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Economic and Energy Efficiency of Growing Different Varieties of Red Clover (*Trifolium pratense* L.) for Fodder

Abstract. The cultivation of red clover for fodder purposes on typical low-humus chernozems of the northern part of the Right-Bank Forest-Steppe of Ukraine is profitable. Regardless of the technology components, it provides a net profit of UAH 14,962-23,743 per hectare with a profitability of 88-259% and a cost of 1 ton of feed units of UAH 1,415-2,662 and raw protein of UAH 5,363-10,265, a payback of energy costs in terms of gross energy (EER) yield per hectare of 6.2-9.0 and metabolisable energy (BER) yield per hectare of 3.2-4.6, with energy costs per 1 ton of feed units of 2.86-4.20 GJ. The purpose of the study was to determine changes in the economic and energy efficiency of growing different varieties of red clover for fodder purposes depending on the methods of sowing, seed inoculation with nodule bacteria and fertilisation. During the research, the following methods were used: field and laboratory – for conducting research in the field and laboratory conditions, analytical – to determine the chemical composition of dry biomass of red clover, calculation – to determine the indicators of economic and energy efficiency. The best rates of economic and energy efficiency of red clover cultivation are provided by the variety Typhoon when seeds are inoculated with nodule bacteria on fertiliser-free soil. The additional application of P60K90 or N60R60K90 against the background of inoculation, which is necessary to preserve soil fertility, worsens them, reducing net profit by 3,486-5,943 UAH/ha

Keywords: bioenergy factor, cost and energy inputs, economic and energy efficiency, cost recovery, profitability, cost price, net profit

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RELEVANCE

The successful development of Ukraine's livestock industry requires the development of energy- and resource-saving technologies in fodder production and grassland farming, based on the use of the enormous potential of perennial grasses, and legumes in particular, as a source of natural cheap symbiotic nitrogen. Only calculations of economic and energy efficiency make it possible to evaluate the relevant technological elements, identify the best ones, and provide the basis for a reasonable recommendation of certain feed production technologies to be implemented in agricultural production. Therefore, the final stage of research, including the identification of the best elements of technology for the formation of forage phytocoenoses, their fertilization systems and modes of use, etc. is their economic and energy assessment (Babich & Motornyi, 1986).

Technologies for the improvement and rational use of perennial grasses, including legumes, should be resource- and energy-saving, based on a combination of the latest scientific achievements and best practices, at the same time, providing a high return on the material and technical means used. Failure to comply with at least one requirement in the overall technological process leads to a decrease in yield and a sharper decline in the level of cost recovery. The cost of grass feed produced on forage lands, in particular on pastures, is several times lower than that obtained in the field (Kurhak, 2010).

The summarisation of published data, research results, and the experience of advanced farms in terms of the economic efficiency of feed production suggests that grass feed is the most economically efficient. However, the cost of 1 ton of feed units of fodder obtained from cultivated pastures is 1.9 times lower than the mowed green mass of perennial grasses, 2.5 times lower than hay from natural hayfields, 10.5 times lower than fodder root crops, and 3.9 times lower than concentrated fodder (Babich & Motornyi, 1986; Kurhak, 2010; Blagoveshchenskiy, 1995).

The low cost of fodder from perennial grasses is primarily attributable to the fact that the funds for grassland management and landscaping are distributed over a number of years, during which it is planned to use them with relatively low maintenance and operation costs (Andreev & Zotov, 1985; Kutuzova & Kozminykh, 1998; Yarmolyuk *et al.*, 2013).

It should be noted that in recent years, due to rising energy costs and rising prices for mineral fertilisers and fuel, the cost of fertilising and cuttings and, in general, grass feed production has increased. Therefore, in the context of rising prices of mineral fertilisers, in particular nitrogen, an important factor in reducing the cost of feed is the use of legumes as a source of symbiotic nitrogen (Voloshyn, 2018; Prorochenko, 2020).

The energy analysis of technologies in feed production is particularly important because the energy contained in the feed is essential not only for the functioning of animals but also for the production of animal products. On the one hand, the energy output from 1 ha of forage land is used to determine the payback of costs for growing forage crops or producing certain types of grass feed, and on the other hand, to determine the energy-intensive units of feed. Ukraine has a tendency to accelerate the development of knowledge-intensive industries in line with changes in the structure and investment policy of the state in the agricultural sector (Medvedovsky & Ivanenko, 1988).

Given the rising cost of non-renewable energy sources used for feed production, an increase in feed and livestock production is possible with the widespread introduction of energy and resource-saving technologies, unconventional and continuously renewable energy sources, which reduce energy consumption for the production of certain types of feed.

Depending on the type of livestock product, feed accounts for 50 to 80% of the cost of production, so reducing energy consumption for its production is extremely important for reducing the cost of livestock products.

It is known that feed is a source of energy obtained both through photosynthesis and the total energy consumption for its production. The effect of converting the latter type of energy into livestock products is a criterion for assessing the energy saving balance. Therefore, the criterion of economic assessment of any technological process in agricultural production should include the criterion of energy balance assessment (Kulyk, 1997).

The life of any living organism is inextricably linked with the exchange and transformation of energy. Nutrients, in particular in the form of hydrocarbons, proteins, fats, etc., play a crucial role in the metabolism and energy in the animal body. Therefore, energy analysis of feed production is extremely important. The main task of the energy analysis of agricultural production is to comply with the basic principles that provide for the rational use of non-renewable (fuels and lubricants) and renewable (solar radiation) energy, operating assets and natural resources, and the protection and improvement of the agroecological condition of soils and agrophytocenoses (Kulyk, 1997).

According to V. Kurhak (2010), the energy efficiency coefficient as a ratio of output per 1 ha of gross energy to total costs for growing perennial legumes ranged from 6-8, and the bioenergy coefficient as a ratio of output per 1 ha of metabolisable energy to total costs – 3-4. An increase in these coefficients means an increase in energy efficiency. The task is reduced to obtaining the largest yield from 1 ha of gross or exchange energy at the lowest total cost.

The purpose of the study is to determine changes in the economic and energy efficiency of growing different varieties of red clover for fodder purposes depending on the methods of sowing, seed inoculation with nodule bacteria and fertilisation.

MATERIALS AND METHODS

The research plan included laboratory, field, and production experiments that were carried out in the scientific laboratories of the Department of Feed Production, Land Reclamation, and Meteorology in Field Crop Rotation of the Agronomic Research Station, a separate subdivision of the National University of Life and Environmental Sciences of Ukraine.

The soil structure is dominated by ordinary chernozems (about 70%) and meadow chernozems (20%), with a mix of meadow chernozem and podzolised chernozems. Meadow chernozems are characterised by the content of carbonates, the line of which varies from the surface to 1.2-1.5 m depending on moisture conditions, which significantly affects the phosphate regime of the soil. Common chernozems and meadow chernozems have a high supply of nitrogen and phosphorus, and a medium to low supply of potassium (according to *Machygin*). The humus content in the arable layer is 4.4-4.6%. The research was conducted in the period 2018-2020, according to the following scheme (Table 1).

Table 1. Experiment scheme

Factor A (fertiliser)	Factor B (varieties)	Factor C (sowing method)
1. No fertilisers (control)	1. Lybid	1. Bezpokryvnyy
2. seed inoculation with nodule bacteria (background)	2. Tayfun	2. undersown spring barley

Table 1, Continued

Factor A (fertiliser)	Factor B (varieties)	Factor C (sowing method)
3. Background + $P_{60}K_{90}$	3. Tina	
4. Background + $N_{60}P_{60}K_{90}$		

The economic assessment of the studied elements of the technology for growing red clover was carried out according to the methodology for assessing the effectiveness of scientific research using technological maps at prices prevailing in 2020 (Babich & Motornyi, 1986).

The energy efficiency of the studied elements of the technology for growing red clover was estimated according to the methods of O.K. Medvedovsky and P.I. Ivanenko (1988).

The initial indicators for calculating economic efficiency are the cost of gross output received and the total cost of funds for its production. Energy analysis is based on combining all types of labour and production costs in feed production through the production equivalent, which is reflected as the amount of non-renewable energy consumed by a particular process or technology in general. The energy efficiency of the technologies was assessed by the payback of total energy inputs in terms of gross or exchangeable energy output per hectare in GJ, which are called the energy efficiency ratio (EER) and the bioenergy ratio (BER), respectively.

RESULTS AND DISCUSSION

Analysis of the data on the economic efficiency of the cultivation of different varieties of red clover under different cultivation technologies showed that the cost of gross production ranged from 27,700-38,200 UAH/ha (Table 2). Similarly, to the fodder productivity, the highest yield per 1 ha of gross production among the varieties of red clover was achieved by the Tayfun variety, which outperformed the Lybid and Tina varieties by 2,550-6,000 UAH on different fertilisation backgrounds and with different sowing methods.

Table 2. Economic efficiency of growing red clover varieties under different cultivation technologies (average for 2018-2020)

Fertilisation	Cultivar	Gross production. UAH/ha	Costs. UAH / ha	Net profit. UAH/ha	Rentability. %	Cost price per ton. UAH	
						fodder unit	crude protein
Pure sowing							
No fertilisers	Lybid	28.350	8.325	20.025	241	1.468	6.033
	Tayfun	31.900	9.025	22.875	253	1.415	5.785
	Tina	27.700	8.205	19.495	238	1.481	5.659
Inoculation (background)	Lybid	30.400	8.755	21.645	247	1.440	5.956
	Tayfun	34.100	9.495	24.605	259	1.392	5.790
	Tina	30.100	8.675	21.425	247	1.441	5.597
Background + $P_{60}K_{90}$	Lybid	31.350	14.868	16.482	111	2.371	9.470
	Tayfun	35.700	15.748	19.952	127	2.206	8.999
	Tina	31.050	14.808	16.242	110	2.385	8.975

Table 2, Continued

Fertilisation	Cultivar	Gross production. UAH/ha	Costs. UAH / ha	Net profit. UAH/ha	Rentability. %	Cost price per ton. UAH	
						fodder unit	crude protein
Background + $N_{60}P_{60}K_{90}$	Lybid	32.000	17.038	14.962	88	2.662	10.264
	Tayfun	36.050	17.838	18.662	105	2.474	9.642
	Tina	32.200	17.078	15.122	89	2.652	9.703
Undersown spring barley							
No fertilisers	Lybid	28.900	8.455	20.445	242	1.463	5.831
	Tayfun	31.450	8.956	22.494	251	1.424	5.363
	Tina	28.600	8.395	20.205	241	1.468	5.750
Inoculation (background)	Lybid	29.950	9.052	20.898	231	1.511	5.955
	Tayfun	33.500	9.757	23.743	243	1.456	5.607
	Tina	28.650	8.793	19.857	226	1.535	5.710
Background + $P_{60}K_{90}$	Lybid	31.300	14.994	16.306	109	2.395	9.458
	Tayfun	34.100	15.554	18.546	119	2.281	8.546
	Tina	31.900	15.674	16.226	104	2.457	9.616
Background + $N_{60}P_{60}K_{90}$	Lybid	32.200	17.143	15.057	88	2.662	10.265
	Tayfun	38.200	17.943	20.257	113	2.349	9.544
	Tina	33.050	17.303	15.747	91	2.618	9.944

Regardless of the variety of red clover, the highest value of gross output (32,200-38,200 UAH/ha) was obtained by inoculating seeds with nodule bacteria in combination with the introduction of $N_{60}P_{60}K_{90}$, which is 8-11% more compared to the variant without fertilisers. When seeds were inoculated with nodule bacteria in the background without fertilizers and when $P_{60}K_{90}$ was applied in the background of inoculation, the cost of gross production increased less, namely by 3-8% compared to the variant without fertilisers.

On average, over the three years of research, there was no significant difference in the cost of gross production between sowing methods.

The lowest total costs for the cultivation of different varieties of meadow clover were in the variant without fertilisation and with different sowing methods, ranging from 8,325-9,025 UAH/ha. When seeds were inoculated with nodule bacteria, compared to the variant without fertilisers, they increased by only 403-470 UAH/ha. When applied in combination with inoculation of seeds with nodule bacteria $P_{60}K_{90}$, they increased to 14,868-15,748 UAH/ha, which is 1.7-1.8 times more compared to the variant without fertilisers. The highest total costs were for inoculation of seeds with nodule bacteria in combination with $N_{60}P_{60}K_{90}$, which ranged from 17,038-17,943 UAH/ha, 1.1-1.2 times more compared to the variant of inoculation of seeds with nodule bacteria in combination with $P_{60}K_{90}$ and 2.0 times more compared to the variant without fertilisation.

The sowing method and use of grass stands did not naturally affect the total costs of growing red clover over an average of three years of research. Among the varieties, regardless of fertilizers and sowing methods, energy costs were somewhat higher for the cultivation of the Tayfun variety.

The main indicator of economic efficiency is the net profit, which in this study on cultivation under different technologies and varieties of red clover ranged from 14,962 to 23,743 UAH/ha. Among the varieties of red clover, the highest net profit was provided by Tayfun, which on different fertiliser backgrounds and with different sowing methods prevailed over Lybid and Tina varieties – by 2,049-5,200 UAH/ha.

In the cultivation of different varieties of red clover among the fertilizer variants, the highest (except for the variety Tina with undersown spring barley) net profit (19,857-24,605 UAH/ha) was obtained for inoculation of seeds with nodule bacteria, which is 1,620-1,930 UAH/ha more compared to the variant without fertilisation, 3631-5,197 UAH/ha more compared to the fertilisation of seeds with nodule bacteria $_{60}K_{90}$ and 3,486-5,841 UAH/ha more compared to inoculation of seeds with nodule bacteria in combination with the introduction of $N_{60}P_{60}K_{90.}$ With the additional application of N_{60} on the background of $P_{60}K_{90}$ for the cultivation of red clover, the net profit varied differently. In most cases, it decreased by 479-1,249 UAH/ha, and for the Tayfun variety with undersown spring barley, it increased by 1,711 UAH/ha.

The analysis of economic efficiency indicators showed that the profitability of cultivating varieties of red clover under different technologies ranged from 88-251%. Regardless of the method of sowing and variety, it was the highest in the variant without fertilisers and under inoculation of seeds with nodule bacteria with fluctuations of 226-253%, which is 2.0-2.2 times more compared to the introduction of seeds with nodule bacteria $P_{60}K_{90}$ and 2.2-2.8 times more compared to the introduction of seeds with nodule bacteria $N_{60}P_{60}K_{90}$.

Among the varieties of red clover, the highest profitability was provided by Tayfun, which on different fertiliser backgrounds and with different sowing methods prevailed over Lybid and Tina varieties – by 12-25%. According to the calculations for an average of three years of research and use of grass stands, the method of sowing did not influence the profitability of growing red clover.

Unlike profit and profitability, the cost of 1 t of feed units and crude protein had an opposite dependence on varieties and technologies of growing red clover and ranged from 1,392-2,662 UAH and 5,363-10,265 UAH, respectively. Regardless of the method of sowing and variety, it was the lowest in the variant without fertilisers and under inoculation of seeds with nodule bacteria with fluctuations of 1,392-1,535 and 5,363-10,265 UAH, respectively, which is 1.6-1.7 times less compared to the introduction of seeds with nodule bacteria $P_{60}K_{90}$ and 1.7-1.8 times more compared to the introduction of seeds with nodule bacteria $N_{60}P_{60}K_{90}$.

Among the varieties of red clover, the most cost effective was Tayfun, which was 3-12% less expensive than Lybid and Tina with different fertilisers and different sowing methods. According to the calculations for an average of three years of research and use of grass stands, the method of sowing did not influence the cost of growing red clover.

The analysis of data on the energy efficiency of cultivating different varieties of red clover for fodder purposes showed that the total energy consumption ranged from 17.6-27.7 GJ/ha (Table 3).

Table 3. The energy efficiency of growing red clover varieties under different cultivation technologies (average for 2018-2020)

Fertiliser	Cultivar	Energy costs, GJ/ha	EER	BER	Energy consumption per 1 ton of feed, GJ
Pure sowing					
No fertilisers	Lybid	17.8	8.4	4.2	3.14
	Tayfun	18.3	8.9	4.6	2.87
	Tina	17.8	8.3	4.3	3.21
Inoculation (background)	Lybid	18.5	8.5	4.4	3.04
	Tayfun	19.3	8.7	4.6	2.83
	Tina	18.5	8.5	4.3	3.07
Background + $P_{60}K_{90}$	Lybid	22.6	7.2	3.7	3.76
	Tayfun	23.4	7.4	3.9	3.28
	Tina	22.5	7.2	3.8	3.62
Background + $N_{60}P_{60}K_{90}$	Lybid	26.9	6.3	3.2	4.20
	Tayfun	27.5	6.6	3.4	3.81
	Tina	27.0	6.3	3.3	4.19
Undersown spring barley					
No fertilisers	Lybid	17.6	8.6	4.4	3.04
	Tayfun	18.0	9.0	4.6	2.86
	Tina	17.6	8.6	4.4	3.08
Inoculation (background)	Lybid	18.4	8.5	4.4	3.07
	Tayfun	19.0	8.8	4.6	2.84
	Tina	18.3	8.4	4.4	3.19
Background + $P_{60}K_{90}$	Lybid	22.6	7.1	3.7	3.61
	Tayfun	23.1	7.5	3.9	3.39
	Tina	22.7	7.4	3.7	3.52
Background + $N_{60}P_{60}K_{90}$	Lybid	27.0	6.2	3.3	4.19
	Tayfun	27.7	6.5	3.5	3.62
	Tina	27.1	6.5	3.3	4.10

Note: EER is the ratio per 1 ha of gross energy to total energy consumption. BER is the ratio per 1 ha of exchangeable energy to total energy consumption

The lowest total energy costs for the cultivation of different varieties of red clover and sowing methods were in the variant without fertilisation, which ranged from 17.6-18.3 GJ/ha. When seeds were inoculated with nodule bacteria, they increased by 0.7-1.0 GJ/ha compared to the variant without fertilisers. When applied in combination with inoculation of seeds with nodule bacteria $P_{60}K_{90}$, they increased to 22.5-23. GJ/ha, which is 1.2-1.3 times more compared to the variant without fertilisers. The highest total energy costs were for inoculation of seeds with nodule bacteria in combination with $N_{60}P_{60}K_{90}$, which ranged from 26.9-27.7 GJ/ha, being 1.1-1.2 times more compared to the variant of inoculation of seeds with nodule bacteria in combination with $P_{60}K_{90}$ and 1.5 times more compared to the variant without fertilisation.

The method of sowing did not affect the total energy consumption for the cultivation of meadow clover on average over three years of cultivation and use of grass stands.

The main indicator of energy efficiency in fodder production is the return on energy costs per hectare of gross (energy efficiency ratio) and metabolic (bioenergy ratio) energy, which in this study on cultivation under different technologies and different varieties of red clover ranged from 6.2-9.0 and 3.3-4.6, respectively. Among the varieties of red clover, the Tayfun variety provided a slightly higher return on energy inputs in terms of gross and metabolisable energy per 1 ha than the Lybid and Tina varieties.

When growing different varieties of red clover among the fertilizer variants, the highest EER and BER were obtained in the variants without fertilisation and under seed inoculation with nodule bacteria with indicators of 8.3-9.0 and 3.2-4.6, respectively, which is 1.2-1, 5 and 0.5-0.8 units more compared to the application against the background of seed inoculation with nodule bacteria $P_{60}K_{90}$ and 2.1-2.3 and 1.0-1.2 units more compared to the inoculation of seeds with nodule bacteria in combination with the application of $N_{60}P_{60}K_{90.}$ With the additional application of N_{60} on the background of $P_{60}K_{90}$ for the cultivation of red clover, the payback of energy costs per 1 ha of gross and metabolisable energy decreased by 0.8-1.0 and 0.4-0.5, respectively.

Energy consumption per 1 t of feed units under different technologies of cultivation of red clover varieties ranged from 2.84-4.20 GJ. Regardless of the method of sowing and variety, it was the lowest in the variant without fertilisers and under inoculation of seeds with nodule bacteria with fluctuations of 2.84-3.21 GJ, which is 1.2 times compared to the background of inoculation of seeds with nodule bacteria $P_{60}K_{90}$ and 1.3-1.4 times less compared to the background of inoculation of seeds with nodule bacteria $N_{60}P_{60}K_{90}$.

The lowest energy consumption per 1 ton of feed units among the varieties of meadow clover was provided by Tayfun, and on different fertilisation backgrounds and with different sowing methods it was inferior to Lybid and Tina varieties – by 0.27-0.57 GJ. According to the calculations for an average of three years of cultivation and use of grass stands, the method of sowing did not affect the energy consumption per 1 t of feed units for growing red clover.

CONCLUSIONS

The cultivation of red clover for fodder purposes on typical low-humus chernozems of the northern part of the Right-Bank Forest-Steppe of Ukraine is profitable. Regardless of the technology components, it provides a net profit of UAH 14,962-23,743 per hectare with a profitability of 88-259% and a cost of 1 ton of feed units of UAH 1,415-2,662 and raw protein of UAH 5,363-10,265, a payback of energy costs in terms of gross energy (EER) yield per hectare of 6.2-9.0 and metabolisable energy (BER) yield per hectare of 3.2-4.6, with energy costs per 1 ton of feed units of 2.86-4.20 GJ.

The best rates of economic and energy efficiency of red clover cultivation are provided by the variety Typhoon when seeds are inoculated with nodule bacteria on fertiliser-free soil. The additional application of $P_{60}K_{90}$ or $N_{60}R_{60}K_{90}$ against the background of inoculation, which is necessary to preserve soil fertility, worsens them, reducing net profit by 3,486-5,943 UAH/ha.

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Економічна та енергетична ефективність вирощування різних сортів конюшини лучної (*Trifolium pratense* L.) на корм

Анотація. Вирощування конюшини лучної на кормові цілі на чорноземах типових малогумусних північної частини Правобережного Лісостепу України є рентабельним. Незалежно від складових технології воно забезпечує отримання чистого прибутку 14 962-23 743 грн з гектара за рівня рентабельності 88-259% та собівартості 1 т кормових одиниць 1 415-2 662 грн і сирого протеїну 5 363-10 265 грн, окупність енергетичних витрат за виходом валової енергії (ВЕР) з гектара 6. 2-9,0 та виходу обмінної енергії (ОЕ) з гектара 3,2-4,6, при витратах енергії на 1 т кормових одиниць 2,86-4,20 ГДж. Метою дослідження було визначити зміни економічної та енергетичної ефективності вирощування різних сортів конюшини лучної на кормові цілі залежно від способів сівби, інокуляції насіння бульбочковими бактеріями та внесення добрив. Під час досліджень використовували такі методи: польовий і лабораторний – для проведення досліджень у польових і лабораторних умовах, аналітичний – для визначення хімічного складу сухої біомаси конюшини лучної, розрахунковий - для визначення показників економічної та енергетичної ефективності. Найкращі показники економічної та енергетичної ефективності вирощування конюшини лучної забезпечує сорт Тайфун за інокуляції насіння бульбочковими бактеріями на бездобривному ґрунті. Додаткове внесення Р60К90 або N60R60K90 на фоні інокуляції, необхідне для збереження родючості ґрунту, погіршує їх, зменшуючи чистий прибуток на 3486-5943 грн/га

Ключові слова: біоенергетичний фактор, затрати коштів та енергії, економічна та енергетична ефективність, окупність витрат, рентабельність, собівартість, чистий прибуток