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BIOENERGY POTENTIAL OF PERENNIAL GRASSES' PHYTOCENOSIS

The purpose. To determine bioenergy potential of perennial grasses' phytocenosis of Ukraine and to make suggestions on its implementation. **Methods.** System analysis, field, laboratory, economic-mathematical. **Results.** Bioenergy potential is shown of perennial grasses' phytocenosis of Ukraine and power productivity of rare perennial crops and varied meadow grass stands depending on technological receptions of growing. **Conclusions.** Perennial agrophitocenosises (natural forage lands, vegetation of overflow lands, marshes, and power crops) are the important reserve for production of biological fuel from biomass. The most efficient perennial power crops (Miscanthus× giganteus J.M. Greef, Deuter ex Hodk., Silphium perfoliatum, Polygonum weyrichii and Polygonum sachalinensis, Sida hermaphrodita Rusby, Heliánthus tuberósus) ensure deriving of 14 – 18 tons of dry solid matter from 1 hectare and 250 – 300 gigajoules of heat energy, improved natural forage lands — 4 – 6 tons and 75 – 110 gigajoules accordingly.

Key words: perennial grasses' phytocenosis, bioenergetics, biomass, energy potential, natural forage lands, productivity.

To reduce Ukraine's energy dependence great value has the development and use of biofuel renewable energy, in particular biomass. Due to the cost rising of energy resources, huge amounts of renewable energy, including biomass, successfully used worldwide. In current situation, approximately 80% of world energy supplies rely on nonrenewable fossil fuels. At the current rate of consumption, all types of traditional fuel expected to last for around 60 years [11]. Today the volume of biomass production as fuel is the fourth largest in the world. Its share in total primary energy production is 10%. In the European Union the share of biomass in total energy consumption is 7% [9]. In leaders among EU countries (Latvia, Finland, Sweden, of Denmark, Austria) share of biomass in gross energy consumption is between 16 and 28%, while in Ukraine - not more than 1%. Among all types of biomass, share of solid biomass is the largest and makes 80% and vary by country from 0 to 94%. The largest is in Finland.

Ukraine has great potential of biomass available for energy use, has good conditions for increased use as fuel. Energy Strategy of Ukraine foresees dynamic growth of biomass energy use in 2030, 20 mln tons of standard fuel, which will be 10% of total energy consumption [4]. According to the Institute of Thermal Physics NASU, full use of biofuels at cultivation of energy crops on an area of 5 million hectares will bring the production of energy from biomass to 18% of total energy consumption [2]. Our calculations showed that the economically feasible potential of biomass (without peat) is estimated mln tons of standard fuel per year [6].

Analysis of literary sources [1, 2, 3, 8, 10] showed that studies on the energy potential of perennial herbaceous phytocenoses of Ukraine and the development of measures to improve their energy productivity until recently is not sufficient. Therefore, study of these issues is imperative, the relevance of which is increased due to the significant rise in price of non-renewable primary energy sources and also because significant reduction in need of herbal fodder due to the reduction in the number of livestock [5, 6].

Purpose of research. Establish bioenergy potential of herbaceous phytocenoses of Ukraine and provide suggestions of its implementation.

Methods of research. Research carried by generally accepted field and laboratory methods using measurement and weighing, comparative, chemical, mathematical and statistical methods. The content of gross energy calculated according to the chemical composition of biomass dry substance.

Results of research. Using biomass of perennial herbaceous phytocenoses as biofuel is an alternative their appliance. Our analysis of biofuel resources in Ukraine (Table. 1) showed that the energy-economical potential of perennial herbaceous phytocenoses is 7,05 mln tons of standard fuel per year, which is 20% of the total economically reasonable biomass (straw and waste production, bioenergy crops, wood biomass, biogas, bioethanol, etc.) and peat potential in Ukraine which is 34,32 mln tons of standard fuel. Including natural grasslands account – 4,22 million tons or 12%, marshes and swamps – 2,48 or 7%, non-conventional energy crops – 0,35 or 1%.

Among energy perennial phytocenoses special attention in Ukraine deserve natural grasslands, area of which is about 6,6 mln hectares. Unlike previous years when the degradation of pasturelands took place due to the large load from cattle and excessive use of meadow herbage, now the degradation is due to the lack of use because reduced number of livestock. Meadows overgrown with rough grasses (sow thistle, sorrel, erigeron, goldenrod, etc.), wetlands are often covered with tussocks, and those bordering with forest overgrown with shrubs (it begins 6-8 years after the last mowing and every year extends to 6-12 m from forest) and become unsuitable for mowing for fodder purposes, but the energy potential increases. Their biomass can be used for the production of solid biofuels and for biogas production.

For an estimation of current state of natural grasslands during the 2011-2014 we conducted their geobotanic examination in Polissya regions of Kyiv and Zhytomyr regions. Analysis of results showed that the energy performance of different types of meadow land without improvement was very contrasting and varied in a wide range, from 0,9 to 4,4 tonnes of dry weight or from 17,0 to 78,3 GJ of heat energy per hectare. The most valuable for the accumulation of biomass were forb and cereal herbage from wet lowland and floodplain meadows.

According to statistical data in Ukraine the average productivity of not improved natural grasslands not more than 1,4-2,2 t/ha of dry weight or 22,2-38,7 GJ/ha of thermal energy [4]. Adding of fertilizers can increase productivity in 2-3 times [5].

The scientific researches and production practice showed that the creation of sown herbage from cultural species and varieties of perennial grasses at most unproductive natural grasslands can increase their productivity in several times. According to our research, which is conducted on not flooded floodplain drained meadows with sod-gley, sandy loam soils of Kyiv Polissya (village Lytvynivka, Vyshgorod district of Kyiv region.) productivity of sown meadow clover-grass herbage depending on species and varietal composition of cereal components in average for 4 years was located in the range 4,77-

10,36 t of dry mass per one hectare. Which is equivalent to 83,4-184,8 GJ of thermal energy or 2,3-5,2 tons of standard fuel. The highest energy productivity provided a mixture of dactylis varieties of Kyivska Rannya and Natalka, festuca pratensis Rosinka and Siveryanka and bromus inermis Arsen and Helius, which provided obtaining from 1 hectare 7,16-10,36 t of dry weight, or 129-185 GJ of thermal energy, which in 1,3-2,4 times more, compared to other sown cenoses. Adding in cultivated cereal herbage N_{120} increased productivity of lands by 4,51-6,00 t/ha of dry weight or by 78,8-108,1 GJ/ha of thermal energy, or in 1.8-2.2 times in comparison with options without adding nitrogen. Natural herbage were in the 1,7-3,4 times less productive compared to sown.

In another experiment involving a mixture of different species and new varieties of perennial legumes in legume-cereal mixtures at the same drained floodplain meadows provided obtaining from 1 ha - 7,82-12,02 t of dry weight and 140,4-212,2 GJ of thermal energy or 4,27-6,40 tons of standard fuel. Which in 1,3-1,9 times more compared to cereal mixtures and in 2,4-3,5 times compared to the natural (Table 1).

1. Influence of species and varietal composition of legume components of grass mixtures on sown legume-cereal mixtures productivity, 2012-2014 years.

The composition of grass mixtures and norms of sowing seeds, kg/ha	Without liming			Lime background		
	dry weight, t/ha	thermal energy, GJ/ha	standard fuel, t/ha	dry weight, t/ha	thermal energy, GJ/ha	standard fuel, t/ha
Cereals*	6,10	108,1	3,33	6,58	115,7	3,60
Cereals* + Trifolium pratense Polyanka, 9	10,80	189,3	5,90	11,71	199,1	6,40
Cereals* + Trifolium pratense Polisyanka, 9	10,77	179,8	5,89	11,56	204,6	6,32
Cereals* + Trifolium pratense Polyanka, 4,5 and Polisyanka, 4,5	11,51	2029	6,29	12,02	212,2	6,57
Cereals* + Alfalfa Olga, 10	8,05	142,2	4,40	10,52	184,6	5,75
Cereals* + Alfalfa Intensivna 174, 10	8,02	143,0	4,38	10,67	189,4	5,83
Cereals* + Alfalfa Olga, 5 and Intensivna 174, 5	8,25	147,1	4,51	10,78	190,7	5,89
Cereals* + Lotus Ukrainian and local, 5	8,20	143,	4,4	8,52	151,	4,66

		1	8		2	
Cereals* + Lotus Ukrainian and local, 2,5 Trifolium pratense Polyanka, 4,5	10,38	181,1	5,67	10,5	185,6	5,74
Cereals* + Trifolium repens Sprint, 5	7,82	137,0	4,27	7,98	140,4	4,36
Cereals* + N_{120}	10,30	180,5	5,63	10,91	185,1	5,96
Natural grassland	3,56	59,0	1,95	3,68	64,0	2,02
$HIP_{0,5}$ t/ha	0,85			0,85		

* Cereals – Bromus inermis, 10 + Festuca pratensis, 8 + Timothy-grass, 6 kg/ha

Most efficient in these environmental conditions were sown legume-cereal herbage with clover Polyanka or Polisyanka in mixtures, and with alfalfa Olga or Intensivna 174 at lime background , which provided 9,61-11,92 t of dry weight from 1 hectare. With soil liming productivity of herbage increased by 0,12-2,65 t/ha of dry weight. Grass mixtures involving alfalfa best reacted for liming.

In the swamps and floodplain, where the main energy resource is peat and reed and other aquatic vegetation economically feasible energy potential is 0,40 and 2,00 mln tons of standard fuel. Energy productivity of reeds thickets averages around 8-10 tons of dry weight or 4,4-5,5 tons of standard fuel.

Comparative energy evaluation of unconventional perennial crops in the northern forest-steppe, in order to produce solid biofuels, we conducted on dark gray soils at research station of NSC «Institute of Agriculture of NAASU» in Chabany. Studies have shown (Table 2), that in average in 2011-2014 years, by introducing $N_{60}P_{60}K_{60}$, rare energy crops provided 5,4-14,1 t/ha of dry weight, 96-251 GJ/ha of thermal energy and 2,9-7,6 t/ha of standard fuel.

2. Comparative energy productivity and energy crops biometric indicators, the average for 2011-2014.

Crops	Productivity			Biometric indicators		
	dry weight, t/ha	thermal energy, GJ/ha	standard fuel, t/ha	height, cm	stalk diameter, mm	Weight of 1 m^3 of dry stalks chaff, kg
Polygonum wyrichii	12,6	221	6,9	213	14,5	100

Polygonum divaricatum	10,8	190	6,3	240	15,7	129
Polygonum sachalinensis	14,1	251	7,6	221	15,2	100
Hyssopus officinalis	5,4	96	2,9	49	2,4	62
Sida hermaphrodita	13,9	247	7,6	287	15,2	132
Silphium	12,6	224	6,9	284	12,2	96
Topinambour	11,8	207	6,5	228	12,6	144
Miscanthus giganteus	12,0	210	7,2	238	10,1	136
Agastache foeniculum	5,7	100	3,1	78	3,1	66
Solidago canadensis	8,2	144	4,5	127	5,1	66
Rumex	10,2	184	5,6	142	8,9	-
Helianthus annuus	12,1	201	6,7	203	11,9	42

Most efficient perennial crops proved Miscanthus giganteus, Silphium, Polygonum wyrichii and sachalinensis, Sida hermaphrodita, Topinambour, and Helianthus annuus. The least productive proved Agastache foeniculum and Hyssopus officinalis, which are ether-oil plants.

The highest linear growth were characterized by Sida hermaphrodita and Silphium herbage (284-287 cm), after that – Polygonum sachalinensis and divaricatum, Miscanthus giganteus, Topinambour and also Helianthus (221-240 cm) and the last one
– Hyssopus and Agastache (49-78 cm).

The diameter of energy crop stalks ranged from 3.1 mm to 15.7 mm. The largest diameter has Polygonum, Sida hermaphrodita, Topinambour of first year. After that were Topinambour, Silphium, Helianthus annuus. The smallest stalk diameter has Hyssopus officinalis and Agastache foeniculum.

The density, expressed as a mass of 1 m^3 of unpressed dry chaff from the stalks of studied herbaceous plants, ranged from 42 to 144 kg. The biggest density has Sida hermaphrodita, Topinambour, Miscanthus giganteus, Polygonum divaricatum (129-144 kg), which indirectly is evidence of their highest calorific value, and lowest has Hyssopus officinalis, Agastache foeniculum and especially Helianthus annuus.

Most of the studied species of energy crops on the $N_{60}P_{60}K_{60}$ background introducing do not lay down, indicating their good suitability for mechanized cutting, shredding stalks and biomass picking up. Partial stalks slope by 20-50^o from vertical has Polygonum, especially Polygonum wyrichii.

Most of the studied species of energy crops are late ripening with the exception of Rumex and Helianthus annuus, so harvesting ripeness by dry weight content for the solid biofuels production begins in late autumn or even winter period. In our studies its content in different crops by 10.10 ranged from 37,3 to 52,1 %. 01.11 dry weight content ranged from 51,5 to 81,1 %, 10.11 – from 52,3 to 86,5 % (Table 3). When the content of dry weight more than 80%, chaff drying in the producing of solid biofuels is not required. In our experiments at 10.11 this level of dry mass has Polygonum wyrichii and almost Sida hermaphrodita and Agastache foeniculum. The smallest content of dry weight were characterized by Silphium and Topinambour (56,2-60,0 %), indicating the need, if harvesting at this time, to increase the costs for final drying of biomass for storage in the form of chaff and for the technological cycle of production pellets or granules.

The content of thermal energy in the dry rare biomass energy crops ranged from 17,4 to 18,2 MJ/kg and little depended from crop type. Energy intensity of 1 m^3 of studied dry energy crops chaff due to different densities of 1 m^3 was significantly different and ranged from 1,13 to 2,56 GJ/m^3. The biggest energy intensity of 1 m3 of dry chaff has Sida hermaphrodita, Topinambour, Miscanthus giganteus, Polygonum divaricatum, indicating their highest calorific value, and the lowest – Hyssopus officinalis, Agastache foeniculum and especially Helianthus annuus.

3. The content of dry weight and thermal energy in energy crops, 2011-2014.

Crops	The content of dry weight in different mowing terms, %			The content of thermal energy in the dry chaff	
	10.10	1.11	10.11	MJ/kg	GJ/m3
Polygonum wyrichii	42,3	81,1	86,5	17,7	1,77
Polygonum divaricatum	48,4	73,1	78,2	18,0	2,32
Polygonum sachalinensis	42,2	63,9	68,8	17,9	1,79
Hyssopus officinalis	51,6	65,3	72,0	18,2	1,13
Sida hermaphrodita	51,1	77,4	84,1	17,7	2,34

Silphium	29,1	51,5	56,2	18,0	1,73
Topinambour	36,3	55,9	60,0	17,8	2,56
Miscanthus giganteus	44,1	62,8	70,3	17,4	2,37
Agastache foeniculum	47,7	77,9	83,0	18,1	1,19
Solidago canadensis	52,1	62,4	79,0	17,7	1,17
Rumex*	51,6	-	-	18,0	-
Helianthus annuus	39,0	60,7	77,3	17,8	0,75

Note. Rumex is early ripening plant and therefore ripening and harvesting ripeness for biofuels occurs early

One of the main factors of increasing the productivity of energy crops is the use of mineral fertilizers. The reaction of crops to fertilizer application we examined on the example of Silphium. Analysis of the studies results have shown that productivity of Silphium, plantation of which planted about 30 years ago, depending on the variants of fertilization collection of dry mass ranged from 6,6 to 14,6 t/ha, thermal energy – from 119 to 261 GJ/ha and standard fuel – from 3,9 to 8,8 t/ha. The most effective was nitrogen. Compared with a variant without fertilizers gathering of dry mass from 1 ha, at different phosphate and potash fertilizers backgrounds, after adding N_{60} increased by 2,1-2,9 tons or in 1,3-1,4 times, N_{120} – by 5,1-6,0 tons or in 1,8 times, N_{180} –by 7,1 tons or in 2,2 times. However, the payback of 1 kg of nitrogen by growth of dry mass was greatest with adding N_{60} (41-61 kg) and payback with N_{120} and N_{180} accordingly – 30-52 and 33-44 kg.

Depending on fertilizers varied the height and diameter of the stalk, according to the range 197 to 303 cm and from 7 to 16 mm. The biggest influence at stalks height and diameter has nitrogen, highest were with adding N_{180}.

4. Energy productivity of Silphium based on fertilizers, average 2011-2014.

Fertilizer	Productivity			Biometric		payback of 1 kg of fertilizer by dry mass, kg
	dry weight, t/ha	thermal energy, GJ/ha	standard fuel, t/ha	height, cm	stalk diameter, mm	
Without fertilizer	6,6	119	3,9	197	7	–
N_{60}	8,7	153	5,2	200	10	35
N_{120}	11,7	207	6,5	252	13	43
N_{180}	13,7	24	8,2	30	15,	39

		2		3	5	
$P_{60}K_{60}$	7,5	13 3	4,5	22 0	11	8
$N_{60}P_{60}K_{60}$	10,4	18 9	6,2	24 0	13	21
$N_{120}P_{60}K_{60}$	13,5	24 0	7,4	25 0	15	29
$N_{180}P_{60}K_{60}$	14,6	26 1	8,8	29 4	16	27
HIP_{05}, t/ha	0,84					

Conclusions

Perennial agrophytocenoses (natural grasslands, marshes, swamps and energy crops) is an important reserve of herbal mass for biofuel production, which economically feasible energy potential in Ukraine is around 7 mln tons of standard fuel or 20 % of all biomass, that can be used for fuel. Energy productivity of not improved 1 ha of natural grasslands depending on the type is about 1,4-3,6 tons of dry weight or 0,75-1,95 tons of standard fuel. With including legumes to mixtures or fertilization their productivity increases in 1,5-3,5 times.

Productivity of the best perennial energy crops is 10-14 t/ha of dry weight or 5,5-7,5 t/ha of standard fuel. The most productive are Silphium, Polygonum wyrichii and sachalinensis, Sida hermaphrodita and Miscanthus giganteus. Energy intensity of dry weight of perennial herbaceous phytocenoses is 17-18 MJ per 1 kg and little depends on crop type, 1 m^3 of dry and unpressed chaff of energy crops ranging from 1,13 to 2,56 GJ. The highest energy intensity and accordingly calorific value has Sida hermaphrodita, Topinambour, Miscanthus giganteus, Polygonum divaricatum.

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