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## **EMPIRICAL DETERMINATION OF BIOGAS EMISSION FROM PERMANENT GRASSES VEGETATIVE MASS**

*The article deals with theoretical calculation of biogas emission, obtained in the course of anaerobic digestion of permanent grass plant mass in Polissya region. It was proved that total annual actual biogas emission of permanent grasses totals 14399 - 3608 m<sup>3</sup>/ha (methane 727 - 1822 m<sup>3</sup>/ha).*

**Keywords:** *Biogas, methane, vegetative sources, renewable energy, productiveness*

**Introduction.** Due to urgent needs of mankind in various forms of energy, in fossil resources specifically, scientists constantly study non-traditional energy sources as the greatest assistance. They believe that the third place in their order of preferences among biofuel products (along with ethanol and biodiesel), should be granted to biogas production and usage [1-5]. Biogas production allows to prevent methane emission into atmosphere, which causes 21 times greater increase of greenhouse effect than CO<sub>2</sub>; despite this fact methane remains in the atmosphere for 12 years. Methane capture is the best short-term way to prevent global warming. Therefore biogas production is a real example of industrial ecology. Thus, one can obtain energy out of its waste, as well as valuable fertilizers, which are byproducts obtained out of its organic matter remains [6-9]. Energy production from biomass has become an economic sector, which is developing most dynamically in many countries. This is furthered by significant energy potential, renewable production and non-waste properties, which are based on vegetative mass crops.

By-product bioenergy processing of vegetative material results in obtaining robust and balanced organic fertilizer, which can increase crop yield by 10-20%.

*Problem setting and ways solve it.* The development of present-day agricultural sector is impossible without biofuel. For Polissya region we propose innovations into the existing crop rotation and sowing of those Polissya lands that have not been farmed by tall-stalked plants intended for complex usage, in order to gain renewable energy sources, fodder and also for other purposes. It should be also noted that meadows and fallow lands function as reliable, annually renewable biomass sources of the grasses, even without our fertilizing the soil, hence around 20 million GJ gross energy, 50 % of which, due to decreasing number of livestock in Ukraine, can be used for biofuel production [10]. Consequently, the expansion of areas under permanent grasses will help restore livestock in the area, and the use of biofuel as an alternative energy source will reduce the cost of livestock production.

Therefore, this issue has become rather topical. Particularly interesting in this respect is the fact that we propose processing of raw materials for biofuels in the form of solid-phase supply, which is now less common and has been not technologically investigated by scientists.

**Research methodology.** The study was conducted in the course of 2011-2012 at the experimental field of the Institute of Polissya Farm attached to NAAS using turf-mesopodzol sandy soil.

The object of the research was the vegetative mass of permanent grasses after threshing the seeds. Biogas emission empirical determination was calculated on the basis of computations proposed by V.M. Pavlisky and Yu.P. Nagirnyy [11].

Fermentation method of organic vegetative matter sources was based on the standard of GOST 10.09-014:2010 "Waste. Recycling technology of organic matter within waste". Content analyses of organic fertilizer nutrients was based on the following RD: determination of moisture and dry residue in accordance with GOST 26713-85, determination of total nitrogen was calculated according to GOST 26715-

85, total phosphorus was calculated in keeping with GOST 26717-85, determination of total potassium was based on GOST 26718-85, pH was calculated according to GOST 27979-88, organic matter was determined in accordance with GOST 27980-88.

These research methods as well as agricultural technology of growing crops are generally accepted in terms of Polissya.

**Research findings.** Permanent grasses after threshing the seeds enabled the collection of vegetative mass at 8-21 t / ha or in terms of dry matter 2,5-5,7 t / ha. The largest mass was formed by bluegrass gray 13-20 t / ha of green and 5,8-8,7 t / ha of dry matter and awnless brome grass 14-21 and 4,6-6,5 t / ha, depending on the fertilizer. The highest yield of after-grass was gathered in autumn from acrocephalus usual 5,0-12,5 t / ha of green 1,4-3,3 t / ha of dry matter, awnless brome grass 1,2-3,0 and 5-13 respectively. The most productive total per annum turned to be bluegrass grey – ( 16-29 t / ha of green and 6,9-10,3 t / ha of dry matter) , awnless brome (19-34 t / ha, 5,9-9,5 t / ha) and acrocephalus usual (13-28 t /ha, 4,5-9,2 t / ha).

According to our data biogas theoretical emission out of 1 kg has correlation dependence of  $r=1,0$  with dry substance content in 1 kilo of dry matter. So the best crop for energy purposes may be the culture, which contains the greatest amount of dry matter. Gathering of the first mowing was conducted in the phase of ripe grasses for seed with maximum dry matter content, which made 31-45 % in the vegetative mass after harvest seeds and in after-grass period from 19 to 43%.

Chemical analysis resulted in calculating theoretical plant thermal energy for wet mass (WM), dry matter (DM) and through heating organic dry matter (ODM), which after thrashing grasses remained in a vegetative mass in the amount of 17,29-18,76 MJ / kg and somewhat lower rates 7,75-10,3 MJ / kg in after-grass herbs. Corresponding coefficients of content in biomass crops are represented in Table 1. The lowest heating energy content of organic dry matter of 17.5 MJ / kg was found in

fescue reed with fertilizer at a rate of  $N_{90+30}P_{60}K_{90}$ , the reed usual had the highest content of controlled 18.47 MJ / kg.

Through heating energy of organic matter, we calculated that theoretical biogas emission out of cultures that ranged from 0.856 to 0.903  $m^3/kg$ , methane content (50%) was 0,432-0,456  $m^3/kg$ , which is also confirmed by other research data [9].

Taking into account coefficients  $K_6$  (decrease in biogas emission associated with microorganism activity) and  $K_r$  (lignification coefficient) theoretical methanogenic energy of 1 kg dry matter of these crops ranges from 13.08 to 13.72 MJ / kg, which is 72.3 - 75.3 % of theoretical heating energy.

Therefore, feasible biogas output amounts to 0,623-0,660  $m^3/kg$ , and methane (50%) – 0,315-0,333  $m^3/kg$ . Splitting ratio of biomass crops makes 0,72-0,75 %.

The actual biogas emission out of 1 kg of dry mass cultures is significantly lower than the one attainable through lignin access blocking of microorganisms and enzymes penetration into culture medium. Thus we determined actual biogas emission out of 1 kg of vegetative mass cultures through their digestible energy, which equals to actual energy of these crops converted into biogas energy.

In our studies, actual energy content was 9,27-11,39 MJ / kg, which was 36-47 % less than the thermal energy content of organic dry matter. Accordingly, actual biogas emission out of 1 kg of dry organic matter makes 0,441-0,542  $m^3/kg$  (0,223-0,274  $m^3/kg$  methane), which is 39-48 % less than theoretical biogas emission. The highest actual energy content of 11.39 MJ / kg and biogas emission of 0.542  $m^3/kg$  (0.274  $m^3/kg$  methane) was observed in cockfoot applying  $N_{90+30}P_{60}K_{90}$ , the lowest indexes of 9.27 MJ / kg and 0.441  $m^3/kg$  ( 0.223  $m^3/ kg$ ) were observed with brome reed.

The results of calculations of actual energy show that the share of which is converted into biogas energy is 53 – 66 % of theoretical thermal energy and 53–68 % of the theoretical methanogenic energy.

Table 1.

### Calculation of heating and methanogenic energy of permanent grasses

Biorawmaterials and computational constants	Theoretical values				Available values			Factual values					KI
	Culture heating energy $E_T$ , MJ/kg	Biogas emission $V_t$ , m <sup>3</sup>	Methane emission $V_{mt}$ , m <sup>3</sup>	Methanogenic energy 1 kg dry matter $E_M$ , MJ/kg	biogas $V_{MD}$ , m <sup>3</sup> /kg	methane $V_{mf}$ , m <sup>3</sup> /kg	Index $K_{rd}$	Heating energy converted to biogas	biogas $V_f$ , m <sup>3</sup>	Methane $V_{mf}$ , m <sup>3</sup>	$K_{rft}$	$K_{rfm}$	
1	2	3	4	5	6	7	8	9	10	11	12	13	14
<b>Brome-grass reed without fertilizers (control)</b>													
WM = 1 kg	9,88	0,484	0,244	7,33	0,349	0,176	0,742	5,30	0,252	0,127	0,536	0,542	
DM = 1 kg (0,656 kg/kg WM)	16,33	0,799	0,404	12,12	0,577	0,291	0,742	8,75	0,417	0,211	0,536	0,542	0,798
ODM = 1 kg (0,709 kg/kgWM)	17,65	0,864	0,436	13,10	0,624	0,315	0,742	9,46	0,451	0,228	0,536	0,542	
<b>Brome-grass reed N<sub>30</sub>P<sub>60</sub>K<sub>90</sub></b>													
WM = 1 kg	8,70	0,498	0,252	7,64	0,297	0,150	0,878	4,62	0,220	0,111	0,531	0,454	
DM = 1 kg (0,734 kg/kg WM)	16,86	0,966	0,488	14,81	0,577	0,291	0,878	8,96	0,427	0,215	0,531	0,454	0,805
ODM = 1 kg (0,679 kg/kgWM)	18,23	0,890	0,450	13,64	0,624	0,315	0,748	9,68	0,461	0,233	0,531	0,532	
<b>Brome-grass reed N<sub>90+30</sub>P<sub>60</sub>K<sub>90</sub></b>													
WM = 1 kg	10,92	0,534	0,270	8,17	0,405	0,205	0,748	5,78	0,275	0,139	0,530	0,531	0,698
DM = 1 kg (0,744kg/kg WM)	16,19	0,792	0,400	12,11	0,601	0,303	0,748	8,57	0,408	0,206	0,530	0,531	
ODM = 1 kg (0,688 kg/kgWM)	17,50	0,856	0,432	13,09	0,650	0,328	0,748	9,27	0,441	0,223	0,530	0,531	
<b>Cocksfoot grass without fertilizers (control)</b>													
WM = 1 kg	9,85	0,484	0,244	7,33	0,349	0,176	0,744	6,23	0,296	0,150	0,633	0,637	
DM = 1 kg (0,676kg/kg WM)	16,51	0,811	0,410	12,29	0,585	0,296	0,744	10,45	0,496	0,251	0,633	0,637	0,800
ODM = 1 kg (0,625 kg/kgWM)	17,85	0,877	0,443	13,29	0,633	0,320	0,744	11,29	0,537	0,271	0,633	0,637	
<b>Cocksfoot grass N<sub>30</sub>P<sub>60</sub>K<sub>90</sub></b>													
WM = 1 kg	10,28	0,520	0,262	7,63	0,363	0,174	0,742	6,58	0,313	0,158	0,641	0,647	
DM = 1 kg (0,610kg/kg WM)	16,31	0,825	0,416	12,10	0,576	0,303	0,742	10,45	0,497	0,251	0,641	0,647	0,798
ODM = 1 kg (0,565 kg/kgDM)	17,63	0,891	0,450	13,08	0,623	0,327	0,742	11,29	0,538	0,272	0,641	0,647	
<b>Cocksfoot grass N<sub>90+30</sub>P<sub>60</sub>K<sub>90</sub></b>													
WM = 1 kg	10,94	0,536	0,271	8,18	0,390	0,197	0,748	6,85	0,326	0,165	0,626	0,628	
DM = 1 kg (0,739kg/kg WM)	16,83	0,825	0,416	12,58	0,599	0,303	0,748	10,54	0,502	0,253	0,626	0,628	0,804
ODM = 1 kg (0,684 kg/kgEM)	18,19	0,891	0,450	13,60	0,648	0,327	0,748	11,39	0,542	0,274	0,626	0,628	

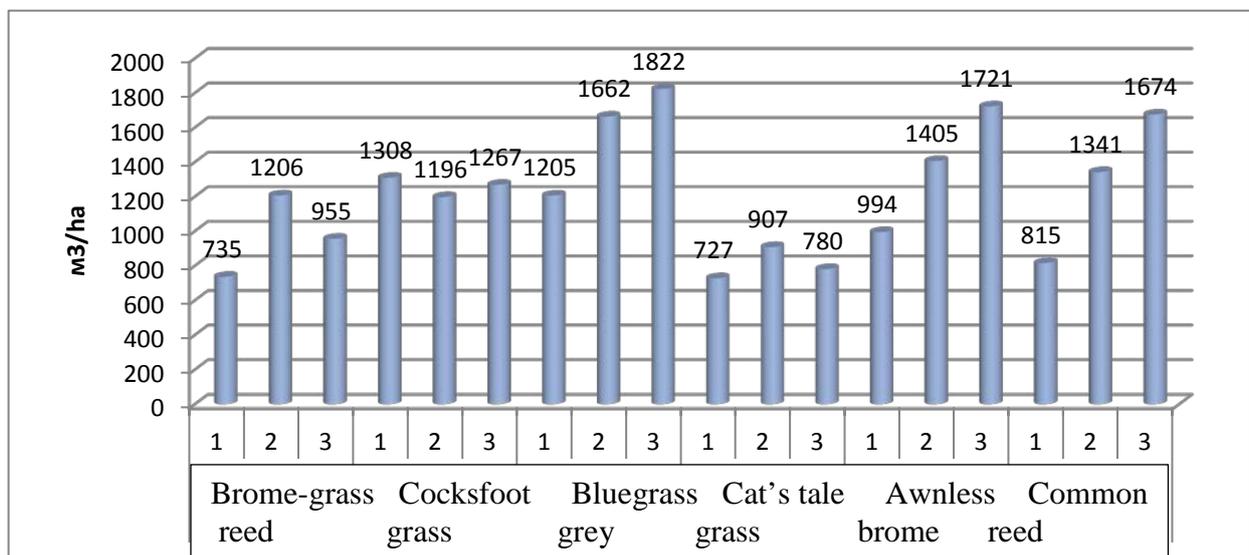
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Bluegrass grey (control)													
WM = 1 kg	9,17	0,448	0,226	6,83	0,325	0,164	0,745	5,33	0,254	0,128	0,581	0,585	
DM = 1 kg (0,584kg/kg WM)	16,59	0,811	0,410	12,36	0,589	0,297	0,745	9,63	0,459	0,232	0,581	0,585	0,801
ODM = 1 kg (0,631 kg/kgWM)	17,93	0,877	0,443	13,36	0,636	0,321	0,745	10,41	0,496	0,250	0,581	0,585	
Bluegrass grey N <sub>30</sub> P <sub>60</sub> K <sub>90</sub>													
WM = 1 kg	9,51	0,466	0,235	7,07	0,336	0,170	0,743	5,48	0,261	0,132	0,576	0,581	
DM = 1 kg (0,642kg/kg WM)	16,39	0,802	0,405	12,18	0,580	0,293	0,743	9,44	0,450	0,227	0,576	0,581	0,799
ODM = 1 kg (0,594 kg/kgWM)	17,72	0,867	0,438	13,17	0,627	0,317	0,743	10,21	0,486	0,245	0,576	0,581	
Bluegrass grey N <sub>90+30</sub> P <sub>60</sub> K <sub>90</sub>													
WM = 1 kg	9,67	0,473	0,239	7,23	0,344	0,174	0,748	5,64	0,268	0,136	0,583	0,585	
DM = 1 kg (0,572kg/kg WM)	16,84	0,823	0,416	12,59	0,600	0,303	0,748	9,81	0,467	0,236	0,583	0,585	0,804
ODM = 1 kg (0,619 kg/kgWM)	18,20	0,889	0,449	13,61	0,648	0,327	0,748	10,61	0,505	0,255	0,583	0,585	
Cat's tale grass without fertilizers (control)													
BM = 1 kg	9,43	0,461	0,233	7,061	0,336	0,170	0,748	5,33	0,254	0,128	0,565	0,566	
DM = 1 kg (0,645 kg/kg WM)	16,88	0,825	0,417	12,634	0,602	0,304	0,748	9,53	0,454	0,229	0,565	0,566	0,805
ODM = 1 kg (0,597 kg/kgWM)	18,25	0,892	0,450	13,66	0,650	0,328	0,748	10,30	0,491	0,248	0,565	0,566	
Cat's tale grass N <sub>30</sub> P <sub>60</sub> K <sub>90</sub>													
WM = 1 kg	9,53	0,465	0,235	7,16	0,339	0,171	0,751	5,37	0,256	0,129	0,563	0,562	
DM = 1 kg (0,642 kg/kg WM)	16,83	0,887	0,414	12,63	0,599	0,303	0,751	9,48	0,451	0,228	0,563	0,562	0,804
ODM = 1 kg (0,594 kg/kgWM)	18,19	0,887	0,448	13,66	0,648	0,327	0,751	10,24	0,488	0,246	0,563	0,562	
Cat's tale grass N <sub>90+30</sub> P <sub>60</sub> K <sub>90</sub>													
WM = 1 kg	9,97	0,488	0,247	7,46	0,355	0,179	0,748	5,49	0,261	0,132	0,551	0,552	
DM = 1 kg (0,678 kg/kg WM)	16,88	0,827	0,418	12,63	0,602	0,304	0,748	9,30	0,443	0,224	0,551	0,552	0,805
ODM = 1 kg (0,627 kg/kgWM)	18,25	0,894	0,451	13,66	0,650	0,328	0,748	10,05	0,479	0,242	0,551	0,552	
Awnless brome without fertilizers (control)													
WM = 1 kg	10,06	0,334	0,169	5,13	0,244	0,123	0,509	3,93	0,187	0,095	0,391	0,575	
DM = 1 kg (0,689 kg/kg WM)	24,17	0,803	0,406	12,31	0,586	0,296	0,509	9,44	0,450	0,227	0,391	0,575	0,805
ODM = 1 kg (0,638 kg/kgWM)	17,78	0,869	0,439	13,31	0,634	0,320	0,749	10,21	0,486	0,245	0,574	0,575	
Awnless brome N <sub>30</sub> P <sub>60</sub> K <sub>90</sub>													
WM = 1 kg	8,88	0,434	0,219	6,63	0,316	0,159	0,746	5,10	0,243	0,123	0,574	0,577	
DM = 1 kg (0,673 kg/kg WM)	16,69	0,816	0,412	12,45	0,593	0,299	0,746	9,58	0,456	0,230	0,574	0,577	0,802
ODM = 1 kg (0,623 kg/kgWM)	18,04	0,883	0,446	13,46	0,641	0,324	0,746	10,35	0,493	0,249	0,574	0,577	

1	2	3	4	5	6	7	8	9	10	11	12	13	14
Awnless brome N <sub>90+30</sub> P <sub>60</sub> K <sub>90</sub>													
WM = 1 kg	10,34	0,505	0,255	7,74	0,369	0,186	0,749	5,84	0,278	0,140	0,565	0,566	
DM = 1 kg (0,689 kg/kg WM)	16,90	0,826	0,417	12,65	0,602	0,304	0,749	9,54	0,454	0,229	0,565	0,566	0,805
ODM = 1 kg (0,638 kg/kgWM)	18,27	0,893	0,451	13,68	0,651	0,329	0,749	10,32	0,491	0,248	0,565	0,566	
Common reed without fertilizers (control)													
WM = 1 kg	10,39	0,508	0,256	7,80	0,371	0,187	0,751	5,74	0,273	0,138	0,553	0,552	
DM = 1 kg (0,626 kg/kg WM)	17,08	0,835	0,422	12,82	0,611	0,308	0,751	9,44	0,450	0,227	0,553	0,552	0,807
ODM = 1 kg (0,579 kg/kgWM)	18,47	0,903	0,456	13,86	0,660	0,333	0,751	10,21	0,486	0,245	0,553	0,552	
Common reed N <sub>30</sub> P <sub>60</sub> K <sub>90</sub>													
WM = 1 kg	10,00	0,489	0,247	7,46	0,355	0,179	0,745	5,61	0,267	0,135	0,561	0,564	
DM = 1 kg (0,673 kg/kg WM)	16,60	0,812	0,410	12,38	0,589	0,298	0,745	9,31	0,443	0,224	0,561	0,564	0,801
ODM = 1 kg (0,623 kg/kgWM)	17,95	0,878	0,444	13,38	0,637	0,322	0,745	10,06	0,479	0,242	0,561	0,564	
Common reed N <sub>90+30</sub> P <sub>60</sub> K <sub>90</sub>													
WM = 1 kg	10,50	0,514	0,259	7,86	0,374	0,189	0,749	5,83	0,278	0,140	0,556	0,556	
DM = 1 kg (0,627 kg/kg WM)	16,95	0,829	0,419	12,69	0,605	0,305	0,749	9,42	0,449	0,227	0,556	0,556	0,805
ODM = 1 kg (0,580 kg/kgWM)	18,32	0,896	0,453	13,72	0,654	0,330	0,749	10,18	0,485	0,245	0,556	0,556	

*Notes: Krd – splitting index in the course of fermentation; Krft –energy splitting index, actual from theoretical; Krfm – energy splitting index, actual from methanogenic; Kl – lignification index.*

For a complete description of the crops under analysis we determined their potential energy per unit area (1 ha). Evaluation of cultures was performed according to the efficiency criteria and productivity per hectare.

The analysis showed that the use of permanent grasses for seed makes 75 % of total biomass crop that can be used as a vegetative power source. Under these conditions, permanent grasses can provide output out of one hectare of theoretical energy, which is converted into biogas at 20488.64 - 58393.45 MJ / kg of dry matter after threshing, and after-grass it made 6863.05 - 30706.62 MJ / kg, which will totally amount to 30216.48 - 75764.27 MJ / kg annually.



**Fig. 1 Methane output per unit area based on culture type**

Note: 1 - control (without fertilizers); 2 -  $N_{30}P_{60}K_{90}$ ; 3 -  $N_{90+30}P_{60}K_{90}$

The actual biogas emission during the first grass mowing was 976 - 2781 m<sup>3</sup>/ha (methane - 493 - 1404 m<sup>3</sup>/ha), after-grass period it made 326 - 1462 ( 165 - 738 ), and total annual amount was 14,399 - 3608 m<sup>3</sup>/ha (727 - 1822 m<sup>3</sup>/ha ).

The greatest energy output of 5839 MJ / kg and 2781 m<sup>3</sup>/ha biogas (methane 1404 m<sup>3</sup>/ha ) during the first mowing (seed threshing) was provided by bluegrass grey on the ground of fertilizer  $N_{90+30}P_{60}K_{90}$ , during the second mowing it made respectively 28153 , 1341 , 677 (aftergrass) of awless brome on the same ground. Total maximum annual of theoretical energy output made 71575 and 75764 MJ/kg

and biogas was 3847 and 3608 m<sup>3</sup>/ha (methane 1721 and 1822 m<sup>3</sup>/ha) were we received awless brome and bluegrass grey after applying N<sub>90+30</sub>P<sub>60</sub>K<sub>90</sub>.

The analysis of the current state of land use showed that only approximately 40% of agricultural lands are used in the Zhytomyr region today. Among them 60.2 hectares are occupied by fallow and 197 by grasslands that due to lack of livestock are not used to the fullest extent. In addition, under the program of livestock development in the area, one should assure growing permanent grasses in the area of 21 hectares for seed. This suggests of potential for bioenergy field development without great energy consumption on growing raw biomaterials both in Zhytomyr oblast and entire Polissya region.

Taking into account the present-day situation concerning the amount of organic fertilizers (in terms of manure) per hectare of arable land (in early 90s it used to make 8-10 t/ha per hectare of arable land or crop rotation area, compared to current number of 0.5-3 0 t/ha, and in some cases only by-products or sow green manure are left in the field). To address the problem of organic fertilizers shortage and to reduce the energy load of growing crops technology in Polissya, we studied agrochemical composition of processed substrate. It was observed that raw materials resulting from anaerobic digestion, had the following content: N - 0,49-1,17%, P 0,18 - 0,27%, K - 0,60 - 0,99%; and with cattle manure – 0,49-1,76 , 0,27-0,38 , 0,60-1,64 % respectively. That is, when they are deposited along with one ton of recycled substrate, the soil gets from 4,9 to 17,6 kg nitrogen , 1,8-3,8 kg phosphorus and 6,0 - 16,4 kg potassium.

**Conclusions.** Polissya area has a considerable potential for phytoenergy development. There is every possibility for alternative energy productions, viz. biogas from vegetative mass anaerobic processing out of permanent grasses grown in rotation or developed on the lands withdrawn from agriculture. Permanent grass crops can annually provide theoretical energy converted into biogas at 30216-75764

MJ /kg and actual biogas emission will range from 1439 to 3608 m<sup>3</sup>/ha (methane 493 - 1404 m<sup>3</sup>/ha).

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### *Анотація*

***Вишневіська О.В., Дмитренко Т.Ф., Тугуєва І.В., Дідківський С.Ю.***

***Емпіричне визначення виходу біогазу з вегетативної маси багаторічних злакових трав***

*Визначено теоретичний вихід біогазу, який отримують шляхом анаеробного зброджування з рослинної маси багаторічних злакових трав в зоні Полісся. Встановлено, що в сумі за рік фактичний вихід біогазу з багаторічних трав становить – 14399 - 3608 м<sup>3</sup>/га (метану 727 - 1822 м<sup>3</sup>/га).*

**Ключові слова:** біогаз, метан, вегетативні джерела, відновлювальна енергія, продуктивність

### **Аннотація**

**Вишневская О.В., Дмитренко Т.Ф., Тугуева И.В., Дидковский С.Ю.**

**Эмпирическое определение выхода биогаза из вегетативной массы многолетних злаковых трав**

Определено теоретический выход биогаза, который получают путем анаэробного сбраживания растительной массы многолетних злаковых трав в зоне Полесья. Установлено, что в сумме за год фактический выход биогаза с многолетних трав составляет – 14399 - 3608 м<sup>3</sup>/га (метану 727 - 1822 м<sup>3</sup>/га).

**Ключевые слова:** биогаз, метан, вегетативные источники, возобновляемая энергия, продуктивность