°C, and in December from -1.2°C to 2.5°C. The highest temperatures in November and December were recorded in 2021 and 2023, respectively.

Regarding precipitation, September totals varied from 78.8 mm (2023) to 180.4 mm (2022). In October, rainfall ranged from 4.2 to 68.9 mm. November generally experienced moderate precipitation (21.5-39.8 mm), except in 2023, when rainfall exceeded the long-term average by 34.7 mm, while December precipitation ranged from 8.2 to 63.7 mm, peaking in 2021. These weather patterns indicate a trend towards a mild autumn with elevated temperatures and variable rainfall, as well as gradual warming during the winter period (Fig. 2).



	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
2021	51.2	50.6	42.3	39.8	52.7	80.2	64.4	128.8	75.9	4.2	22.9	63.7
2022	36.5	31.1	15.8	53.6	25.8	36.9	85.9	98.2	180.4	36.9	39.8	52.9
2023	70.1	43.8	85.2	71.4	46.1	187.9	217.3	129.8	78.8	68.9	73.7	60.7
2024	53.9	41.2	71.1	44.7	44.2	91.2	127	115.5	104.6	71	21.5	8.2
long-term average	29	31	38	53	97	119	110	92	62	44	39	41

Figure 2. *Monthly distribution of precipitation during the growing seasons of 2021-2024*
Source: *developed by the authors*

Overall, the data indicate a steady increase in air temperatures during the growing season over recent years, suggesting a trend towards global warming that affects agronomic conditions for crop cultivation. Additionally, the changing precipitation regime, characterised by uneven monthly distribution, necessitates the adaptation of agronomic practices to maintain stable yields. Considering these factors, agricultural management methods must be adjusted to respond to evolving climatic conditions.

Based on the analysis of precipitation, considerable variability can be observed, particularly during the summer months, when rainfall totals often exceeded long-term averages, indicating an increase in the frequency of intense rainfall events. This can affect the water supply available to crops, necessitating adjustments to agronomic practices to ensure stable yields. Changing climatic conditions, including rising temperatures and fluctuations in precipitation, require a comprehensive adaptation of agricultural practices, encompassing the optimisation of cultivation techniques and the selection of crops resilient to emerging climatic challenges. Harvests were assessed using a complete (whole-plot) method. The cut grass was weighed immediately, and a representative sample of 1-2 kg was taken for drying. Each sample was labelled with the experiment name, replicate, treatment variant, and date of assessment. The air-dry mass was weighed twice at intervals of 2-3 days, and the lower value was recorded in the log. From this, the hay yield per plot and hectare was calculated. The initial moisture content was determined using the formula:

$$X_1 = \frac{B-C}{B_1} \cdot 100, \quad (1)$$

where B_1 is the sample mass before drying and C is the mass after drying.

The air-dry matter content of the grass was calculated as:

$$100 - X_1. \quad (2)$$

Hay and pasture yields were expressed in terms of absolute dry matter. For this, the hygroscopic moisture in the air-dry mass was determined, after which the total water content in the grass was calculated. To determine hygroscopic moisture, the air-dry mass was chopped, placed in crucibles, weighed, and dried in a thermostat at 100°C-150°C for 4-5 hours. The crucibles with the samples were then removed, placed in a desiccator for one hour to cool, weighed, and the percentage of hygroscopic moisture was calculated using the formula:

$$X_2 = \frac{B_1}{B_2} \cdot 100, \quad (3)$$

where B_1 is the mass after drying (g) and B_2 is the mass of the air-dry sample (g).

The total water content in the grass consists of the initial moisture (X_1) and the hygroscopic moisture (X_2):

$$A = X_1 + \frac{X_2 \cdot (100 - X_1)}{100}. \quad (4)$$

The percentage of absolute dry matter is then 100 − A (%). For the determination of absolute dry matter during harvest assessment, samples of green mass were taken, chopped, placed in crucibles (3-4 per sample), weighed, and dried at 105°C to constant mass according to DSTU ISO 6497:2005 (2008). Botanical composition of the hay was assessed by sorting samples of grass taken for drying from two non-adjacent replicates following DSTU 6017:2008 (2010). Onekilogram portions of grass were divided into three groups: grasses, legumes, and mixed herbs, indicating the predominant species in each group. During species analysis, each sample was separated into individual plant species. The identified species were weighed on laboratory scales with 0.1 g precision, recorded in a botanical analysis register, and calculated as a percentage of the sample mass. Statistical analysis was applied to summarise and process the results of the study (Ushkarenko *et al.,* 2014). The values obtained from the analysis were expressed as percentages, rounded to the nearest whole number for each defined category. The reliability of the analysis was assessed by comparing the extreme values of the replicates with the arithmetic mean.

The energy assessment of the studied practices was carried out in accordance with relevant methodological guidelines and the methodology of O. Medvedovskyi & P. Ivanenko (1988). The study compared energy expenditures for cultivating different types of grass mixtures, considering each stage of the technological process (soil preparation, sowing, fertilisation, harvest, etc.), standardised to a single unit (GJ), and used to determine the active component of each element. Energy analysis of crop production concludes with the calculation of the energy cost of the harvest – the ratio of the amount of non-renewable energy contained in the harvested product to the amount of non-renewable energy expended to produce it. This ratio is referred to as the energy efficiency ratio (EER). During the study, the authors adhered to the norms established by the Convention on Biological Diversity (1992) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1979).

RESULTS AND DISCUSSION

Based on the research conducted from 2021 to 2024, the highest yields were observed in multi-component grass mixtures (Table 1).

Table 1*. Grass mixture yields depending on component composition, dry matter t/ha (2021-2024)*

No. Var.	Grass mixture (species)	2021	2022	2023	2024	Average
1	Timothy	7.56	4.44	7.12	5.42	6.14
2	Timothy + Red clover	12.0	10.2	8.24	7.11	9.39
3	Timothy + Alfalfa	7.31	10.0	8.97	6.79	8.27
4	Timothy + Common bird's-foot trefoil	8.66	7.5	8.36	7.98	8.13
5	Timothy + Red clover + Alfalfa + Common bird's-foot trefoil	11.4	10.8	11.4	6.94	10.14
6	Timothy + Perennial ryegrass + Tall fescue + Red clover + Alfalfa + Common bird'sfoot trefoil	12.6	11.8	14.49	7.49	11.60

Source: *developed by the authors*

The highest yield was recorded in variant 6 (timothy, tall fescue, perennial ryegrass, common bird's-foot trefoil, red clover, and alfalfa), which reached 11.60 t/ha. The second most productive mixture consisted of timothy, red clover, common bird's-foot trefoil, and alfalfa, yielding 10.14 t/ha. In variant 2, the mixture including red clover showed a substantial increase in yield (9.39 t/ha) compared with timothy alone (6.14 t/ha). It is worth noting that in the first year, the mixture of timothy and alfalfa produced slightly lower yields than the other variants, reaching 7.31 t/ha of dry matter. The grass mixture of red clover and timothy achieved the highest dry-matter yield among two-component mixtures, at 9.39 t/ha.

The data indicate that in the first year of use, the rate of vegetative mass accumulation in red clover was considerably higher than in common bird's-foot trefoil or alfalfa. The accumulation of green mass in alfalfa was significantly lower compared with common bird's-foot trefoil. However, by the second year, this figure increased to 10.0 t/ha. As shown in the table, the yield of timothy in 2021 was 7.56 t/ha, but it declined to 4.44 t/ha the following year. Botanical analysis indicates changes in the proportion of different plant groups in the harvest structure across the three cuttings (Table 2). Grasses generally dominate the first cutting, comprising around 86% of the yield; however, their share decreases in subsequent cuttings, while the proportion of herbs increases, reflecting the depletion of grasses and the growth of competing species. The inclusion of leguminous plants (red clover, common bird's-foot trefoil, alfalfa) significantly reduces the proportion of grasses in the green mass yield.

Table 2*. Botanical composition of sown stands depending on the species composition of the mixtures,% of green mass (average 2021-2024)*

No. Var.	Grass mixture (species)	Plant type	Cutting I	Cutting II	Cutting III
1	Timothy	Grasses	86	75	84
		Herbs	14	25	16

Table 2. Continued

No. Var.	Grass mixture (species)	Plant type	Cutting I	Cutting II	Cutting III
2	Timothy + Red clover	Grasses	51	81	45
		Legumes	45	10	48
		Herbs	5	15	7
3	Timothy + Alfalfa	Grasses	42	40	21
		Legumes	52	54	74
		Herbs	7	7	4
4	Timothy + Common bird's-foot trefoil	Grasses	43	45	37
		Legumes	49	48	55
		Herbs	8	7	8
5	Timothy + Red clover + Alfalfa + Common bird's-foot trefoil	Grasses	32	46	23
		Red clover	46	3	27
		Alfalfa	22	34	38
		Common bird's-foot trefoil	8	13	8
		Herbs	4	7	5
6	Timothy + Perennial ryegrass + Tall fescue + Red clover + Alfalfa + Common bird's-foot trefoil	Grasses	34	46	26
		Red clover	43	3	37
		Alfalfa	23	30	26
		Common bird'sfoot trefoil	6	14	7
		Herbs	6	10	4

Source: *developed by the authors*

In variant 2 (timothy + red clover), the proportion of grasses decreases to 51%, while legumes account for 45%. In the variant sown with alfalfa and timothy, the legume content reaches 52%-74%, particularly in the third cutting, indicating a gradual increase in their productivity. Variant 4 (timothy + common bird's-foot trefoil) demonstrates a more balanced composition, with a relatively even proportion of grasses (37%-45%) and legumes (48%-55%), indicating a stable growth dynamic between both plant groups. According to research, increasing diversity in grass mixtures promotes more even resource utilisation and enhances grass stand stability. The variant including timothy, red clover, alfalfa, and common bird's-foot trefoil exhibited the greatest variability in species proportions: red clover (3%-46%), alfalfa (22%-38%), and common bird'sfoot trefoil (8%-13%), allowing a gradual increase in their share over successive cuttings. The multicomponent mixture (Variant 6) was characterised by a balanced ratio of grasses (26%-46%), red clover (3%-43%), alfalfa (23%-30%), and common bird's-foot trefoil (6%-14%), reflecting a more even coexistence of different species, which positively influences grass stand resilience.

Overall, increasing the proportion of legumes in grass mixtures improves total yield, particularly in later cuttings. Multi-component mixtures are more stable in terms of productivity, as different plant species compensate for seasonal fluctuations in each other's growth. In contrast, dominance of grasses is observed in single- or low-component mixtures, whereas in complex mixtures the share of grasses gradually declines. The study also found that energy expenditure for soil preparation and harvest constitutes a significant portion of total energy costs for crop production. Therefore, reducing energy inputs at these stages could substantially enhance the energy efficiency of the cultivation technology. The botanical composition of grass mixtures directly affects their energy efficiency, that is, the ratio of energy invested to energy obtained from the harvest. Analysis of the data indicates that mixed stands containing both grasses and legumes are more productive and energy-efficient (Table 3).

Table 3*. Energy efficiency of sown stands depending on the species composition of grass mixtures (2021-2024)*

No. Var.	Grass mixture (species)	Energy expenditure for crop cultivation, GJ	Gross energy output from the harvest, GJ	Metabolisable energy output, GJ	EER
1	Timothy	19.4	103.1	59.2	3.0
2	Timothy + Red clover	22.4	164.3	94.3	4.2
3	Timothy + Alfalfa	22.6	142.0	81.5	3.6
4	Timothy + Common bird's-foot trefoil	22.4	132.3	75.9	3.4
5	Timothy + Red clover + Alfalfa + Common bird's-foot trefoil	25.9	181.3	104.1	4.0
6	Timothy + Perennial ryegrass + Tall fescue + Red clover + Alfalfa + Common bird's-foot trefoil	28.7	209.7	120.4	4.2

Source: *developed by the authors*

Energy expenditure for cultivating grass mixtures varies according to their composition. The lowest energy input (19.4 GJ) was observed for pure timothy, reflecting its low maintenance requirements. In two-component mixtures (timothy + red clover or alfalfa), energy expenditure rises to 22.4-22.6 GJ due to the higher maintenance demands of legumes. The highest energy input (28.7 GJ) was recorded for the multi-component mixture (Variant 6), where grasses (timothy, perennial ryegrass, tall fescue) are grown together with several legume species (red clover, alfalfa, common bird's-foot trefoil). The greater the diversity of the grass mixture, the higher the gross energy output. A monoculture of timothy yields 103.1 GJ, whereas the six-species mixture produces 209.7 GJ. A pure stand of timothy provides 59.2 GJ of metabolisable energy; when red clover or alfalfa is added, this rises to 75.9-94.3 GJ. The highest metabolisable energy (120.4 GJ) was observed in the multi-component mixture (Variant 6), making it the most nutritious and energy-efficient as fodder.

The lowest EER of 3.0 was recorded for pure timothy, indicating that its cultivation is less advantageous from an energy perspective. The highest EER of 4.2 was observed in two mixtures: (timothy + red clover) and (timothy + red clover + perennial ryegrass + tall fescue + red clover + common bird's-foot trefoil + alfalfa), reflecting a high energy return and making these mixtures optimal for cultivation. Thus, mixed grass–legume mixtures provide a higher energy yield, enhancing their feed value. Multi-component mixtures (Variants 5 and 6) demonstrated the highest metabolisable energy output and efficiency ratio, making them the most favourable for cultivation. The inclusion of legumes (red clover, alfalfa, common bird's-foot trefoil) improves the energy balance of the sward, reducing dependence on additional fertilisation.

According to O. Rognli *et al.* (2021), legume-grass stands provide high-quality fodder with lower energy and financial inputs due to the high productivity of these stands. They can increase yields by 1.3-2.0 times without the application of nitrogen fertilisers compared with grass-only stands, thereby reducing nitrogen requirements and improving overall soil fertility. Legume-grass stands surpass other fodder types in protein, mineral, and vitamin content, with a single feed unit containing 140-160 g of digestible protein, compared with only 62-95 g in cereal grains. The careful selection of fodder species in optimal proportions enhances the productivity of grasslands. It also allows for the production of balanced plant material in terms of nutrients while reducing production costs. In stands, legumes should exhibit high vigour and productivity, while grasses are expected to form a strong root system. Phenological studies confirm that grasses vary in growth and development rates, being classified as early-, mid-, or late-maturing. This classification enables a continuous supply of green fodder, extending the harvesting period without compromising feed quality (from 7 up to 25-38 days). Morphological and agronomic traits of different grass and legume species are determined by root system types, which differ in branching and depth of soil penetration during the growing season, ensuring efficient uptake of nutrients from various soil layers.

Red clover is most commonly sown in a mixture with common bird's-foot trefoil, as the latter compensates for any losses of clover in the stand. Common bird's-foot trefoil is a perennial plant that can persist in the stand for 6-8 years. I. Senyk (2020) and V. Olifirovych & Yu. Veklenko (2021) noted that common bird's-foot trefoil can be successfully cultivated even on low-fertility and acidic soils, where other legumes perform poorly. In addition, common bird's-foot trefoil is frost-tolerant and exhibits greater resistance to pests and diseases compared with other legume species. According to K. Kovtun *et al.* (2020), it has high nutritional and fodder value; its hay contains 14%-22.3% protein, 1.5%-3.6% fat, 22.4%-26.0% fibre, 39%-51% digestible nutrients, and 6.9%-11.2% ash. The stand tolerates regular mowing and grazing well. All researchers emphasise the importance of studying the development of legume-grass mixtures under changing climatic conditions. These findings should be considered when designing grass mixtures for hay production, as they contribute to higher yields and improved feed quality.

CONCLUSIONS

Research showed that multi-component grass mixtures yield more and are more stable compared with single- or low-component mixtures. The best results were obtained from a mixture comprising timothy, tall fescue, perennial ryegrass, red clover, alfalfa, and common bird's-foot trefoil, with an average yield of 11.60 t/ha. The high efficiency of these mixtures is attributed to the ability of different species to compensate for each other's seasonal growth fluctuations and to provide a balanced proportion of grasses and legumes. A stand of timothy and legume species (red clover, common bird's-foot trefoil, and alfalfa) also performed well, ranking second in productivity. The lowest average yield was observed in the treatment with timothy as the sole component (6.13 t/ha). Therefore, for a stable yield, it is advisable to use multi-component mixtures that combine grasses and legumes.

The inclusion of legumes in the grass mixtures composition significantly alters the harvest structure: the proportion of grasses decreased from 86% in the timothy monoculture to 21%-45% in mixed stands, while legumes accounted for 48%-74%, particularly in the later cuttings. The most stable results were observed in the multi-component mixtures (variants 5 and 6), where grasses comprised 26%-46% and legumes up to 74%, ensuring uniform growth, high adaptability, and stable productivity of the sown agrocenoses in the Precarpathian region. Future research should focus on the detailed study of legume persistence in perennial cenoses, the development of adaptive fertilisation schemes for different mixture types, and the assessment of how agronomic practices influence feed quality and the ecological stability of sown areas in the Foothill zone. Hence, a multi-component grass mixture represents an optimal choice for cultivation, as it provides the highest energy yield with relatively moderate inputs.

ACKNOWLEDGEMENTS

None.

FUNDING

This study was conducted under the commission of the National Academy of Agrarian Sciences of Ukraine in accordance with task 09.01.04.02.F, "Improving the scientific foundations for modelling meadow phytocoenoses of multifunctional use within zonal adaptive-landscape systems for meadow forage production in the Precarpathian region".

CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

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Оцінка впливу компонентного складу травосумішей на продуктивність сіяних агроценозів в умовах Передкарпаття

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Анотація. Метою дослідження було встановити вплив компонентного складу багаторічних травосумішей на продуктивність сіяних агроценозів у ґрунтово-кліматичних умовах Передкарпаття. Польові дослідження проводили у 2020-2024 роках на дерново-підзолистих ґрунтах із використанням безпокривного літнього способу сівби та застосуванням мінерального удобрення в дозі $N_{30}P_{60}K_{90}$ відповідно до методичних рекомендацій Національної академії аграрних найк України. Урожайність оцінювали поділяночно-ваговим методом; вміст абсолютно сухої речовини визначали шляхом висушування зразків при температурі 105 °C; ботанічний склад травостоїв аналізували на основі вибіркових проб зеленої маси. Результати досліджень засвідчили, що найбільшу продуктивність забезпечували багатокомпонентні травосуміші, до складу яких входили як злакові, так і бобові види. Встановлено позитивний вплив оптимального співвідношення компонентів у сумішах на показники урожайності сухої речовини, енергетичну ефективність та стійкість травостоїв. Узагальнення результатів показало, що включення бобових культур, зокрема конюшини лучної (*Trifolium pratense*), люцерни посівної (*Medicago sativa*) та лядвенцю рогатого (*Lotus corniculatus*), сприяло підвищенню урожайності на 30-45 % порівняно з одновидовими посівами. Проаналізовано динаміку зміни ботанічного складу протягом трьох укосів. Встановлено, що багатокомпонентні травосуміші формують стабільнішу структуру травостоїв і забезпечують вищу частку бобових компонентів у другому та третьому укосах. Проведена енергетична оцінка підтвердила доцільність використання змішаних посівів завдяки вищому коефіцієнту енергетичної віддачі. Отримані результати можуть бути використані агрономами, фахівцями з кормовиробництва та екосистемного землеробства для створення високопродуктивних і стабільних травостоїв у зоні Передкарпаття

Ключові слова: продуктивність урожаю; вміст сухої речовини; ботанічний склад травостою; травосуміші; енергетична ефективність