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ECOLOGICAL AND ECONOMIC EFFICIENCY OF GROWING ON DARK GRAY SOILS OF BEAN-CEREAL GRASSES

Uliana Karbivska[1], Yevheniia Butenko[2], Valentyna Nechyporenko[2], Olena Shumkova[2], Viktoriia Shumkova[2], Dmytro S. Tymchuk[3], Nataliya Tymchuk[4], Dmytro Litvinov[5], Anna Hotvianska[6], Valentina Toryanik[7]

[1]Vasyl Stefanyk Precarpathian National University, 57 Shevchenko St., Ivano-Frankivsk, 76018, Ukraine
[2]Sumy National Agrarian University, 160 H. Kondratieva St., Sumy, 40021, Ukraine
[3]Kharkiv International Medical University, 38 Molochna St., 61001, Kharkiv, Ukraine
[4]Kharkiv National Medical University, 4 Nauky Ave., 61022, Kharkiv, Ukraine
[5]National University of Life and Environmental Sciences of Ukraine, 12 Heroyiv Oborony, 03041, Kyiv, Ukraine
[6]Dnipro State Agrarian and Economic University, 25 Sergey Efremov St., Dnipro, 49600, Ukraine
[7]Sumy State Pedagogical University named after A.S. Makarenko, 87 Romenska St., Sumy, 40002, Ukraine

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Vastutav autor: Corresponding author: Yevheniia Butenko

E-mail: evg.butenko2011@ukr.net

ORCID:
0000-0002-0540-8887 (UK)
0000-0001-8904-519X (YB)
0000-0001-8257-2720 (VN)
0000-0002-5971-3561 (OS)
0000-0003-4640-6359 (VS)
0000-0002-4198-8372 (DST)
0000-0002-6523-9966 (NT)
0000-0001-6589-3805 (DL)
0000-0003-3887-3192 (AH)
0000-0003-0590-1345 (VT)

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ABSTRACT. The efficiency of growing leguminous and cereal agrophytocenoses (*Trifolium pratense* and *Medicago sativa* sown with the addition of *Bromus inermis*, *Lolium multiflorum*, *Festuca rubra*), highlighted their economic and energy advantages over cereal grasses. The article presents the results of the study of the influence of grass mixtures on the main indicators of the efficiency of growing sowing phytocenoses during haymaking in the Carpathians on dark grey soil. Growing agrophytocenoses without mineral fertilizers ensures the maintenance of 370–520 € ha^{-1} of net profit, with the profitability of 151–187%, the cost of 1 ton of feed units – 56.7–66.7 €, bioenergy coefficient – 2.5–2.9, energy efficiency ratio – 5.8–6.5 and energy consumption per 1 ton of feed units – 4.0–4.7 GJ. The cultivation of alfalfa-cereal grasses is ensured on dark-wet soil with three years of use of the best indicators of economic and energy efficiency. It was found that on both experimental bean-cereal grasses the highest efficiency is maintained when $P_{60}K_{60}$ is applied in combination with inoculation of seeds of bean strains of nodule bacteria.

Introduction

By development level, forage production in Ukraine lags far behind member states of the world economic community due to extensive, resource- and nature-intensive and environmentally hazardous management. This fact significantly affects the process of production of quality food raw materials and food products of animal origin and the formation of state food security (Pidpalyi *et al.*, 2013; Konyk, 2016). The largest share of the cost of livestock products is the cost of procurement of feed, so increasing their production at the moment will stop the decline of this industry (Klymenko, 2009; Karpenko *et al.*, 2019; Karbivska *et al.*, 2020). The cheapest food today can be obtained by growing meadow grasslands (Veklenko, 2003;

Scherner *et al.*, 2016; Cordeau *et al.*, 2017; Voloshyn, 2018; Hryhoriv *et al.*, 2022).

Grasslands are a major component of landscapes and are increasingly appreciated for their important role in providing sustainable development of ecosystems and they form a general positive impact on the environment (Hlushchenko, 2008; Capelo *et al.*, 2014; Isselstein, 2014; Paz-Ferreiro, 2016; Litvinov *et al.*, 2020).

The efficiency of growing agrophytocenoses largely depends on the species composition of grasses. According to studies conducted in Turkey, the introduction of *Lotus corniculatus* and *Medicago falcata* in the grass mixture can increase relatively net income by 83 USD compared to cereal grassland (Ates *et al.*, 2017). The main index of meadow agrophytocenoses economic efficiency is the cost of their creation, which is significant and takes the main share of all costs (Pukalo, 2015; Biermacher, 2012). The use of bean-cereal grasses is economically beneficial only with a high proportion of bean grasses, and, as it is known, they grow at a high level for only 2–3 years (Vyhovskyi, 2013; Panakhyd *et al.*, 2020).

One of the most important factors influencing the efficiency of growing meadow grasses is mineral fertilization (Schellberg, 1999). However, there are much data concerning the negative effects of mineral nitrogen on bean grasses. An alternative to it is the use of biological products which reduce agrochemical load and provide high-quality competitive agricultural products and preserve soil and environmental fertility. The use of inoculants is highlighted in the work of Dutch researchers Köhl *et al.* (2015). According to their data, seed inoculation is effective even on poor soils, in particular with a lack of phosphorus. The cost of bio preparations is only 3–5% of the profit (Petrichenko *et al.*, 2012; Patyka *et al.*, 2015).

With the help of energy assessment of agrophytocenoses cultivation, it is possible to compare different technologies of agricultural production with the help of energy costs and determine the structure of energy flows in agrocenoses and identify the main reserves of technical energy savings in agriculture (Konyk, 2016; Kvitko *et al.*, 2021; Mishchenko *et al.*, 2022a,b). Quantitatively determining the energy efficiency of growing meadow phytocenoses can be with the help of spent and received energy (Tatariko *et al.*, 2005; Hetman, 2014; Karbivska *et al.*, 2020).

Our work was based on a working hypothesis, the essence of which was in the complementary influence of cereal and bean grasses with complex fertilization systems, the economic efficiency of which is still insufficiently studied in the conditions of Precarpathians. However, until recently, such issues have not been studied enough, which became the goal of our research.

Materials and Methods

The research was conducted on dark grey drained soil of SE "Victory" (GPS coordinates latitude 48°56'55', longitude – 24°41'35') of Ivano-Frankivsk Institute of AIP, Tysmenytsk district of Ivano-Frankivsk region during 2017–2019. The research was conducted according to methodology of the Institute of Fodders of NAAS (Babych, 1994).

The study was conducted on seven fertilization backgrounds in combination with the use of appropriate strains of nodule bacteria – without fertilizers (control), $N_{30}P_{60}K_{60}$, $N_{30}P_{60}K_{60}$ + strain, $P_{60}K_{60}$, $P_{60}K_{60}$ + strain, $P_{90}K_{120}$, $P_{90}K_{120}$ + strain, and experiments on cereals were conducted on two backgrounds – without fertilizers, $N_{30}P_{60}K_{60}$.

Areas of sown plots – 180 m^2, accounting – 25 m^2. Seeds of bean grasses were treated by strains of nodule bacteria immediately before sowing grass mixtures. Seeds of perennial bean grasses before sowing were inoculated with nodule bacteria *Rhizobium trifolii* (*Trifolium pratense*) and *Rhizobium meliloti* (*Medicago sativa*).

The soil of the experimental area was dark grey podzolic heavy loam with the following agrochemical parameters: humus content in an arable layer – 2.12%, saline soil pH – 4.8, alkaline-hydrolyzed nitrogen – 53, mobile phosphorus – 83, mobile potassium – 69 mg kg^{-1} soil.

Evaluation of weather conditions in the years of research was carried out based on meteorological data obtained at Ivano-Frankivsk Regional Center for Hydrometeorology. They differed from long-term indices, but were favourable for the formation of agrophytocenoses of bean-cereal grasses, 2017 was characterized by unfavourable weather conditions, as a period with dry vegetation season and thermal regime with average monthly air temperature only 0.6 °C above normal 13.6 °C (long–term average for 2008–2019). The annual precipitation amount was 637 mm, and during vegetation season – 429 mm, which was respectively at the level of 67 mm or 14% less than the long-term average index. In April, July, August and September precipitation amount was significantly smaller than the norm (496 mm), by 1.6–2.6 times, in May and June precipitations were within the norm. This, of course, negatively affected the regrowth of grasses in the aftermath, and especially in the 3rd mowing, 2018 was characterized by the best weather conditions for perennial grasses compared to all years, with the highest precipitation amount at relatively moderate temperatures. The average air temperature both for the year and the growing season was higher than the norm (13.6 °C) by 0.9 and 1.0 °C, respectively. The annual precipitation amount was 1 015 mm, and during vegetation season – 778 mm, which is 387 and 282 mm more than the norm (496 mm).

In 2019 were recorded unfavourable weather conditions for the growth and development of perennial grasses, primarily due to lack of moisture, although air temperature during the vegetation period was moderate, with an average temperature of only 0.6°C above normal, and in May, June, July weather conditions were normal. The annual precipitation amount was 490 mm, and during the vegetation period – 386 mm, which is 138 and 110 mm less than the norm.

An economic evaluation of growing technologies for perennial grasses based on the studied elements was performed according to the method of evaluating the effectiveness of research with the help of technological maps with prices of 2020, energy evaluation was made according to the method by Medvedovskyi and Ivanenko (1988).

Statistical processing of yield data was performed by Microsoft Excel 2010.

Results and Discussion

When growing bean grasses at the control the following indices were obtained: net profit (389.7–521.0 € ha^{-1}), profitability level (151–187%) and the cost of 1 ton of fodder units (66.5–98.4 €) and 1 ton of crude protein (268.2–331.5 €) (Table 1).

On cereal grassland net profit and profitability were lower by 1.5–2.0 and 1.1–1.3 times, respectively, and prime cost of 1 ton of fodder units and crude protein – higher by 1.1–1.2 and 1.4–1.8 times. Alfalfa-cereal grasses provided higher indices of economic efficiency in the variants without fertilizers than clover-cereal grasses with a net profit of 1.3 times higher. A similar advantage of alfalfa-cereal grasses was on other studied backgrounds.

Research has proved that the variant with leguminous grasses had the highest level of profitability (145%), and in our study, it was higher than 42% in the variant of alfalfa-cereal grasses, while in cereals this figure was 141% (Konyk, 2016; Kvitko *et al.*, 2021; Mishchenko *et al.*, 2022a,b).

In comparison with the results obtained in similar climatic conditions, the researchers Panakhyd *et al.* (2020) proved that the costs of creating alfalfa-lovage-cereal agrophytocenosis ranged from 158.45 to 469.35 € ha^{-1}, whereas our costs were at the level of 250.25–476.10 € ha^{-1} in clover-alfalfa-cereal grass and depended on the type of fertilizer (Panakhyd *et al.*, 2020). In the background, $N_{30}P_{60}K_{60}$ the indices of economic efficiency of growing bean-cereal grasses compared to the variant without fertilizers decreased. Net profit and profitability decreased by 1.3–1.5 and 2.3–2.6 times, and the prime cost of 1 ton of fodder units and crude protein increased by 1.6 times. This is stipulated by the fact that due to a sufficient supply of soil with essential nutrients the grasses reacted poorly to nitrogen in cereal grassland.

Analysis of the research results showed that among fertilizer variants on both studied bean-cereal grasslands, the best indices of economic efficiency were obtained when applying $P_{60}K_{60}$ in combination with strains of nitrogen-fixing preparations. Net profit and profitability on clover grassland amounted to 359.1 € ha^{-1} and 85% accordingly, with the prime cost of 1 ton of fodder units and crude protein 92.03 and 451.33 €.

On alfalfa-cereal grassland, net profit and profitability were 478.0 € ha^{-1} and 107% respectively, and the prime cost of 1 ton of fodder units and crude protein was lower (80.53 and 375.6 €). However, the addition of only a strain of nitrogen-fixing drug, especially on alfalfa-cereal grassland, both with the application of $N_{30}P_{60}K_{60}$ and $P_{60}K_{60}$, $P_{90}K_{120}$ was generally ineffective. It was found that the most important economic indicators depended on the composition of the legume component of the grass mixture and fertilizer. With the application of mineral fertilizers, energy consumption, and gross and exchange energy output increased proportionally.

Payback of total energy consumption per 1 ha of exchange and gross energy on the background of $P_{60}K_{60}$ was the lowest with indices of 1.8 and 3.8 respectively, which is by 0.2 and 0.4 less compared to the background of $N_{60}P_{60}K_{60}$ and by 0.5 and 1.0 less than in the variant without fertilizers (Table 2).

Table 1. Economic efficiency of growing bean-cereal grasses with different fertilization in combination with strains of nodule bacteria

Grass mixture (species of grass and sowing rates of their seeds, kg ha^{-1})	Fertilization	Gross products, € ha^{-1}	Costs, € ha^{-1}	Net profit, € ha^{-1}	Profitability, %	The prime cost of 1 ton, €	
						fodder units	crude protein
Trifolium pratense, 10 + cereals (*Bromus inermis*, 12 + *Lolium multiflorum*, 12 + *Festuca rubra*, 10)	without fertilizers (control)	648.3	258.6	389.7	151	66.5	331.5
	$N_{30}P_{60}K_{60}$	720.0	453.3	266.7	59	104.9	503.6
	$N_{30}P_{60}K_{60}$ + strain	763.3	467.6	295.7	63	102.1	492.2
	$P_{60}K_{60}$	726.7	409.9	316.7	77	94.0	460.6
	$P_{60}K_{60}$ + strain	768.3	424.3	359.1	85	92.0	451.3
	$P_{90}K_{120}$	755.1	452.4	302.6	67	99.9	486.4
	$P_{90}K_{120}$ + strain	791.7	467.4	324.3	69	98.4	476.9
Medicago sativa, 10 + cereals (*Bromus inermis*, 12 + *Lolium multiflorum*, 12 + *Festuca rubra*, 10)	without fertilizers (control)	800.0	279.0	521.0	187	58.1	268.2
	$N_{30}P_{60}K_{60}$	868.3	477.0	391.4	82	91.5	422.1
	$N_{30}P_{60}K_{60}$ + strain	903.3	492.0	411.4	84	90.8	411.8
	$P_{60}K_{60}$	890.0	431.6	476.4	110	80.8	375.3
	$P_{60}K_{60}$ + strain	925.0	13409	478.0	107	80.5	375.6
	$P_{90}K_{120}$	903.3	14182	430.6	91	87.2	400.6
	$P_{90}K_{120}$+ strain	921.7	447.0	433.9	89	88.2	406.4
The cereals (*Bromus inermis*, 12 + *Lolium multiflorum*, 12 + *Festuca rubra*, 10)	without fertilizers (control)	438.3	181.7	256.7	141	69.1	478.1
	$N_{30}P_{60}K_{60}$	560.0	369.7	190.3	51	110.0	637.4

Table 2. The energy efficiency of growing bean-cereal grasses with different fertilizers in combination with strains

Grass mixture (species of grasses and sowing rates of their seeds, kg ha^{-1})	Fertilization	Energy consumption, GJ ha^{-1}	CEE	BEC	Energy consumptions per 1 ton of fodder units, GJ
Trifolium pratense,10 + cereals (*Bromus inermis*, 12 + *Lolium multiflorum*, 12 + *Festuca rubra*, 10)	without fertilizers (control)	15.7	6.5	2.9	4.04
	$N_{30}P_{60}K_{60}$	25.4	4.5	2.0	5.89
	$N_{30}P_{60}K_{60}$ + strain	27.3	4.3	1.9	5.96
	$P_{60}K_{60}$	24.8	4.5	2.0	5.69
	$P_{60}K_{60}$ + strain	25.3	4.7	2.1	5.49
	$P_{90}K_{120}$	27.7	4.3	1.9	6.11
	$P_{90}K_{120}$ + strain	28.6	4.3	1.9	6.02
Medicago sativa, 10 + cereals (*Bromus inermis*, 12 + *Lolium multiflorum*, 12 + *Festuca rubra*, 10)	without fertilizers (control)	22.6	5.8	2.5	4.71
	$N_{30}P_{60}K_{60}$	29.5	4.6	2.0	5.66
	$N_{30}P_{60}K_{60}$ + strain	30.3	4.7	2.1	5.59
	$P_{60}K_{60}$	27.7	5.1	2.2	5.19
	$P_{60}K_{60}$ + strain	28.3	5.3	2.3	5.15
	$P_{90}K_{120}$	30.8	4.5	2.0	5.68
	$P_{90}K_{120}$ + strain	31.5	4.5	2.0	5.70
The cereals (*Bromus inermis*, 12 + *Lolium multiflorum*, 12 + *Festuca rubra*, 10)	without fertilizers (control)	14.2	4.6	2.2	5.40
	$N_{30}P_{60}K_{60}$	24.7	3.4	1.6	7.35

The best energy efficiency indices were obtained when growing bean-cereal grasses in the variant without fertilizers. In particular, the total energy consumption both per 1 ha and per 1 ton of fodder units was the lowest and ranged between 15.7–22.6 and 4.04–4.71 GJ respectively, and the payback of energy consumption per exit from 1 ha of exchange and gross energy as bioenergy coefficient (BEC) and energy efficiency ratio (CEE) was the highest (2.0–2.9 and 5.8–6.5).

On cereal grassland energy consumption per 1 ton of fodder units was 1.1–1.4 times higher compared to alfalfa- and clover-cereal grasslands and payback of total energy consumption as BEC and CEE were 1.1–1.3 and 1.3–1.4 times lower respectively. Clover-cereal grassland provided higher energy efficiency in these environmental conditions than alfalfa-cereal grassland, where in particular in the variant without fertilizers energy consumption per 1 ton of fodder units was lower, and BEC and CEE 1.1 times higher. A similar advantage of alfalfa-cereal grassland was recorded in other studied backgrounds.

On the background of $N_{30}P_{60}K_{60}$ indices of energy efficiency of growing both bean-cereal grasses compared to the variant without fertilizer deteriorated. The cost recovery of both BEC and CEE decreased by 1.5–1.6 times, and energy consumption per 1 ha and per 1 ton of fodder units increased by 1.5–1.6 times. Similar deterioration regularity of cultivation energy efficiency from the application of $N_{30}P_{60}K_{60}$ compared to the control was in cereal grassland, but with lower BEC and CEE and higher energy consumption per 1 ton of fodder units.

Among fertilizer variants on both studied bean-cereal types of grass, slightly better energy efficiency indices were obtained during the application of $P_{60}K_{60}$ in combination with the use of nitrogen-fixing strains. In this case, BEC and CEE on clover-cereal grassland were 2.1 and 4.7 respectively, with energy consumption per 1 ton of fodder units of 5.49 MJ. On alfalfa–cereal grassland BEC and CEE compared to clover–cereal grassland, as well as in the variant without fertilizers, were higher with rates of 2.3 and 5.3 respectively, and energy consumption per 1 ton of fodder units less with parameters of 5.00. However, the addition of only strain of nitrogen-fixing drug, both on the background of $N_{30}P_{60}K_{60}$, and on the background of $P_{60}K_{60}$ and even $P_{90}K_{120}$ was not always effective, both by indices of BEC and CEE and energy consumption per 1 ton of fodder units.

With increasing doses of phosphorus and potassium fertilizers, energy efficiency also deteriorated. In particular, when applying $P_{60}K_{60}$ compared to the control on bean-cereal grasslands, BEC and CEE decreased by 0.9 and 1.9–2.0 respectively, the payback of 1 t of fodder units increased by 1.4 times, and with an application of $P_{90}K_{120}$ decreased accordingly by 1.0–1.1 and 2.2–2.5 and increased by 1.5 times. The highest forage productivity with grass was observed for the third year of use, in this period the yield of forage units reached 7.1 t ha^{-1}.

Conclusion

The best indices of economic and energy efficiency are provided by growing alfalfa-cereal grasslands. Among fertilizer variants, the highest indices of economic efficiency are provided with the application of $P_{60}K_{60}$ in combination with the use of drugs of appropriate strains of symbiotic nitrogen fixation with net profit and profitability of 360–477 € ha^{-1} and 85–107% with a cost of 1 ton of fodder units 80–93 €. Application of $P_{60}K_{60}$, $P_{90}K_{90}$ and $N_{30}P_{60}K_{60}$ worsens economic and energy efficiency indicators.

Obtained results will allow agricultural producers to choose optimal measures for the creation and use of bean-cereal grasses taking into account their needs and possibilities. A promising area of research in this context is establishing of economic efficiency of technologies for radical improvement of meadows, which would ensure quality fodder at a minimal cost.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publications of this paper.

Author contributions

UK – study conception and design, drafting of the manuscript;
YB – performed the literature data analysis and discussion of the results;
VN, AH – analysis and interpretation of data and is the corresponding author;
VT, DL – author of the idea, guided the research;
DST, NT – acquisition of data, drafting of the manuscript;
OS, VS – critical revision and approval of the final manuscript.
All authors read and approved the final manuscript.

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