TEKA. COMMISSION OF MOTORIZATION AND ENERGETICS IN AGRICULTURE – 2016, Vol. 16, No.3, 95-100

Bioenergetic and economic estimation of sewage sludge use in osier cultivation

V. Lopushniak[1,2], G. Lopushnjak[2], G. Grytsulyak[1]

[1]Lviv National Agrarian University; e-mail: Vasyl2016@i.ua
[2]University of Science and Technology, Bydgoszcz;, e-mail: Halstep@ukr.net

Received June.2016: accepted June.2016

Summary. Osier (*salix viminalis*) is a promising energy crop for the growing bioenergy purposes in Ukraine. It is unpretentious to the conditions of growth, marked with simplicity of cultivation technology, well-withdrawn for fertilization. Sewage sludge, due to its chemical composition and high content of organic matter, can be successfully used to fertilize the willow.

The calculations of bioenergetic and economic efficiency showed that application of sewage sludge and compost with sawdust and straw in a ratio of 3: 1 at osier is marked with a high effect. In the studies performed in conditions of Ukraine's Precarpathians on sod-podzolic soils we found that the highest biomass output and, therefore, gross energy per unit of area in agrocenoses of osier provided the application of fresh sewage sludge at a rate of 80 t / ha. In this option the dry biomass output made 39.4 t / ha, gross energy with the yield - 1,580 GJ / ha, the costs of energy generation - 6.2 UAH / GJ, the costs of gross output - 17.8 thousand UAH / ha, the rate of energy efficiency - 1.69.

However, the highest rates of economic and bioenergetic efficiency after the fourth year of the willow vegetation we observed when the sewage sludge compost with straw of grain crops at a doze 40 and 60 t / ha was applied. In these variants the lowest cost of the biomass production was obtained (at the level 109 - 111 UAH / ton), the cost of the received energy from the biomass (5.6 - 5.7 UAH / GJ), the highest profitability value (97 - 101%) and the best performing of energy efficiency coefficient - 1.85 - 1.89.

Key words: biomass, osier (*salix viminalis*), sewage sludge (SS), bioenergetic estimation

INTRODUCTION

Renewable energetics is growing rapidly in the world. It is projected that by 2050, the energy consumption in the world will increase more than 2 times, and about 40% of energy consumption will be provided by the renewable energy sources, including 32% - due to the bioenergetics [2]. Today, the share of the renewable energy in total consumption in the world makes about 13%, and 10% of it - biomass [4, 6, 8].

In Ukraine, the share of biomass in the output energy consumption makes no more than 1.8%. For comparison, in Poland - 9.1, Latvia and Finland - 27 - 28% [6, 7]. However, Ukraine has a great potential for the growth in the consumption of biomass for energy purposes, which leads to the expansion of areas under energy crops on unproductive lands that are not involved in agricultural production. According to various estimates, the area of the lands is 3 - 4 million hectares [3, 6, 25].

THE ANALYSIS OF RECENT RESEARCHES AND PUBLICATIONS

Energy crops is an important component of the EU bioenergy sector. According to the European Bioenergy Association (AEBIOM) the present potential of energy crops in the EU is at the level 44 - 47 million tons of fuel / year [4, 7]. Among the large number of crops that can be used for energy purposes, the most promising are osier, miscanthus, poplar [1, 7, 9, 22].

Osier is considered as one of the most promising crops in Europe for solid biofuels as a biomass for burning pellets or briquettes [13, 14, 15, 23]. It can grow on badlands, different types of soil, including with low fertility, high content of organic and inorganic pollutants, well-withdrawn at fertilization [5, 11, 12]. The environmental benefits of osier growing are: biodiversity reservation, protecting soil from varying degrees of erosion (water erosion and deflation), utilization of biogenic pollutants, restoration of degraded and disturbed soils [16, 20, 24].

The economic benefits of osier growing lies in the simplicity of the growing technology, intensive accumulation of biomass, high performance of phytocoenosis, the possibility of getting in a short period of large amounts of biomass for use in energy purposes, the possibility to use plantations 3 - 4 years after their laying (unlike other tree species), the use of plantations for 5 - 9 cycles without a significant decrease in performance, high return on investment tools and the biomass energy returns [8, 15, 21, 26].

The studies carried out in Sweden showed that the willow is marked with the lowest costs comparedly to other crops used for energy purposes [19].

The researches of polish scientists noted that in the Poland's market conditions osier is characterized by the

highest potential comparadly with miscanthus and triticale. Moreover, the costs of the willow are competitive with the annual crops, the cultivation of which is more exposed to annual price fluctuations [10].

The studies conducted in Belarus defined that the cost of biofuels obtained from one hectare of willow plantations is around 600 – 800 USD per year depending on the technology. The estimated balance of greenhouse gases shows that if Belarus will be able to sell quotas for greenhouse gas emissions, the use of the willow wood as energy carrier will permit to receive an additional 3500 - 3700 euros per hectare of willow plantations for the whole period of its operation (22 years). The calculations show that locally a certain level of profitability and the use of willow wood for energy purposes can be provided at prices prevailing today for what is imported [17]. The cost structure shows that about 30% are fuel costs needed primarily to additional wood drying. The use of technologies based on gathering wood with simultanious pressing and drying in the field reduces the cost by 20 - 25% [16].

An important aspect of increasing productivity of osier is the use of sewage sludge as fertilizer on energy plantations of this crop. Sewage sludge (SS) can be successfully used as a fertilizer that provides not only an increased productivity of agrocenoses but also causes lower costs for disposal of municipal waste water [11, 12, 21].

OBJECTIVES

The study is to determine the bioenergetic and cost-effectiveness of the willow cultivation at different levels of mineral nutrients using sewage sludge and composts produced on its basis.

THE MAIN RESULTS OF THE RESEARCH

The experiment was carried out in 3-fold repetition in 2011 on the territory of the collectible research field of Ivano-Frankivsk College of LNAU in the village Chukalivka, Tysmenytsya district. Energy The scheme of willow planting - 0.33 x 0.70 m, the area of one registrated plot - 28 m^2.

Experiments options: 1. Control - no fertilizers; 2. Mineral fertilizers - $N_{100}P_{100}K_{100}$; 3. SS - 40 t / ha; 4. SS - 60 t / ha; 5. SS- 80 t / ha; 6. Compost SS + sawdust (3: 1) - 60 t / ha; 7. Compost SS + straw (3: 1) - 20 t / ha; 8. Compost SS + straw (3: 1) - 40 t / ha; 9. Compost SS + straw (3: 1) - 60 t / ha; 10. Compost SS + straw (3: 1) + 10% cement dust - 40 t / ha.

In oreder to determine the performance dynamics of the formation of osier plants vegetative mass we picked out the plants' samples on the second, third and fourth years of growth. They were weighed and dried to a constant weight (Table 1).

Table 1. The effect of fertilization on the osier productivity, average for 2012 - 2014 years

Variant	Harvest of osier vegetative mass , t/ha					Exit of osier dry mass		
	years of researches			2014 ± to control		2014	± to control	
	2012	2013	2014	t/ha	%	t/ha	t/ha	%
1 Control – no fertilizers	5,7	27,0	44,0	-	-	32,9	-	-
2. $N_{100}P_{100}K_{100}$	14,7	32,3	52,3	8,3	18,8	44,1	11,2	34,1
3. SS - 40 t/ha	6,4	22,7	68,6	24,6	55,9	54,6	21,7	65,9
4. SS - 60 t/ha	8,6	27,1	79,7	35,7	81,2	66,9	34,0	103,3
5. SS - 80 t/ha	11,6	33,5	94,8	50,8	115,5	80,8	47,9	145,5
6. Compost SS + sawdust (3 : 1) - 60 t/ha	13,1	30,6	82,8	38,8	88,3	70,0	37,1	112,7
7. Compost SS + straw (3: 1) - 20 t/ha	6,7	31,3	73,7	29,7	67,4	62,0	29,1	88,5
8. Compost SS + straw (3: 1) - 40 t/ha	6,7	37,6	79,6	35,6	80,9	69,4	36,5	110,8
9. Compost SS + straw (3: 1) – 60 t/ha	8,5	31,5	85,8	41,8	95,1	70,6	37,7	114,6
10. Compost SS + straw (3: 1) + 10% cement dust - 40 t/ha	7,6	31,6	79,7	35,7	81,1	65,6	32,7	99,4
LSD 0,5	0,7	1,6	5,3			2,7		

Already in the second year of vegetation in different versions of the experiment we indicated a significant difference in intensity of vegetative growth of the plant's biomass. The most intense vegetative biomass growth was observed in the third year of the growing season in 2013. In the variants with fertilizers that increase was 54.3 - 82.2% comparedly to the second year.

In control variant the growth was 21.3 t / ha or 4.7 times prevailed the performance out of raw biomass from the previous year. In the variants where the mineral fertilizers and fresh sewage sludge were applied the growth rates of vegetative mass were slightly lower, indicating some inhibition of growth and development of the plant in the application of fresh sewage sludge in the early years of the plant's vegetation. However, in the next years of growth (4th year) the increase of vegetative mass in the variants with the application of fresh sewage sludge was 46 - 61 t / ha, 2.8 - 3.0 times more than the previous year.

The value of osier yields after the 3rd year of vegetation in the variantns with adding compost of sewage sludge and sawdust or straw provides the raw biomass growth at 17.5 - 30.9 t / ha or 2.3 - 5.6 times . After the 4^{th} year of vegetation the growth of vegetative mass was 42 - 54 t / ha or 2.1 - 2.7 times.

Overall, no distinct patterns of growth of vegetative mass depending on fertilization were defined. However, the trend of vegetative mass growth characteristics indicate

that the introduction of fresh sewage sludge in the first years of growth somewhat inhibits the growth and development of osier plants. Here, perhaps, there take place intensive processes of decomposition and mineralization of organic matter, which is reflected in the strengthening of microbiological activity and competition of microorganisms for mineral nutrients with osier plants. However, in the subsequent years (3 - 4 years) the intensity of vegetative mass was significantly increasing.

It should be noted that fertilization is an effective means of osier productivity increase that is reflected in the intensity of the vegetative mass growth in the first years of vegetation. But in the fourth year of osier vegetation the use of fertilizers contributed to productivity of agrocenosis only 19% comparedly to the variant without fertilization. The best indicators of the fourth year growth of vegetative mass we marked inthe options, where fresh sewage sludge was applied at a rate of 40 - 80 t / ha. Under these conditions the vegetative mass yield increase made 24.6 - 50.8 t / ha or 56 - 116% comparedly to the variant without fertilization. Osier willow vegetative mass yield in the control variant in the fourth year of vegetation is about 44 t / ha.

High rates of vegetative mass growth were observed in the options, where the compost of sewage sludge with different organic materials (sawdust of coniferous trees, cereals straw) was applied. In these variants, the yield of osier vegetative mass made 74 - 83 t / ha, which is 30 - 42% higher than that of the control option.

By adding compost of SS and sawdust (3: 1) at a rate of 60 t / ha the vegetative mass yield was 82.8 t / ha, which is 38.8 t / ha more comparedly with the control option. Comparing these figures with those of the other options, it should be noted that in the variants where SS compost with straw was applied, the productivity was higher and amounted to 86 t / ha. However, this difference was not significant, the use of SS compost with straw at lower doses (40 t / ha) was less effective in terms of performance than in the version where SS compost with sawdust, but this difference was within the experimental error.

As for the dry biomass release, the most productive options were those where SS rate made 80 t / ha and the composts based on SS + sawdust (3: 1) and SS + straw (3: 1) at a rate of 60 t / ha. In these variants, the yield of dry biomass made 70 - 80 t / ha.

Energy value of osier biomass makes 19.56 MJ / kg of dry weight [9, 18]. This figure we used in assessing the value of the energy potential of osier plantations under different conditions of mineral nutrition agrocenosis (Fig 1).

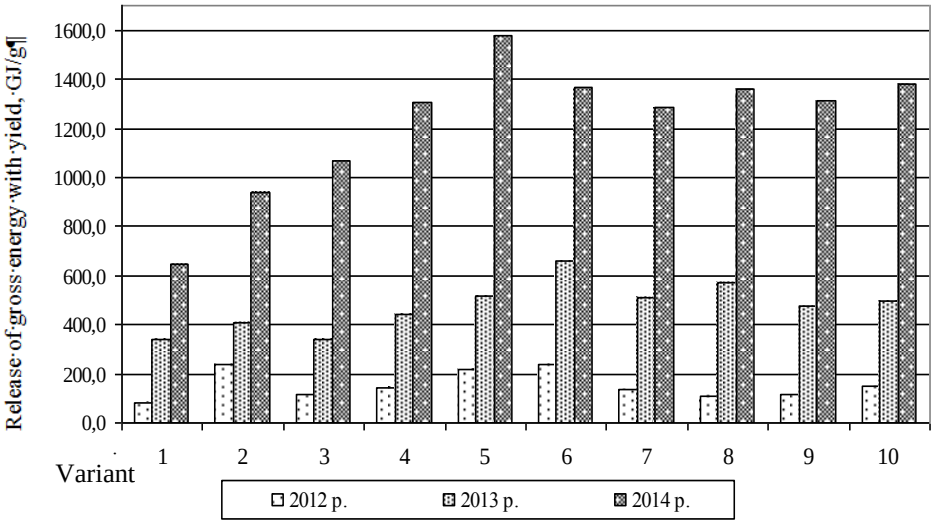

Fig. 1. Osier gross energy release with biomass influenced by sewage sludge application, for 2012 - 2014: 1. Control - no fertilizers; 2. Mineral fertilizers - $N_{100}P_{100}K_{100}$; 3. SS - 40 t / ha; 4. SS - 60 t / ha; 5. SS - 80 t / ha; 6. Compost SS + sawdust (3: 1) - 60 t / ha; 7. Compost SS + straw (3: 1) - 20 t / ha; 8. Compost SS + straw (3: 1) - 40 t / ha; 9. Compost SS + straw (3: 1) - 60 t / ha; 10. Compost SS + straw (3: 1) + 10% cement dust - 40 t / ha

In the second year of growth the gross energy output was low and was within 200 GJ / ha, with exception to options, where the fertilizers and sewage sludge were applied at a rate of 80 t / ha and compost SS with sawdust at a doze 60 t / ha. In the third year of growth the differences between the options of the experiment were more significant and were in the range of 300 - 600 GJ / ha. The highest rates were observed in the option, where compost SS with sawdust at a doze 60 t / ha was applied.

In the fourth year of osier vegetation with the highest rates of gross energy output per hectare was marked the option, where sewage sludge was applied at a rate 80 t / ha. It significantly surpassed that of the other options of the experiment and made about 1600 GJ / ha. In the range of values of gross energy output between 1200 - 1400 GJ / ha provided osier fertilization in the options 4, 6 - 10.

According to the calculations, osier willow growing cost in the control variant totaled 4737 UAH / ha. With sewage sludge application, all the transportation and preparation works, the cost of the willow cultivation increased and reached respectively 9875 UAH / ha (Table. 2).

Table 2. The economic efficiency of osier growing, 2014

Variant	Costs of cultivation		Dry biomass output, t/ha	Gross value of production, UAH/ha	Cost of production, UAH/ha	Profitability, %
	UAH/ha	GJ/ha				
Control – no fertilizers	4737	543,72	32,91	7240,2	143,9	52,84
2. $N_{100}P_{100}K_{100}$	5344	565,03	44,12	9706,4	121,1	81,63
3. SS - 40 t/ha	6427	639,15	54,59	12009,8	117,7	86,86
4. SS - 60 t/ha	8141	771,60	66,91	14720,2	121,7	80,82
5. SS - 80 t/ha	9875	935,95	80,78	17771,6	122,2	79,97
6. Compost SS + sawdust (3: 1) - 60 t/ha	8438	799,75	70,01	15402,2	120,5	82,53
7. Compost SS + straw (3: 1) - 20 t/ha	7394	700,80	62,02	13644,4	119,2	87,06
8. Compost SS + straw (3: 1) - 40 t/ha	7588	719,19	69,36	15259,2	109,4	101,10
9. Compost SS + straw (3: 1) – 60 t/ha	7882	747,05	70,64	15540,8	111,6	97,17
10. Compost SS + straw (3: 1) + 10% cement dust – 40 t/ha	7734	733,03	65,61	14434,2	117,9	86,63

However, with applying compost, the cultivation costs slightly decreased to 7,4 - 8,4 thousand UAH / ha and the lowest cost of osier growing in these variants was by adding compost of SS and straw at a rate of 20 t / ha.

The cost of production changed in accordance with the variant of the experiment. In particular, in the control option the production costs remained the largest and amounted to 143.9 UAH / t, with adding SS at a rate of 40 t / ha the cost reached 117.7 UAH / t. But by with adding SS 60 and 80 t / ha the cost of production increased to 121.7 and 122.2 UAH / t, respectively.

The lowest cost of production ensures application of compost SS and straw (3: 1) at a rate of 40 t / ha, that in terms of the experiment provided 109.4 UAH / t.

In order to calculate the value of gross output we took the osier willow chipped wood price which, at the end of 2014 totaled 220 UAH / t. Against the background of the increasing osier dry weight crop, the value of gross output significantly increased on the experiment's options. It was the highest in the option where was the highest yield (option 5) and amounted to almost 18 thousand UAH / ha. In the variants with adding compost in various dozes, the cost of osier crop was 13.6 - 15.5 thousand UAH / ha.

Considering the indicator of osier profitability, economically the best in terms of the experiment was an option with applying SS compost with straw at a rate of 40 t / ha. In this variant, the profitability was over 100%. In the other variants of compost application the profitability was slightly lower and amounted to 83- 97%. With the application of fresh sewage sludge the profitability level was commensurate with the performance options where compost was applied. But in the variant, where the SS doze was of the highest rate (80 t / ha) (option 5), the profitability was within 80%. In the option with mineral fertilizers application the indicator of profitability was slightly higher and amounted to 81%.

It should be noted that in the control variant the profitability level was almost 53%, indicating a significant economic interest in osier cultivation and good prospects for expanding its areas in Ukraine.

The indicators of osier energy efficiency also point to the high efficiency of the culture when cultivativated in condition of sewage sludge use (see Table 2, Fig. 2).

The energy cost of osier growing in the control variant amounted to 544 GJ / ha. During fertilization, the figure rose to 565 GJ / ha. The use of SS composts with sawdust and straw contributed to increasing energy costs up to 639 - 800 GJ / ha. With the application of 80 t / ha of fresh SS the power inputs sharply increased to 936 GJ / ha. This served to the energy efficiency reduction of this variant comparedly to the other options, where compost SS with sawdust and straw was applied. The coefficient of energy efficiency in the variants of compost application made 1,73 - 1,89. It was the highest in the variant where compost SS with straw at a rate of 40 t / ha was applied.

With the application of fresh sewage sludge at a rate of 40 t / ha the energy efficiency ratio was 1.75. With increasing the rates of application of sewage sludge to 60 - 80 tons / ha, it declined to 1.7.

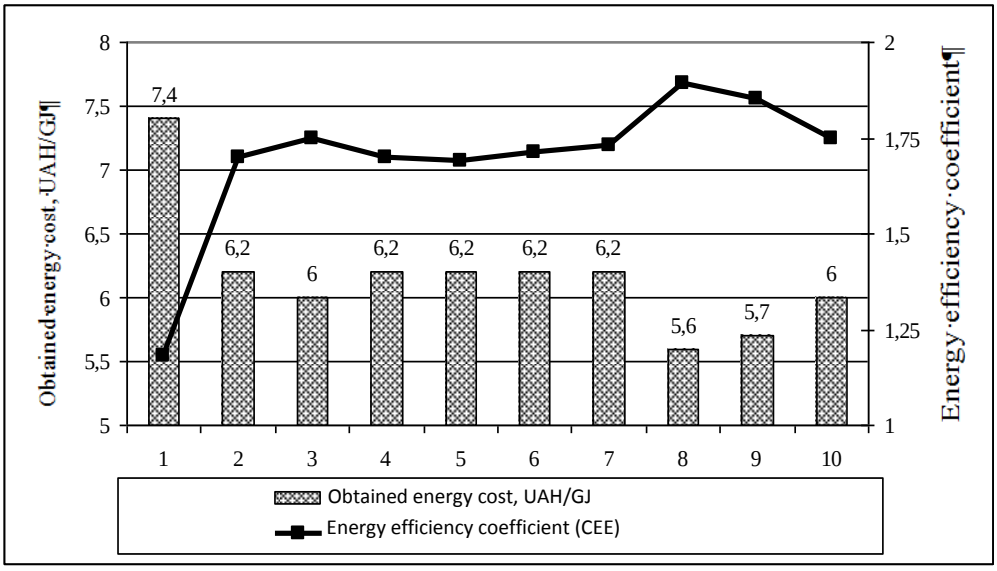

Fig. 2. Bioenergy efficiency of osier cultivation by sewage sludge application, 2014: 1. Control - no fertilizers; 2. Mineral fertilizers - $N_{100}P_{100}K_{100}$; 3. SS - 40 t / ha; 4. SS - 60 t / ha; 5. SS - 80 t / ha; 6. Compost SS + sawdust (3: 1) - 60 t / ha; 7. Compost SS + straw (3: 1) - 20 t / ha; 8. Compost SS + straw (3: 1) - 40 t / ha; 9. Compost SS + straw (3: 1) - 60 t / ha; 10. Compost SS + straw (3: 1) + 10% cement dust - 40 t / ha

The cost of energy obtained from osier willow harvest is quite low. In our studies, the cost per unit of energy of osier accounted for 6 - 7 UAH / GJ and slightly varied in the experimental options. Specifically, in the control variant it was 7.4 USD / GJ by adding SS at a doze 40 - 80 t / ha the energy unit cost was 6.0 UAH / GJ, and in the variants with adding compost from SS and straw (3: 1) at a rate of 20 - 40 t / ha it was 5.6 - 5.7 UAH / GJ respectively.

These figures of energy costs were commensurate with the indicators that were presented in the research of Royik M. et al., 2011 [18].

CONCLUSIONS

Based on the completed fieldwork, the calculations and estimation of the economic and energy efficiency of osier growing we can draw the following conclusions:

- For cultivation on sod-podzolic soils in the Precarpathians of Ukraine osier willow is noted with a high level of productivity performance and provides an output of dry biomass at 33 t / ha, the production cost of 144 UAH / t, the yield of gross energy from biomass - 644 GJ / ha, the cost of energy generation 7.4 UAH / GJ, energy efficiency ratio - 1.18, profitability - 53%;

- An important factor in osier significant productivity is the use of sewage sludge compost with sawdust and straw as fertilizers. If we speak about the features of vegetative mass increase during the years of the research we indicate that the application of fresh sewage sludge in the first years of cultivation somewhat inhibits the growth and development of the willow plants. However, in the subsequent years (3 - 4 years) the intensity of the vegetative mass increase rises significantly;

- In terms of the experiment with applying fresh sewage sludge at a rate of 80 t / ha we recorded the highest rates of dry biomass output - 39.4 t / ha, gross energy output in harvest - 1,580 GJ / ha. In this variant, the resulting energy cost was 6.2 UAH / GJ, the value of gross output - 17.8 thousand UAH / ha, the rate of profitability - 1.69, the coefficient of energy efficiency - 1.69;

- The highest economic and bioenergy efficiency after the fourth year of the willow vegetation we observed in the options, where compost of sewage sludge with grain crops straw at a doze 40 and 60 t / ha was applied. In these variants the lowest biomass production costs (at 109 - 111 UAH / ton) were obtained, the cost of the received energy from biomass (5.6 - 5.7 UAH / GJ), the highest profitability value (97 - 101%) and best performing of energy efficiency coefficient - 1.85 - 1.89;

- Further studies on the characteristics of sewage sludge and compost use with sawdust and straw it is advisable to concentrate on studying the aftereffects of this fertilizer efficiency in the next cycle of osier economic use, as well as exploring the sewage sludge composting with other organic materials.

REFERENCES

1. **Cholduj D., Podlaski S., 2008.** A comprehensive assessment of the biological usefulness of 7 species of plants used in the cultivation of energy crops. Renewable energy, ed. Gradzik P., MODR, Płońsk, 61-76. (in Polish).
2. Energy for Sustainable Development. UNDP. New York, 2002. (in English).
3. Energy strategy of Ukraine on a period 2030 to year. Approved by CMU № 1071 from 24.07.2013. Available online at: <http://mpe.kmu.gov.ua/fuel/control/uk/doccatalog/list?currDir=50358> (in English).

4. European Bioenergy Outlook, 2013. AEBIOM. Available online at: <http://www.aebiom.org/blog/aebiom-statistical-report-2013> (in English).
5. **Fenn, L. B. Gobran G. R., 1999.** Willow tree productivity on fertilizer solutions containing various Ca/Al ratios. Nutrient Cycling in Agroecosystems. Vol. 53(2), 121–131. 7 cycles use) (in English).
6. **Geletukha G., Zelesna T., Kutsheruk P., Olijnyk Je., 2014.** The modern state and prospects of development of bioenergetics are in Ukraine. Analytical message BAU № 9. Available online at: <www.uabio.org/activity/uabio-analytics> (in Ukrainian).
7. **Geletukha G., Zelesna T., Tryboj A., 2014.** Prospects of growing and use of power cultures are in Ukraine Analytical message of BAU № 10. Available online at: http://www.uabio.org/img/files/docs/position-paper-uabio-10-ru.pdf (in Russian).
8. **Grzybek A., 2006.** The use of biomass in the energy system. Wieś Jutra, 8/9 (97/98), 5-7. (in Polish).
9. **Gumentyk M. Ja., 2013.** Atlas of high-performance bioenergetics cultures. Bioenergetics, № 2, 6-7. (in Ukrainian).
10. **Krasuska E., Rosenqvist H., 2011**. Economics of energy crops in Poland today and in the future. Biomass and Bioenergy, doi:10.1016/j.biombioe.2011.09.011. (in Polish).
11. **Lopushniak V., Hrytsulyak G., 2013.** Willow energy productivity for various application rate of sewage sludge on sod-podzolic soils of the Carpathian region. Motrol. Lublin –Rzeszow. Vol. 15. № 4, 249–253. (in Russian).
12. **Lopushniak V., Hrytsulyak G., 2014.** Mathematical model of forming of the productivity of agrocoenosis of willow energy. Motrol. Lublin –Rzeszow. Vol. 6. № 4, 77–81. (in English).
13. **Rode H., 2011.**The energy of cutting process of a selected energy plant. Teka. Lublin. V. 11, 326 -334. (in English).
14. **Rode H., Witkowski P. 2011:** Moisture influence on the unitary energy of a cutting process of selected energy plants. Teka Komisji Motoryzacji i Energetyki Rolnictwa. Lublin, Vol. XI, 317-325. (in English).
15. **Rode H., Witkowski P. 2013:** The position of the research of energy plants cutting process. MOTROL. Commission of motorization and energetics in agriculture. An international journal on operation of farm and agri – food industry machinery. Lublin–Rzeszów, Vol. 15. nr 1, 111-114. (in Polish).
16. **Rodkin O. I., 2013.** Economic aspects of renewable energy from wood-growing. Scientific Journal ITMO. A series of Economics and Environmental Management, № 4. Available online at: <http://www.economics.ihbt.ifmo.ru> (in Russian).
17. **Rodkin O. I., Ivaniukovich V.A., Shabanov A.A., 2014.** Planning Bio Fuel Production from Fast Growing Willow Wood on the Basis of Interactive Model. Vestnik VDU. № 2(80). (in Russian).
18. **Roik M. V., Gumentyk M. Ja., Mamajsur V. V., 2011**. Perspectives of growing of willow energy are for the production of biofuels. Collection of research papers of Institute of bioenergy cultures and sugar beets. Vol. 12, 142–148. (in Ukrainian).
19. **Rosenqvist H., Nilsson L., 2007.** Energy crop production costs in the EU (RENEW project) Lund University. Lund: Lund University). (in English).
20. **Schweier J., Becker G., 2012.** Harvesting of short rotation coppice – harvesting trials with a cut and storage system in Germany. Silva Fennica. Vol. 46. № 2, 287–299. поля короткої ротації в Нім (in English).
21. **Sieciechowicz A., 2011.** Sewage sludge for osier willow plantation. Przegląd Komunalny, nr. 7, 40 – 43. (in Polish).
22. **Sobczyk W., 2011.** Evaluation of harvest of energetic basket willow. Teka. Lublin. V. 11, 343 -353. (in English).
23. **Stolarski M., Szczukowski S., Tworkowski J., Kwiatkowski J., Grzelczyk M., 2005.:** Characteristics of wood chips and pellets (pellets) from the mallow and willow biomass as fuel. Probl. Inż. Rol. 1(47), 13-22. (in Polish).
24. **Szczukowski S., Tworkowski J., Wiwart M., Przyborowski J. 2002:** Willow (Salix sp.) Growing and usability. Publisher University of Warmia and Mazury, Olsztyn. (in Polish).
25. **Tytko R., Kalinitshenko V., 2010**. Renewable sources of energy (experience of Poland and Ukraine). Manual. Warsaw. OWG. 533. (in Ukrainian).
26. **Wcisło G., Labak N., 2014.** The Determination of Energetic Potential of Waste Wood Biomass Coming from Dębica Forestry Management Area as a Potential Basis for Ethanol Biofuels of II Generation. Teka. Commission of motorization and energetics in agriculture. Vol. 14, no. 4, 191–196. (in English).

БИОЭНЕРГЕТИЧЕСКАЯ И ЭКОНОМИЧЕСКАЯ ОЦЕНКИ ПРИМЕНЕНИЯ ОСАДКА СТОЧНЫХ ВОД ПОД ИВУ ЭНЕРГЕТИЧЕСКУЮ

В. Лопушняк, Г. Лопушняк, Г. Грицуляк

Аннотация. Верба энергетическая является перспективной культурой в Украине для выращивания на биоэнергетические цели. Она отмечается неприхотливостью к условиям вегетации, простотой технологии выращивания, хорошо отзывается на внесение удобрений. Осадок сточных вод может с успехом использоваться для удобрения ивы энергетической учитывая его химический состав и высокое содержание органического вещества.
Ключевые слова: биомасса, энергия ивы, осадки сточных вод, оценка биоэнергетики.