JEE Journal of Ecological Engineering

Journal of Ecological Engineering 2023, 24(6), 190–196
https://doi.org/10.12911/22998993/162778
ISSN 2299–8993, License CC-BY 4.0

Received: 2023.03.06
Accepted: 2023.04.17
Published: 2023.05.01

Dynamics of Productivity of Leguminous Plant Groups during Long-Term Use on Different Nutritional Backgrounds

Uliana Karbivska[1], Andrii Butenko[2*], Maksym Kozak[3], Vasyl Filon[4], Mariia Bahorka[5], Nataliia Yurchenko[5], Olena Pshychenko[2], Kateryna Kyrylchuk[2], Serhii Kharchenko[2], Ievgenii Kovalenko[6]

[1] Vasyl Stefanyk Precarpathian National University, Shevchenko Str., 57, Ivano-Frankivsk, 76018, Ukraine
[2] Sumy National Agrarian University, H. Kondratieva Str., 160, Sumy, 40021, Ukraine
[3] Kamianets-Podilskyi National Ivan Ohiienko University, Ohiienko Str., 61, Kamianets-Podilskyi, 32300, Ukraine
[4] Kharkiv State Biotechnological University, Alchevskikh Str., 44, 61000, Kharkiv, Ukraine
[5] Dnipro State Agrarian and Economic University, Sergei Yefremov, Str., 25, Dnipro, 49000, Ukraine
[6] National University of Life and Environmental Sciences of Ukraine, Heroyiv Oborony Str., 15, Kyiv, 03041, Ukraine
* Corresponding author's e-mail: andb201727@ukr.net

ABSTRACT
Deterioration of ecological situation, increase of mineral fertilizer prices and their foreseen increase in recent years force us to look for the ways to reduce the rates of their application and alternative means of maintaining high productivity of sown fodder lands. Fertilization was and remains one of the decisive ways of increasing haymaking productivity, as well as increasing their economic efficiency. The productivity of leguminous grasses based on the study of agrotechnological measures of cultivation in the conditions of the Carpathian region is currently relevant. The studied species of perennial grasses, during the three-year cultivation, showed that the largest number of shoots was formed on the variant with horned sedge and was 1185–1201 pieces/m^2. *Medicago sativa* had the smallest number of shoots (470 pics/m^2, control (without fertilizers)). *Trifolium pratense and Lotus corniculatus* provided the highest productivity in relation to other species from 20 to 31%.
Analysis of single–species crops productivity of perennial bean grasses by cuttings showed that the peculiarities obtained on average for all slopes, were also similar in each of two slopes. During the three–year use of the herbage on the yield from 1 ha of dry mass in both slopes, the herbage factor had the greatest influence, the share of which was 61–62%, while the share of the influence of fertilizer was 38–39%.

Keywords: legumes, productivity, nutrition, botanical composition, density of plants, crude protein, productivity, meadow coenoses.

INTRODUCTION

One of the important things in today's onion production is the creation of sown high–yielding grass stands using perennial leguminous grasses, which ensure high productive longevity of meadow coenoses, proper quality of fodder and provide the opportunity to organize raw material conveyors due to a wide selection of the latest species and varieties. Such grass stands are created under the conditions of applying mineral fertilizers [Kovtun & Veklenko, 2006; Karbivska, 2020; Chețan et al., 2021; Karpenko et al., 2022]. The latest intensive technologies increase the productivity of phytocenoses by 3–4 times, where one of the agrotechnical measures is the selection of varieties, fertilization and the creation of sown grass stands. [Litvinov et al., 2020; Rieznik et al., 2021]. On meadows, high yields can be achieved only with systematic application in optimal doses and ratios of mineral fertilizers in accordance with the composition of grass stands, features of soil cover and modes of use [Mashchak & Mizernyk, 2013; Nan et al., 2019; Tonkha et al., 2021]. Fertilization is one of the decisive measures for increasing the productivity of haymaking. It ensures yield increase as well as extends effective longevity of sown grasses in agrophytocenoses [Kukreja & Meredith, 2011; Woźniak, 2019; Hryhoriv et al., 2022a]. As a result of applying fertilizers that are not balanced in terms of elements, although the yield increases, the botanical composition of plant communities is depleted, and there is also a lack of new types of grasses in the grass stands [Martsinko, 2022; Hryhoriv et al., 2022b].

In Ukraine, the most widespread perennial bean grasses are *Medicago sativa*, *Hizobium trifolii*, *Onobrychis viciifolia*, *Melilotus albus* and *Melilotus officinalis*, *Lotus corniculatus*, etc. [Tsymbal & Kushchuk, 2019; Dziubailo et al., 2020; Tsyuk et al., 2022]. Their value in agriculture and fodder production is extremely important, because it is almost impossible to solve the problem of fodder without them in the regions with developed animal husbandry. They are highly productive, contain a lot of protein, vitamins, and minerals, and they are widely used in feeding all kinds of animals that eat and digest them well [Dziubailo et al., 2020; Madhav et al., 2020; Martsinko, 2022].

However, despite the high agrotechnical, economic and ecological importance of perennial grasses, the area under them is constantly decreasing. Thus, according to Petrychenko, Getman and Tsyganskyi, perennial grass crops in Ukraine decreased from 3752000 ha in 1980 to 950000 ha in 2019 [Demydas & Demtsiura, 2011; Petrychenko et al., 2018; Novák et al., 2020]. Despite the large number of studies conducted on the study of the effect of fertilizer on the productivity of leguminous grasses, it has not been sufficiently studied under the conditions of the Carpathian region, which prompted the publication of the research conducted in this work.

MATERIAL AND METHODS

Field research was conducted on the sod-podzolic soil of the experimental field of the Faculty of Natural Sciences of Vasyl Stefanyk Prykarpattia National University in 2017–2019 according to the generally accepted methodology. The relationship between the following factors was investigated: A – types of grasses; B – fertilizer. Mineral fertilizers in the form of ammonium nitrate were applied superficially, granular superphosphate and potassium magnesia in early spring. The size of sowing plots is 10 m^2, accounting plots – 8 m^2. The experiment was repeated four times. Perennial grasses adapted to the natural and climatic conditions of Prykarpattia were sown.

The scheme of the experiment was as follows: *Trifolium pratense*, 18 kg ha^{-1}; *Medicago sativa*, 18 kg ha^{-1}; *Trifolium hybridum*, 14 kg ha^{-1}; *Lotus corniculatus*, 12 kg ha^{-1}; *Bromus inermis*, 25 kg ha^{-1} (cereal grass). The analysis of climatic conditions during the research was carried out according to the data of the Ivano–Frankivsk Regional Center for Hydrometeorology. In terms of weather conditions, the year 2017 differed somewhat from the indicators, but was favorable for agrophytocenoses of grasses. During the growing season of leguminous grasses, precipitation was 13.1 mm lesser than the norm, and at the same time, a decrease in by 4.5°C temperature was observed in relation to long–term indicators. The temperature regime in 2018 was characterized by elevated air parameters (+1.5°C above the long–term norm), while the amount of precipitation was insufficient (24% less than the norm). The conditions in 2019 were satisfactory for the growth and development of legumes.

Field research was conducted in accordance with the generally accepted methodology of the Institute of Fodder and Agriculture of the Podillia National Academy of Sciences [Babych, 1994]. Harvest accounting was carried out plot by plot, using the weight method. The content of absolutely dry matter was determined by drying plant samples in a thermostat at a temperature of 100–105°C (DSTU ISO 6497:2005). Botanical composition was determined by taking a sample of green mass from the plots of each variant from the first and third repetitions, which were divided into botanic–economic groups: cereals, beans, various herbs (DSTU 6017:2008). The reliability of research results was carried out by statistical methods on a personal computer using the Statistica 6 software package [Dospekhov, 1985].

RESULTS AND DISCUSSION

During the first three years of using the grasslands, of the four species, only *Lotus corniculatus* was well maintained (Table 1). On average, over three years, on different nitrogen–free fertilization backgrounds, its share fluctuated between 81–84%, which is 22–40% more compared to the share of the sown crop in single–species crops of

Table 1. Dynamics of the content of bean grasses and *Lotus corniculatus* on different fertilization backgrounds, 2017–2019, %

Grass species and seed sowing norms, kg ha^{-1}	Fertilization	Years of use			Average
		1st	2d	3d	
Hizobium trifolii	Without fertilizers (control)	90	79	6	58
	$P_{60}K_{60}$	92	82	8	61
	$P_{90}K_{90}$	93	83	9	62
Medicago sativa	Without fertilizers (control)	65	50	8	41
	$P_{60}K_{60}$	67	52	10	43
	$P_{90}K_{90}$	68	53	11	44
Trifolium hybridum	Without fertilizers (control)	87	76	5	58
	$P_{60}K_{60}$	89	77	7	58
	$P_{90}K_{90}$	90	80	8	59
Lotus corniculatus	Without fertilizers (control)	90	78	75	81
	$P_{60}K_{60}$	92	81	77	83
	$P_{90}K_{90}$	93	82	78	84
*Bromus inermis**	Without fertilizers (control)	80	88	86	85
	$P_{60}K_{60}$	82	90	88	87
	$N_{60}P_{60}K_{60}$	83	91	89	88
LSD_{05} %		8	9	5	7

Note: * – the dynamics of *Bromus inermis* content in a single-species crop is given.

Trifolium pratense, *Medicago sativa*, and *Trifolium hybridum* and only 4% less with the crop of *Bromus inermis*. *Medicago sativa* sowing had the smallest share of influence among bean grasses species. *Trifolium pratense* and *Trifolium hybridum* were well-maintained in grass stands at the level of 82–93% only during the first two years of use. In the 3rd year of use, due to the short duration of ontogenesis, they practically fell out of the grass stands, reducing their share to 5–9%. Due to unfavorable soil conditions – high acidity, *Medicago sativa* was liquefied and suppressed already in the first year of use (with a share of 65–68%). In the third year, its share decreased to 8–11%.

According to the number of shoots of the sown crop, during the first three years of grass stands use, of four species only *Lotus corniculatus* had sufficient density and was well maintained, (Table 2). On average, over three years, on different nitrogen–free fertilization backgrounds, the number of its shoots fluctuated between 1185–1201 pcs/m^2, which is 1.9–2.4 times more compared to the number of the sown crop shoots in single–species phytocenoses. Among the species of perennial bean grasses that were studied, the lowest number of shoots of the sown crop was *Medicago sativa* sown (470 units/m^2, without fertilizers).

Trifolium pratense and *Trifolium hybridum* had a full density and were well-maintained in grass stands with a density of 689–782 shoots/m^2 only during the first two years of use. In the third year, due to short vegetation of ontogenesis, they became very thin, reducing their density to 94–120 shoots/m^2. *Medicago sativa* had lower density and was depressed already in the first year of use (the number of shoots per 1 m^2 within the range of 670–690 pics/m); in the third year of use, the number of its shoots per 1 m^2 decreased to 231–255 pics, which is more compared to *Trifolium pratense* and less compared to *Lotus corniculatus*. Among all studied species, the most stable and with the highest density was the variant with *Lotus corniculatus* in the range of 1102–1392 shoots/m^2 during all three years of use. With adding $P_{60}K_{60}N_{60}$, the number of shoots decreased by 123 shoots on average over three years. They were characterized by greater linear growth. Application of phosphorus–potassium fertilizers did not significantly affect the density of perennial bean grasses. The number of shoots increased by 33 pieces/m^2 in the variants of the experiment where $P_{60}K_{60}$ and $P_{90}K_{90}$ were applied. The linear growth of perennial bean grasses during the years of research in the first slope ranged from 50 to 85 cm (Table 3).

Trifolium pratense was characterized by the greatest linear growth with average height of 74–80 cm, and *Lotus corniculatus* – the smallest

Table 2. Dynamics of changes in the density of bean grasses under different fertilization, units/m^2

Grass species and seed sowing norms, kg ha^{-1}	Fertilization	Years of use			Average
		1st	2d	3d	
Hizobium trifolii	Without fertilizers (control)	950	752	100	601
	$P_{60}K_{60}$	972	770	112	618
	$P_{90}K_{90}$	980	782	120	627
Medicago sativa	Without fertilizers (control)	670	510	231	470
	$P_{60}K_{60}$	685	530	241	485
	$P_{90}K_{90}$	690	543	255	496
Trifolium hybridum	Without fertilizers (control)	971	689	94	585
	$P_{60}K_{60}$	983	699	99	594
	$P_{90}K_{90}$	991	708	104	601
Lotus corniculatus	Without fertilizers (control)	1159	1250	1143	1185
	$P_{60}K_{60}$	1168	1259	1149	1192
	$P_{90}K_{90}$	1179	1270	1153	1201
Bromus inermis	Without fertilizers (control)	1270	1380	1293	1314
	$P_{60}K_{60}$	1290	1392	1305	1329
	$N_{60}P_{60}K_{60}$	1102	1300	1215	1206
LSD_{05} shoots/m^2		87	92	73	84

(51–54 cm), which is 23–26 cm less compared to the first species. Within error margin of the experiment, *Trifolium hybridum* was inferior to *Trifolium pratense* in height. An intermediate place between *Hizobium trifolii* and *Lotus corniculatus* was occupied by *Medicago sativa* crop with the height of 65–70 cm. *Trifolium pratense* and *Lotus corniculatus* were characterized by the same linear growth on nitrogen–free backgrounds. With application of N_{60} three–year average linear growth of *Bromus inermis*, in contrast to its shoot density, increased from 87 to 111 cm, or by 24 cm. By the years of use, it was found that the species (*Trifolium pratense* and *Trifolium hybridum* and *Medicago sativa*) decreased their share and density in the grass stand, as well as the height

Table 3. Linear growth of single-species crops of perennial bean grasses, cm

Grass species and seed sowing norms, kg ha^{-1}	Fertilization	Years of use			Average
		1st	2d	3d	
Hizobium trifolii	Without fertilizers (control)	79±5	74±5	69±5	74
	$P_{60}K_{60}$	83±6	78±6	72±6	78
	$P_{90}K_{90}$	85±6	80±6	74±6	80
Medicago sativa	Without fertilizers (control)	71±6	67±6	57±6	65
	$P_{60}K_{60}$	73±7	71±7	61±7	68
	$P_{90}K_{90}$	74±7	73±7	63±7	70
Trifolium hybridum	Without fertilizers (control)	78±5	72±5	68±5	73
	$P_{60}K_{60}$	80±6	75±6	70±6	75
	$P_{90}K_{90}$	81±6	77±6	72±6	77
Lotus corniculatus	Without fertilizers (control)	53±5	50±5	52±5	51
	$P_{60}K_{60}$	54±5	52±5	54±5	53
	$P_{90}K_{90}$	55±5	53±5	55±5	54
Bromus inermis	Without fertilizers (control)	91±6	86±6	71±6	83
	$P_{60}K_{60}$	96±7	91±7	74±6	87
	$N_{60}P_{60}K_{60}$	105±8	113±8	116±8	111
LSD_{05} cm		8	9	8	8

by the years of use. In the third year of use, compared to the first one, their height decreased by 11–14 cm. At the same time, the linear growth of *Lotus corniculatus* during the first three years of use was stable with a height of 50–55 cm.

On nitrogen-free backgrounds, the linear growth of *Bromus inermis* also gradually decreased – for example, in the third year of use – compared to the first one – its height decreased by 20–22 cm. With the addition of N_{60} to $P_{60}K_{60}$, the height of this culture increased from 105 to 116 cm, which indicates a positive effect of nitrogen fertilizers for its linear growth, as well as a highly positive reaction to nitrogen.

In the study, the herbage factor had a significant impact with a share of 63%, while the share of fertilizer was only 37%. It is worth noting that during the first year of using herbs, the herbage had the largest share of influence (61%). In all subsequent years of use, a decrease in the amount of the bean component and the effect of symbiotic nitrogen was noted on average by 64%. On average, over the years of use, the productivity of perennial bean grasses with double-hooked use in variants of control and application of $P_{60}K_{60}$ fluctuated in the range of 5.0–6.5 t ha^{-1} of dry weight, 3.6–5,0 t ha^{-1} of fodder units, 0,8–1.1 t ha^{-1} of crude protein, 43–58 GJ ha^{-1} of exchangeable energy, which is 1.3–2.5 times more than in single–species *Bromus inermis* (Table 4).

The greatest advantage of all types of perennial bean grasses in comparison with *Bromus inermis* was obtained in terms of crude protein yield from 1 ha, which is stipulated by its much higher content in the dry mass of perennial bean grasses. *Trifolium pratense* and *Lotus corniculatus* provided the highest productivity. The most active nutrient element turned out to be nitrogen on cereal grass stand, which is represented in the study by *Bromus inermis*. Thus, productivity on cereal grass stand with application of N_{60} in comparison with the variant without application of nitrogen

Table 4. Productivity of perennial bean grasses and *Bromus inermis* depending on fertilizers by the years of use

Grass species and seed sowing norms, kg ha^{-1}	Fertilization	Dry weight by year, t ha^{-1}			Average for 2017–2019 pp.			
		2017	2018	2019	Dry mass, t a^{-1}	Feeding units, t ha^{-1}	Row protein, t ha^{-1}	Exchange energy, GJ ha^{-1}
Hizobium trifolii	Without fertilizers (control)	7.85	7.10	3.65	6.23	4.55	1.01	54.2
	$P_{60}K_{60}$	8.02	7.11	3.71	6.31	4.61	1.03	55.5
	$P_{90}K_{90}$	8.14	7.22	3.86	6.44	4.77	1.07	57.3
Medicago sativa	Without fertilizers (control)	6.33	5.53	3.13	5.03	3.62	0.79	43.3
	$P_{60}K_{60}$	6.43	5.62	3.27	5.14	3.70	0.82	44.7
	$P_{90}K_{90}$	643	5.54	3.35	5.14	3.80	0.82	44.7
Trifolium hybridum	Without fertilizers (control)	7.38	5.57	2.68	5.18	3.78	0.80	45.1
	$P_{60}K_{60}$	7.59	5.68	2.79	5.39	3.99	0.84	47.4
	$P_{90}K_{90}$	7.44	5.64	2.84	5.34	4.01	0.83	47.5
Lotus corniculatus	Without fertilizers (control)	7.91	6.41	5.07	6.43	4.89	1.07	57.2
	$P_{60}K_{60}$	7.97	6.37	5.18	6.47	4.98	1.08	58.2
	$P_{90}K_{90}$	8.06	6.46	5.15	6.56	5.12	1.10	58.2
Bromus inermis	Without fertilizers (control)	4.10	4.85	2.44	3.80	2.62	0.39	30.8
	$P_{60}K_{60}$	4.15	5.10	2.63	3.96	2.77	0.42	32.5
	$N_{60}P_{60}K_{60}$	5.90	5.75	5.15	5.60	3.98	0.76	45.9
LSD_{05}, t ha^{-1} by factors								
Grass stand		0.38	0.35	0.32	0.35			
Fertilization		0.31	0.29	0.30	0.30			
Factor share, %:								
Grass stand		61	63	64	63			
Fertilization		39	37	36	37			

on the background of $P_{60}K_{60}$, increased on average from 3.96 to 5.60 t ha^{-1} of dry weight, 2.8–4,0 t ha^{-1} of fodder units, 0.4–0.8 t ha^{-1} of crude protein and 32.5–45.9 GJ ha^{-1} of exchange energy. The greatest advantage of applying N_{60} was in collection of crude protein from 1 ha, which is stipulated by an increase of its content in dry weight and collection from 1 ha, respectively.

The effect of combined application of phosphorus and potassium in the doses of $P_{60}K_{60}$ and $P_{90}K_{90}$ on the productivity of bean grasses on average for three years was insignificant, mostly within experimental error. Comparing to the control variant (without fertilizers), in this case, productivity per 1 ha of dry mass increased by only 0.04–0.21 t. at LSD_{05} 0.3 t.

Regardless of agro–background, stable productivity in all years of use among bean grasses was provided by single–species sowing of *Lotus corniculatus*, as well as grass stand of *Bromus inermis*, which is stipulated by the steady stability of mentioned types of perennial grasses. Over the years of use, the productivity of *Lotus corniculatus* ranged from 5.07 to 8.06 t ha^{-1} of dry mass, with an uneven distribution of the yield over the years, expressed by a coefficient of variation 25–30%. The productivity of *Bromus inermis* by the years of use on nitrogen–free backgrounds was in the range of 3.44–4.15, and on the background $N_{60}P_{60}K_{60}$ it was 5.15–5.90 t ha^{-1} of dry mass with an uneven distribution of the yield by years 15–25%. Meanwhile, *Trifolium pratense* and *Trifolium hybridum*, due to low biological productive longevity or short duration of ontogenesis, provided relatively high productivity of grass stands in the 1st and 2nd years of use with a yield of 5.57–8.14 tons of dry weight per 1 ha.

Medicago sativa, apparently due to unfavorable soil acidity, also provided the highest productivity in the first and second years of using the grass stand, but with a lower level of productivity (5.53–6.43 t ha^{-1}), especially compared to *Trifolium pratense*. Accordingly, *Trifolium pratense* and *Trifolium hybridum* sharply reduced their productivity in the third year of use to 2.68–3.86 t., and *Medicago sativa* reduced its productivity already in the second year to 4.53–4.62 t. Coefficient of uneven yield distribution over the years of using these species ranged from 40 to 45%.

CONCLUSIONS

In single–species crops of perennial bean grasses, *Lotus corniculatus* is well-maintained with a shoot density of 1185-1201 pcs/m^2 and a share of the sown crop of 81–84%. *Trifolium pratense* and *Trifolium hybridum* are well-maintained in grass stands only during the first two years of use. The linear growth of perennial bean grasses in the first slope ranges from 50–85 cm, with the greatest height of *Trifolium pratense*.

Single-species crops of perennial bean grasses in the versions without fertilizers and with the introduction of $P_{60}K_{60}$ provided productivity at the level of 5.0–6.5 t ha^{-1} of dry weight, 3.6–5.0 t ha^{-1} of fodder units, 0.8–1.1t ha^{-1} of crude protein, 43.3–58.2 GJ ha^{-1} of exchangeable energy, respectively, it is 1.3–2.5 times more in relation to cereal *Bromus inermis* grass stand.

REFERENCES

1. Babych A.O. 1994. Methods of conducting experiments in fodder production and animal feeding. Kyiv, 16–18. (In Ukrainian)
2. Chețan F., Chețan C., Bogdan I., Pop A.I., Moraru P.I. & Rusu T. 2021. The Effects of Management (Tillage, Fertilization, Plant Density) on Soybean Yield and Quality in a Three–Year Experiment under Transylvanian Plain Climate Conditions. *Land*, 10(2), 200. DOI: 10.3390/land10020200
3. Demydas H.I., Demtsiura Y.V. 2011. Fodder productivity of leguminous-cereal grass mixtures depending on the species composition and the method of grass creation. Collection of Scientific Works of VNAU. Fodder production, 9(49), 95–101. (in Ukrainian)
4. Dospekhov B.A. 1985. Methods of field experience. Kolos, Moscow, 351. (in Russian)
5. Dziubailo A.H., Martsinko T.I., Holovchuk M.I. 2020. Formation of productivity of leguminous-cereal grass mixtures depending on fertilizer. Foothill and mountain agriculture and animal husbandry, 67(1), 39–53. (in Ukrainian)
6. Hryhoriv Y., Butenko A., Kozak M., Tatarynova V., Bondarenko O., Nozdrina N., Stavytskyi A., Bordun R. 2022a. Structure components and yielding capacity of *Camelina sativa* in Ukraine. Agriculture and Forestry, 68(3), 93–102. DOI: 10.17707/AgricultForest.68.3.07
7. Hryhoriv Y., Nechyporenko V., Butenko A., Lyshenko M., Kozak M., Onopriienko I., Shumkova O., Shumkova V., Kriuchko L. 2022b. Economic efficiency of sweet corn growing with nutrition optimization.

Agraarteadus, 33(1), 81–87. DOI: 10.15159/jas.22.07

8. Karbivska U.M. 2020. The effect of fertilizers on the botanical composition of variously mature grasses in the conditions of the Carpathian region. Achroecological journal, 2, 91–97. (in Ukrainian)
9. Karpenko O., Butenko Y., Rozhko V., Sykalo O., Chernega T., Kustovska A., Onychko V., Tymchuk D.S., Filon V., Novikova A. 2022. Influence of Agricultural Systems on Microbiological Transformation of Organic Matter in Wheat Winter Crops on Typical Black Soils. Journal of Ecological Engineering, 23(9), 181–186. DOI: 10.12911/22998993/151885
10. Kovtun K.P., Veklenko Y.A. 2006. Influence of bacterial preparations on feed quality of legume–cereal grass mixtures. Feed and feed production, 58, 39–44. (in Ukrainian)
11. Kukreja R., Meredith S. 2011. Resource Efficiency and Organic Farming: Facing up to the challenge. Brussels, Belgium: IFOAM EU Group, 32.
12. Litvinov D., Litvinova O., Borys N., Butenko A., Masyk I., Onychko V., Khomenko L., Terokhina N. & Kharchenko S. 2020. The Typicality of Hydrothermal Conditions of the Forest Steppe and Their Influence on the Productivity of Crops. Journal of Environmental Research, Engineering and Management, 76(3), 84–95. DOI: 10.5755/j01.erem.76.3.25365
13. Madhav D., Charles P. West Carlos Villalobos, Philip Brown, Paul E. Green. 2020. Interseeding alfalfa into native grassland for enhanced yield and water use efficiency. Agronomy Journal. First published: 23 January, 22. DOI: 10.1002/agj2.20147
14. Martsinko T.I. 2022. Peculiarities of the formation of a leguminous-cereal grass mixture depending on the influence of agrotechnical factors. Foothill and mountain agriculture and animal husbandry, 72(1), 21–32. (in Ukrainian)
15. Mashchak Y.I., Mizernyk D.I. 2013. Yields of degenerated grass stands depending on the sown species and rates of perennial legume. Visnyk ahrarnoi nauky, 9, 16–19. (in Ukrainian)
16. Nan L.-L., Shi S.L., Guo Q.-E., Bai X.-M. 2019. Effects of seeding rate and row spacing on nutritional value of alfalfa in the arid oasis region of Gansu Province. Acta Prataculturae Sinica, 28(1), 108–119. DOI: 10.11686/cyxb2018426
17. Novák V., Křížová K. & Šařec P. 2020. Biochar dosage impact on physical soil properties and crop status. Agronomy Research, 18(4), 2501–2511. DOI: 10.15159/AR.20.192
18. Petrychenko V.F., Hetman N.Ya., Tsyhanskyi V.I. 2018. Alfalfa sowing as a stabilizing factor in the intensification of fodder production. Visnyk ahrarnoi nauky, 10, 19–26. (in Ukrainian)
19. Rieznik S., Havva D., Butenko A., Novosad K. 2021. Biological activity of chernozems typical of different farming practices. Agraarteadus, 32(2), 307–313. DOI: 10.15159/jas.21.34
20. Tonkha O., Butenko A., Bykova O., Kravchenko Y., Pikovska O., Kovalenko V., Evpak I., Masyk I., Zakharchenko E. 2021. Spatial Heterogeneity of Soil Silicon in Ukrainian Phaozems and Chernozems. Journal of Ecological Engineering, 22(2), 111–119. DOI: 10.12911/22998993/130884
21. Tsymbal Y.S., Kushchuk M.A. 2019. Productivity and fodder performance of alfalfa compared to other perennial grasses. Herald of Agrarian Science, 10(199), 24–31. (in Ukrainian)
22. Tsyuk O., Tkachenko M., Butenko A., Mishchenko Y., Kondratiuk I., Litvinov D., Tsiuk Y., Sleptsov Y. 2022. Changes in the nitrogen compound transformation processes of typical chernozem depending on the tillage systems and fertilizers. Agraarteadus, 33(1), 192–198. DOI: 10.15159/jas.22.23
23. Woźniak A. 2019. Chemical Properties and Enzyme Activity of Soil as Affected by Tillage System and Previous Crop. Agriculture, 9(12), 262. DOI: 10.3390/agriculture9120262