Original scientific paper
Journal of Central European Agriculture, 2022, 23(2), p.391-402
DOI: /10.5513/JCEA01/23.2.3431

The impact of natural factors and the interaction of anthropogenic resources on the productivity and energy potential of grasslands

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Received: October 7, 2021; accepted: January 10, 2022

ABSTRACT

The role of natural factors and the interaction of anthropogenic resources with them was researched. The meadow agroecosystems based on income balance, accumulation, and expenditure of energy yield were assessed. The study has been carried out during 2011-2015 at the long-term (47 years) field experiment of the Institute of Agriculture of the Carpathian region, which includes permanent and temporary grasslands. The dry matter (DM) yield and energy yield (EY) of permanent grassland, mainly depend on mineral fertilization. Application of NPK which includes 60 kg P per ha, 90 kg K per ha, and 90 kg N per ha promotes the acquisition of 8.22 t/ha DM with 155.4 GJ/ha EY. The sum of energy yield from the aboveground mass (71.5 GJ/ha), the root (65.9 GJ/ha) and the soil energy (112.7 GJ/ha) is 250.1 GJ/ha. Production of gross energy is 260.1 GJ/ha from this grassland. The use of phosphorus and potassium fertilizers, lime and growth enhancer has a positive impact on the DM yield, soil fertility, and EY of temporary legume-grass grasslands. This combined fertilizer yields 6.65 t/ha DM and 260.3 GJ/ha of EY. Grasslands for the accumulation of total EY used 91-96% of energy from renewable, that is, natural factors provide a positive balance of energy in the Earth biosphere processes.

Keywords: grass, legume, fertilizer, yield, energy

INTRODUCTION

It is known that grasslands are the world's largest ecosystem. Their area is estimated at 52.5 million square kilometers, or 40.5 percent of the terrestrial area excluding Greenland and Antarctica (Reynolds, 2005). Modern meadows have a huge impact on economic development, political activity, and technological progress (Strijker D., 2005; Kanianska et al., 2014). They play an important role in the strengthening of the livestock feed base (Hopkins and Wilkins, 2006; Peeters, 2009; Finneran et al., 2012; Huyghe et al., 2014; Oenema et al., 2014).

Traditional grasslands are a major component of landscapes. They are increasingly valued for their important role in ensuring the ecosystem's sustainable development and the overall positive result for society (Heinsoo et al., 2010; Robertson et al., 2011; Isselstein and Kayser, 2014; Huyghe et al., 2014). It has always been considered as a guarantee of environmental sustainability of any agroecosystem (Rosch et al., 2009; Prochnow et al.6 2009).

The conservation of soil fertility is one of the main tasks of modern agricultural science and grassland husbandry side by side with increased grassland productivity. Meadow grasses stop soil erosion effects. Therefore, the degradation of hills is estimated there as minimal (Jarašiūnas, Kinderienė, 2016.).

Phytocenosis with rich species composition and high productivity enrich the soil by the organic mass of dying belowground and aboveground remains each year. It improves the structure and water-physical properties of the soil. The microflora replenishes the roots-containing layer with nitrogen and elements of mineral nutrition due to mineralization. Grass-crop rotation can reduce soil erosion by 89% (Skuodienė et al., 2020).

Grasslands significantly affect the water availability of soils. In this case, the root system of perennials plays a major role (Yu Liu et al., 2020). The roots of perennial grasses have a significant impact on grass productivity and feed quality (Wang P. et al., 2020). Below-ground habitat is of great significance to land ecological restoration (Feng et al., 2021).

According to many scientists (Pankievicz et al., 2015; Herben et al., 2017), the perennial legume-grasses involve from 45 to 340 kg/ha of symbiotic nitrogen in the cycle of meadow ecosystems depending on the soil-climatic conditions and species composition. It allows to significantly reduce the input of expensive nitrogen fertilizers.

According to researchers (Hofer et al., Nyfeler et al., 2017), the yield of legume-grasses without the introduction of nitrogen fertilizers is equivalent to the yield of grasses that fertilized 112-250 kg/ha of active nitrogen. Other researchers argue that N-fixing legumes exhibit the high activity of root phosphatase, especially with the low availability of phosphorus in soils (Png et al., 2017).

Meadow agroecosystems can accumulate natural factors: self-healing of long phytocenosis, accumulation of symbiotically fixed nitrogen by legume species, and increase soil fertility due to accumulation of organic substances. The root system of meadow grasslands provides the nutrient input from the soil to the overland part of the agrophytocenoses. In addition, it has a significant aftereffect on the change of soil fertility because of its accumulation, partial dying at use, and mineralization. The mineralization of dead roots passes constantly and actively in all meadow soils of normal humidification. It is due to enough oxygen in the soil air and the absence of CO_2. In addition, legume perennial grasses are soil structuring agents. For example, about 60% of its entire meadow clover biomass is the root system. The soil compaction is reduced after the plowing of the field where the clover grew. Its aeration is improved. The soil is enriched with organic matter, humus, and after mineralization, macro-and trace elements of nutrition. The cultivation of legumes provides a reduction of 2.5-3 times the costs of non-renewable energy due to the symbiotic fixation of nitrogen. The content of legumes in herbage within 30-50% promotes not only the increase of the yield of dry matter and feed nutrition but also minimizes nitrogen losses in the environment (Blagoveshchensky, 2013).

Alternative way of the meadow's usage is the bioenergy applications (Florine et al., 2006; Khalsa et al., 2012; Herrmann et al., 2014; Melts et al., 2014; Van Meerbeek et al., 2015; Tilvikiene et al., 2018). This is especially true when the products from grasslands are superfluous for use in cattle breeding (Wachendorf and Soussana, 2012, Scarlat et al., 2018). Perennial grasses can produce 0.076–0.096 L of biogas for 35 days in anaerobic conditions and biogas yield can be from 210.0 to 435.3 NL/kg DM (Amaleviciute-Volunge K et al., 2020).

The aim of the work is to show the role of meadow agroecosystems with different biological features in the general cycle of gross energy. For this purpose, the balance of receipt and expense of gross energy is defined. The working hypothesis of this study is that meadow ecosystems have a high capacity to accumulate natural factors. This is the self-restoration of long-lived grasslands, the supply of symbiotically fixed nitrogen due to legumes, the accumulation of organic matter by root mass, etc. In order to establish the balance of energy flows, the main indicators of the formation of energy productivity by aboveground mass (botanical composition, density and yield of dry matter), energy intake with roots were determined, changes in soil fertility were taken into account. This will show the multifaceted role of meadow agroecosystems not only as a source of exchange energy for farm animals but also will reveal their role in the general cycle of gross energy considering the aftereffects on the change of soil fertility.

MATERIALS AND METHODS

Experimental site and field operations

The study has been carried out during 2011-2015 at the long-term (47 years) grassland (field experiment) of the Institute of Agriculture of the Carpathian region of NAAS. (Stavchany 49°41′ N 23°50′ E, alt. 320 m). The local climate is semi-continental. It has been formed by the Atlantic Ocean (a lot of precipitation and rapid changing of temperature) and by continental atmospheric masses. The climatic regime of the Forest-Steppe is marked by an increase in the continentality of the climate to the east. The average annual temperature is 7–8 °C. The lowest average January temperatures are minus 4-5 °C. The absolute minimum of temperatures is 35 °C. Snow cover occurs on average around November 15-25 and disappears in late March. In winter there are often thaws when the air temperature rises to 10-12 °C. Summer is moderately warm, the average temperature of the warmest month of July plus 18 °C, the growing season lasts 200-212 days. During the years of research, weather conditions were favourable for the growth and development of perennial grasses in terms of temperature and differed in the amount of precipitation. It was 2-20% lower than the long-term average.

The field experiment was created in 1974 on drained pottery drains in low meadows with dark grey podzolized surface gleyed soil (Certificate № 049). During the years of research, the experiment has been reconstructed several times. The perennial (37-41 years old) and temporary (legume-grass) grasslands were used for this research. The temporary grassland was grown by sowing early spring 2011 and composed of meadow clover (*Trifolium pratense* L.) cultivar ‘Precarpathian-6’ at the seed rate of 4 kg/ha + goat's rue (*Galega officinalis* L.) cultivar ‘Caucasian branec’ at the seed rate of 4 kg/ha + meadow fescue (*Festuca pratensis* L.) cultivar ‘Dibrova’ at the seed rate of 8 kg/ha + timothy (*Phleum pratense* L.) cultivar ‘Pidhiryanka’ at the seed rate of 6 kg/ha, awnless bromegrass (*Bromus inermis* Leys.) cultivar ‘Topaz’ at the seed rate of 10 kg/ha.

There were plots without fertilizer and plots with a phosphorus-potassium fertilizer on both researched grasslands. Phosphorus-potassium fertilizer included 60 kg P per ha and 90 kg K per ha. In addition, areas with elements of intensification are used for comparison. NPK variants including 60 kg P per ha, 90 kg K per ha, and 90 kg N per ha were used on the perennial grasslands. The manuring lime and growth enhancer Ecostim (produced by SPPP ‘Rist’, Ukraine) with phosphorus-potassium fertilizer (include 60 kg P per ha, 90 kg K per ha) were used on the temporary grasslands. Pre-sowing seed treatment with growth enhancer Ecostim (water-alcohol solution of metabolites of the strain of the symbiotic fungus of the endophyte Panax Ginseng M. isolated from the root of ginseng) was carried out in a dosage of 2.5 ml per 100 kg of seeds. The size of the experimental plot was 18 m^2. Repetition of all plots is fourfold.

Agrochemical properties

The agrochemical properties of the soil were determined according to the methods: the total humus content according to Tyurin (DSTU 4289: 2004), the pH of the salt extract - potentiometry at the pH meter (DSTU ISO 10390-2001), alkaline hydrolyzed nitrogen according to Cornflind (DSTU 7863: 2015), mobile phosphorus and exchangeable potassium according to Chirikov (DSTU 4115-2002), the amount of absorbed bases is according to Kappen-Gilkovits (GOST 27821-88).

Data analysis

Harvesting was carried out by successive weighing from each plot. The yield was applied in a dry matter. Previously hygroscopic moisture by drying a sample of a sheaf weighing 0.5 kg at a temperature of 105 °C to constant weight was determined (DSTU ISO 6497:2005).

Species, botanical composition, and density of herb were carried out by sampling green mass from an area of 1.25 m^2 from two non-adjoining repeats. They were dismantled for botanical and economic groups as grasses, legumes, and forbs. The density of the grass was determined by counting the number of shoots per 1 m^2 in selected samples of the same groups.

The accumulation of root mass was determined after sampling of soil by cartridge with a size of 516.9 cm^3

from depths of 0-5 and 5-20 cm in a fourfold repeat with subsequent washing on sieves with a diameter of 0.25 mm and weighing. Soil humidity was determined by the thermostat-weighted method (DSTU ISO 11465 2001), density, and total moisture content.

The energy assessment of the studied agroecosystems was carried out based on the balance of income, accumulation, and expenditure of energy (Kutuzova et al., 2015). To compare different grasslands, as well as assessments of anthropogenic factors, the accumulation of energy yield was determined. It included the accumulation of energy by the aboveground and belowground mass of grasslands and the change in the energy capacity of soil fertility. Estimation of the change in energy yield of soil fertility was conducted based on an agro-chemical analysis taking into account the coefficients of fixing mineral fertilizers in soil and energy inputs on fertilizers.

Statistical analysis

The received data was processed by analysis of variance (ANOVA) to determine significance at a 95% probability level (LSD). The correlation between the part of grasses in the long-term grass stand and the amount of nitrogen fertilizer was estimated.

RESULTS AND DISCUSSION

Formation of aboveground mass of grasslands

The main indicators that have an impact on the formation of energy productivity of grasslands are botanical composition, the density of shoots in grasslands and dry matter yield. The botanical composition of the permanent grasslands has been subjected to significant changes under the influence of anthropogenic loads (Table 1.).

All types of botanical groups of plants were noted in the grasslands without fertilizers. The highest percentage is occupied by cereal species (61-66%). LSD was significant at $P \leq 0.05$ level (in particular, in the first slope LSD was 4.2%, which is a very significant difference). A significant proportion was the legumes (12-19%) and forbs (15-27%). This herbage was characterized by rich species composition. The 43 species of herbs were mentioned. The meadow grass (*Poa pratensis* L.), the red fescue grass (*Festuca rubra* L.), and the cocksfoot (*Dactylis glomerata* L.) were dominant species of the herb. However, the absence of mineral fertilizers contributed to the development of certain degradation processes in the grassland, namely the appearance of lime grass (*Deschampsia caespitosa* L.) and the velvet grass (*Holcus lanatus* L).

Table 1. Formation of aboveground mass of permanent sowing grasslands

	NF		PK		NPK		LSD_{05} acc. Fisher	
	1stcut	2ndcut	1stcut	2ndcut	1stcut	2ndcut	1stcut	2ndcut
Botanical composition, %								
Grass	66^{b}	61^{b}	54^{b}	63^{b}	91^{b}	77^{b}	4.2	3.7
Legume	19^{b}	12^{b}	18^{b}	19^{b}	1^{b}	3^{b}	0.49	0.51
Forbs	15^{b}	27^{b}	28^{b}	18^{b}	8^{b}	20^{b}	3.3	3.5
Density of herbs shoots per 1 m^2								
Grass	1064^{a}	2166^{a}	1287^{a}	1897^{a}	1394^{a}	1212^{a}	43.2	36.8
Legume	58^{b}	82^{b}	425^{b}	238^{b}	6^{b}	10^{b}	0.37	0.18
Forbs	222^{b}	154^{b}	96^{b}	144^{b}	148^{b}	227^{b}	11.5	9.4
Total	1344^{b}	2402^{b}	1808^{b}	2279^{b}	1548^{b}	1449^{b}		
Average height of plants, cm	36^{a}		37^{a}		52^{a}			

Note. NF: non-fertilized; PK includes 60 kg P per ha and 90 kg K per ha; NPK includes 60 kg P per ha, 90 kg K per ha, and 90 kg N per ha; LSD: ^{a} significant at $P \leq 0.01$, ^{b} significant at $P \leq 0.05$ level

The presence of these species in the herb more than 15% leads to a significant decrease in the productivity of meadow phytocoenosis and deterioration of the feed quality.

The use of phosphorus and potassium fertilizers decreased the proportion of grasses to 54% and extended the percentage of forbs to 28% in the first cut. Long-term exposure to nitrogen fertilizers contributed to the transformation of sown forbs-grasses into grass stands.

The temporary grassland was shared by legumes and grasses on average for five years' usage. (Table 2).

The highest percentage of legumes was recorded in untreated grass and underuse of phosphorus and potassium fertilizers. The fraction of legumes was 46-49% for the first cut. There were legumes of 54-58% in the second cut. The growing share of legumes has a positive effect on the productivity of grasslands, their energy value and soil fertility. The number of herbs shoots per 1 m^2 fluctuates from 1249 to 2402 in permanent grassland and from 782 to 2277 in temporary grass stand. The highest number of shoots was observed in the non-fertilized perennial grassland.

The density of herbs shoots per 1 m^2 was the lowest in the non-fertilized temporary grassland on average for 2011-2015. There were 1157 in the first cut and 782 in the second one. The introduction of phosphorus and potassium fertilizers on this grassland contributed to the increase in the number of perennial herbs shoots to 1504 in the first cut and 938 in the second one.

The use of phosphorus and potassium fertilizers on permanent grasslands provided a significant increase in legumes, especially in the second cut (19%). This is explained by the better competitiveness of the birds-foot in the summer season (Arzani et al., 2006). The part of grasses in the permanent grass stands closely correlated with the amount of nitrogen fertilizer introduced. The correlation coefficient (r) was 0.73.

According to the statistical analysis, the correlation between the proportion of cereal grasses and weather conditions was not detected.

Similar results, where the application of nitrogen fertilizers contributed to the increase in the proportion of grasses due to the reduction in the number of legumes and forbs was noted in studies of many other scientists (Kanianska et al.,2014; Luscher et al., 2014). According to

Table 2. Formation of aboveground mass of temporary grasslands

	NF		PK		PK + lime + GE		LSD_{05} acc. Fisher	
	1stcut	2ndcut	1stcut	2ndcut	1stcut	2ndcut	1stcut	2ndcut
Botanical composition, %								
Grass	45^b	39^b	45^b	37^b	49^b	36^a	5.2	4.4
Legume	46^b	54^b	49^b	58^b	48^b	61^b	3.2	3.1
Forbs	9^b	7^b	6^b	5^b	3^b	3^b	0.3	0.2
Density of herbs shoots per 1 m^2								
Grass	819^a	522^a	1102^a	538^a	1813^a	1253^a	29.0	39.0
Legume	260a	199^a	352^a	584^a	408^a	393^a	6.8	8.7
Forbs	78^b	61^b	50^b	16^b	56^b	16^b	3.4	3.2
Total	1157^b	782^b	1504^b	1138^b	2277^b	1662^b		
Average height of plants, cm	31^a		52^a		63^a		16	

Note. NF: non-fertilized; PK includes 60 kg P per ha and 90 kg K per ha; GE: natural plant growth enhancers; LSD: ^{a} significant at $P \leq 0.01$, ^{b} significant at $P \leq 0.05$ level

Croatian scientists, the use of nitrogen fertilizers per 150 kg ha^{-1} contributed to the reduction in the proportion of legumes in pasture grass to 0.86%, and grasses to 3.88%, while in grassland without fertilizer a percent of legumes was 2.52%, a part of forbs was 9.29% (Leto et al., 2008).

All legume species of grasses are sensitive to the reaction of soil solution, which was confirmed by the results of the research. The application together with the growth enhancer of the lime on temporary grasslands contributed an increase in the percentage of legumes to 61% on average over five years. This has led to improved feed quality. The use of limestone materials in the creation of legume-grasses increases the yield of feed units (Panakhyd et al., 2020).

The usage of legume grass for five years has increased the share of rootstock grasses its percentage has increased almost threefold in non-fertilized grasslands. An increase in the number of rootstock grasses is due to the appearance of red and dry weather conditions in the herbage. The highest percentage of these herbs in the fifth year of life was recorded in grass fields where spray enhancer growth was carried out.

Dry matter yield

The dry matter yield of the permanent grassland depended on the treatments and averaged 3.78 - 8.22 t/ha (Table 3). The highest rates of dry matter are recorded in the first cut. This grassland ensured a dry mass yield of 1.96 t/ha in the first cut and 1.82 t/ha in the second one on average for five years. %). LSD was significant at $P \leq 0.05$ level (in particular, in the first slope LSD was very significant 0.4 - 0.7 t / ha). The treatment of nitrogen fertilizer along with the PK fertilizers contributed to the growth of the dry matter yield by 102-162%.

The highest dry matter yield of permanent grassland has been recorded in the 37^{th} year of use. In this year the yield of untreated meadow phytocenosis was 3.9 t/ha DM. The use of mineral fertilizers (NPK) prolonged the increase of dry matter to 12.4 t/ha. Such high rates were noted only in one year of research, which is explained by favourable weather conditions. Reducing the amount of precipitation and increasing the temperature during the growing seasons of the following years caused a decrease in yield. According to the correlation analysis, the dry matter yield of permanent grassland, on average during the growing season, was in the medium correlation

Table 3. Yield of aboveground and belowground mass of permanent sowing grasslands, yield, t/ha dry matter

		NF		PK		NPK		LSD_{05} acc. Fisher	
		1^{st}cut	2^{nd}cut	1^{st}cut	2^{nd}cut	1^{st}cut	2^{nd}cut	1^{st}cut	2^{nd}cut
Aboveground mass									
Years	2011	2.03^b	1.82^b	3.06^b	2.15^b	5.38^b	4.18^b	0.6	0.1
	2012	1.90^b	1.55^b	2.26^b	2.84^b	4.33^b	3.49^b	0.5	0.2
	2013	1.75^b	1.92^b	2.01^b	2.57^b	3.37^b	2.66^b	0.4	0.1
	2014	2.19^b	2.26^b	3.50^b	1.94^b	6.61^b	3.58^b	0.5	0.1
	2015	1.91^b	1.55^b	2.58^b	2.10^b	4.60^b	2.90^b	0.7	0.2
Average of the sum of two cuts		3.78^a		5.00^a		8.22^a			
Belowground mass									
Average of 2011-2015		18.31^b		18.97^b		11.03^b		6.5	

Note. NF: non-fertilized; PK includes 60 kg P per ha and 90 kg K per ha; NPK includes 60 kg P per ha, 90 kg K per ha, and 90 kg N per ha; LSD: [a] significant at $P \leq 0.01$, [b] significant at $P \leq 0.05$ level dependence on hydrothermal indices. The exception was only grasslands without fertilizers during the 41 years of use.

The increase in the amount of root mass on unhealthy permanent grasslands in the upper layer of soil is due to their biodiversity. Because there were many kinds of grass and legumes in the species composition.

In the first year temporary legume-grass without fertilizers yielded 2.6 t/ha of dry matter. The phosphoric and potassium fertilizer, liming, and growth enhancer increased the output of dry matter to 3.8-5.9 t/ha depending on the type of fertilizer in the first year of use (Table 4).

The highest yield of temporary grassland was recorded in the second and third years. A decrease in dry matter was recorded in the fourth and fifth years. The lowest dry matter yield on average for five years has been noted on this agrophytocenosis without fertilizer of 2.40 t/ha DM in the first cut and 2.13 t/ha in the second one. The use of phosphorus and potassium fertilizers contributed to the 32% increase in yield, and, on average, over five years yielded 6.01 t/ha DM. Like untreated grass, yields on cuts were uneven. A slight advantage was on the first cut (52-53% of DM yield in the first cut and 47-48% in the second one).

Unfavourable weather conditions of the summer months have contributed to the decrease in the dry matter yield of temporary legume-grass, especially in the second cut. But LSD was significant at $P \leq 0.05$ level (0.1-0.2 t/ha).

The lowest yield of roots was recorded on non-fertilized temporary grassland (9.7 t/ha). The increase in root mass on this grassland was mainly due to phosphorus and potassium fertilizers.

The energy potential of grasslands

In conditions of the Western Forest-steppe of Ukraine, under favourable weather conditions permanent grasslands allowed to receive 260.1 GJ/ha of energy yield (Table 5).

Aboveground mass accumulated 71.5-155.5 GJ/ha of energy yield. The primary path of grass energy resaved from NPK fertilization. Fertilized grasslands gave the highest amount of energy yield per hectare ones. Energy yield could also be influenced by the time of sward harvesting (Tonn et al., 2010) and grass

Table 4. Yield of aboveground and belowground mass of temporary grasslands, yield, t/ha dry matter

		NF		PK		PK + lime + GE		LSD_{05} acc. Fisher	
		1stcut	2ndcut	1stcut	2ndcut	1stcut	2ndcut	1stcut	2ndcut
Dry matter yield, t/ha									
Years	2011	1.57^{b}	1.05^{b}	2.48^{b}	2.37^{b}	2.70^{b}	2.77^{b}	0.2	0.1
	2012	3.02^{b}	2.87^{b}	4.06^{b}	3.44^{b}	4.41^{b}	3.58^{b}	0.3	0.1
	2013	2.89^{b}	2.46^{b}	3.87^{b}	3.40^{b}	4.68^{b}	3.79^{b}	0.1	0.1
	2014	2.40^{b}	2.66^{b}	2.57^{b}	3.16^{b}	3.83^{b}	3.39^{b}	0.2	0.2
	2015	2.18^{b}	1.60^{b}	2.80^{b}	1.93^{b}	2.61^{b}	1.47^{b}	0.3	0.2
Average of the sum of two cuts		4.54^{a}		6.01^{a}		6.65^{a}			
Belowground mass									
Average of 2011-2015		9.7^{b}		11.25^{b}		11.58^{b}		1.2^{b}	

Note. NF: non-fertilized; PK includes 60 kg P per ha and 90 kg K per ha; GE: natural plant growth enhancers; LSD: ^{a} significant at $P \leq 0.01$, ^{b} significant at $P \leq 0.05$ level

Table 5. Distribution of energy yield by elements of agroecosystem of different grasslands for 5 years of use

Treatment	Energy yield, GJ/ha				Distribution of energy yield, %			Payback of anthropogenic costs by the accumulation of gross energy, times
	above-ground	below-ground	change of soil fertility	total	above-ground	below-ground	change of soil fertility	
Permanent grassland								
NF	71,5[b]	65.9[b]	112.7[b]	260.1[b]	27[b]	25[b]	43[b]	26.2[a]
PK	94.5[b]	63.4[b]	23.7[b]	193.8[b]	49[b]	33[b]	12[b]	15.9[a]
NPK	155.4[b]	36.4[b]	35.7[b]	241.9[b]	64[b]	15[b]	15[b]	16.7[b]
Temporary grassland								
NF	59.4[b]	34.1[b]	101.25[b]	105.6[b]	56[b]	32[b]	96[b]	10.6[a]
PK	97.8*	39.6[b]	12.78[b]	162.4[b]	60[b]	24[b]	8[b]	13.3[a]
PK + lime + GE	144.1[b]	40.8[b]	57.80[b]	260.3[b]	55[b]	16[b]	22[b]	14.8[a]

Note. NF: non-fertilized; PK included 60 kg P per ha and 90 kg K per ha; NPK includes 60 kg P per ha, 90 kg K per ha, and 90 kg N per ha; GE: natural plant growth enhancers. LSD: [a] significant at $P \leq 0.01$, [b] significant at $P \leq 0.05$ level

species (Pociene et al., 2016). However, the application of mineral fertilizers harms the root energy storage of permanent grassland. The highest accumulation of energy in the roots of permanent grasslands (329.6 GJ/ha) was recorded for its use without fertilizer application. The application of phosphorus and potassium fertilizers resulted in a decrease in the energy yield fixed in the root mass by 12.9 GJ/ha.

And conversely, on the temporary grasslands, the elements of technology promote to increase the grass energy yield as well as the root energy. The liming of the soil during the establishment of legume-grass allowed boosting the aboveground energy potential of the temporary grasslands by 4%. The least energy yield was fixed as 170.7 GJ/ha in the root mass of this agrophytocenosis without using fertilizer. The introduction of phosphorus and potassium fertilizers contributed to the increase in gross energy in the root mass up to 198 GJ/ha. This measure increased to 244.6 GJ/ha for the use of lime with enhancer growth.

The aggregate energy supply in the soil mainly depends on the content of humus and, to a lesser extent, on nitrogen, phosphorus, and potassium (Grman et al., 2013).

The energy capacity of soil fertility of permanent agrophytocenoses over the past 5 years has increased by 1-20%. The average annual growth rate of gross reserves of energy for non-fertilized grassland was 22.5 GJ/ha, for the introduction of phosphorus and potash fertilizers 4.7 GJ/ha, and for the introduction of nitrogen fertilizers - 0.8-7.1 GJ/ha (Table 6).

The energy capacity of soil fertility increased by only 1-7% for fertilizer application. Using NPK fertilization during 41 years on permanent grassland promote the increase of soil energy capacity by 35.65 GJ/ha in the last five years. Relatively low this indicator (23.7 GJ/ha) is also noted for the use of phosphorus-potassium fertilizer. Application of mineral fertilizers contributed to accelerating the process of mineralization of organic matter of turf and re-utilization of nutrients with grass yields. The highest rates of growth of energy indices of soil fertility were noted without fertilizer use, which was due to the high growth rates of humus stocks.

The soil energy capacity of the temporary legume-grass over the five years of research has increased by 12.48-105.55 GJ/ha. The energy intensity of the soil increased by 20% without the fertilizers. The lowest increases in the energy capacity of soil fertility were recorded for the

Table 6. Agro-energy estimation of soil fertility of different grasslands (soil surface at 0-20 cm depth)

Treatment	Year	Energy content, GJ/ha					Change of soil fertility, %
		Humus	Nitrogen alkaline hydrolyzed	P_2O_5, mobile	K_2O, metabolic	Total	
Permanent grassland							
NF	2010	562.63[b]	3.59[a]	0.09[a]	0.53[a]	566.83[b]	20
	2015	674.66[b]	4.29[a]	0.09[a]	0.52[a]	679.56[b]	
PK	2010	582.82[b]	3.54[a]	0.42[a]	0.85[a]	587.64[b]	4
	2015	606.42[b]	3.67[a]	0.42[a]	0.83[a]	611.34[b]	
NPK	2010	480.86[b]	3.88[a]	0.18[b]	0.34[a]	485.26[b]	7
	2015	520.38[b]	4.28[a]	0.18[b]	0.37[a]	520.91[b]	
Temporary grassland							
NF	2010	521.22[b]	3.88[b]	0.08[b]	0.30[b]	525.48[b]	20
	2015	621.71[b]	4.66[b]	0.09[b]	0.27[b]	631.03[b]	
PK	2010	571.55[b]	4.13[b]	0.35[a]	0.64[b]	576.67[b]	2
	2015	593.10[b]	3.85[b]	0.44[b]	0.66[b]	589.45[b]	
PK + lime + GE	2010	567.62[b]	3.75[b]	0.12[b]	0.29[b]	571.77[b]	10
	2015	586.26[b]	4.20[b]	0.13[b]	0.27[a]	629.57[b]	

Note. NF: non-fertilized; PK includes 60 kg P per ha and 90 kg K per ha; NPK includes 60 kg P per ha, 90 kg K per ha, and 90 kg N per ha; GE: natural plant growth enhancers, LSD: [a] significant at $P\leq0.01$, [b] significant at $P\leq0.05$ level

introduction of phosphorus and potassium fertilizers. The average annual increase was 2.6 GJ/ha, which has provided an increase in soil fertility by 2% or five years after the use of legume grass.

The energy intensity of the temporary grassland soil increased by 10% for the application of lime and the growth enhancer. The application of limestone fertilizers contributed to the decrease of the soil level of acidity, which, in its turn, increased its energy content. The energy yield increased by 4.3 GJ/ha at the displacing the active acidity of the soil by 0.1 pH for acidic soils (Pfisterer and Schmid, 2002).

In the soils of temporary legume-grasses, bio preparations are used. The accumulation of energy is much higher than for use of mineral fertilizers on cereals permanent grass stands. It is due to the additional influence of the biological factor. The use of a growth enhancer against the background of phosphoric and potassium fertilizer and liming helped increase the proportion of legumes in the grass, which in turn accelerated the processes of mineralization of dead roots.

Permanent grasslands accumulated 260.1 GJ/ha of gross energy. The fertility of the soil replaced 43% (112.7 GJ/ha) of them. Anthropogenic costs on this grassland paid off 26.2 times by the accumulation of energy yield.

The bulk of energy yield was distributed over the aboveground (49-75%) and belowground (15-33%) mass for the use of fertilizer on the long-term meadow. Payback of anthropogenic costs by the accumulation of energy was 13.3-16.7 times. The highest payback ratio was fixed for the use of NPK fertilizers. The highest percentage of energy accumulated by the root mass (33%) was noted for phosphorus and potassium fertilizers.

The accumulation of gross energy was 105.6-260.3 GJ/ha on the temporary grassland. Unlike permanent grassland, the accumulation of energy yield was the lowest (105.6 GJ/ha) on legume-grass without the use of fertilizer. The invoice cost of man-made expenditures by gross energy was 10.6 times. The use of phosphorus and potassium fertilizers on this grass stand contributed to the increase in total energy by 56.8 GJ/ha. However, 96% of gross energy had a change in soil fertility without fertilizers. The change of soil fertility accounted for only 8% of the total energy at the use of phosphorus and potassium fertilizers, whereas 60% of energy yield was accumulated by an aboveground mass. Anthropogenic inputs cost 13.3 times their energy for phosphoric and potassium fertilizers.

The use of liming and growth enhancers contributed to the increase of energy yield accumulated by the aboveground and underground mass and as a result the soil fertility changes to 260.3 GJ/ha. It should be noted that due to the large man-made costs caused by using limestone fertilizers, their payback was 2.9 times lower than without the use of lime.

Accumulation of energy in grasslands reveals their role in modern biosphere processes. The accumulation of energy yield by perennial agroecosystems in general, due to the aboveground and belowground mass, together with the change in soil fertility, reached 260.1 GJ/ha (Table 7).

It is due not only to anthropogenic costs but also to the mobilization of natural factors into production processes. The inflow of energy from natural factors was the highest in a permanent grasslands agroecosystem without the use of fertilizers - 250.1 GJ/ha or 96% of all energy inputs. The coefficient of the useful effect of photosynthetically active radiation (PAR) in this agroecosystem was 1.53 and was the highest among all studied permanent grasslands.

The part of natural factors in the production of gross energy of meadow agroecosystems, which used mineral fertilizers, declined to 92-94%. The coefficient of the useful effect of photosynthetically active radiation of this ecosystem was also lowered to 1.13. The high efficiency of the PhAR was marked by permanent using NPK fertilizers.

The temporary grassland part of natural factors in the formation of energy yield was 91-94%, which is 9 times higher than anthropogenic costs.

The highest coefficient of the beneficial effect of photosynthetically active radiation (1.53) was characterized by a laced agroecosystem with legume-

Table 7. Acquisition of energy into meadow agroecosystems, the average for 2011-2015

Treatment	Production of gross energy y, GJ/ha	Total anthropogenic costs, GJ/ha	Receipt of energy due to natural factors		CE PAR
			GJ/ha	% of production	
		Permanent grassland			
WF	260.1^{b}	9.9^{b}	250.1^{b}	96	1.53^{a}
PK	193.8^{b}	12.2^{b}	181.6^{b}	94	1.14^{b}
NPK	241.9^{b}	14.5^{b}	227.5^{b}	94	1.42^{a}
		New-established grassland			
WF	105.6^{b}	9.9^{b}	95.6^{b}	91	0.62^{b}
PK	162.4^{b}	12.2^{b}	150.2^{b}	92	0.96^{b}
PK + lime + GE	260.3^{b}	17.6^{b}	242.7^{a}	93	1.53^{a}

Note. WF: without fertilizer; PK includes 60 kg P per ha^{-1} and 90 kg K per ha; NPK include 60 kg P per ha, 90 kg K per ha, and 90 kg N per ha; GE: natural plant growth enhancers; CE PAR: coefficient of efficiency of photosynthetically active radiation, LSD: ** significant at $P \leq 0.01$, * significant at $P \leq 0.05$ level grass, where phosphorus and potassium fertilizers, liming, and growth enhancers were used.

CONCLUSIONS

The dry matter yield of permanent grassland depends on mineral fertilization. Application of NPK which includes 60 kg P ha^{-1}, 90 kg K ha^{-1} and 90 kg N ha^{-1} promotes the acquisition of 8.22 t ha^{-1} of dry matter yield and 155.4 GJ/ha energy yield. The root of permanent grassland without fertilization accumulates 65.9 GJ/ha of energy. The sum of energy from the aboveground mass (71.5 GJ/ha) and the soil energy (112.7 GJ/ha) is 260.1 GJ/ha.

The use of phosphorus and potassium fertilizers, lime and growth enhancer has a positive impact on the dry matter yield, soil fertility, and gross energy of temporary legume-grass grasslands. This combined fertilizer yields 6.65 t/ha of dry matter, 11.58 t/ha of roots, and saves 260.3 GJ/ha of energy.

The increase in the root mass on the permanent grassland leads to an increase in the density of the soil but decreases the porosity. The soil density decreases and the porosity increases, which positively affects the fertility on the temporary legume-grass when the accumulated root mass increases.

Permanent and temporary grasslands agroecosystems for the accumulation of total energy yield used 91-96% of energy from renewable, that is, natural factors provide a positive balance of energy in the Earth biosphere processes.

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