SOME PERENNIAL HERBACEOUS SPECIES FOR MULTIPLE ENERGY PURPOSES IN THE REPUBLIC OF MOLDOVA

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Abstract

The sources of renewable energy have acquired considerable interest in recent years, at global and national level. The investigation of local as well as introduced herbaceous plant species for multiple energy purposes is an important objective.
We investigated some agro-biological peculiarities, the biochemical composition of the green mass and silage; energy characteristics of dry biomass of the perennial herbaceous species: local cv. *Energo* of Virginia mallow, *Sida hermaphrodita*, and an local ecotype of elecampane, *Inula helenium*, the most frequently used energy crops: maize – for biogas production and wheat straw – for solid biofuel production were used as control variants. It has been established that the gas-forming potential of the green mass of perennial species varied from 440 to 454 l/kg ODM and silage – 433 to 458 l/kg ODM, maize – 536 and 557 l/kg ODM, respectively. The best results of biomethane production were achieved by cv. Energo of *Sida hermaphrodita* (4000-4050 m^3/ha) versus maize *Zea mays* (3127- 3296 m^3/ha). *Inula helenium* substrate had higher content of methane (53.1-53.8 %). The briquettes of *Sida hermaphrodita* and *Inula helenium* were distinguished by high bulk density (813-1162 kg/m^3), moderate gross calorific value (18.3-18.7 MJ/kg) and ash content (1.5-3.0 %), but wheat straw– by low bulk density (704 kg/m^3) and calorific value (17.0 MJ/kg) and very high content of ash (5.1 %). Potential of energy production – 240-380 GJ/ha. The best results were achieved by cv. *Energo* of Virginia mallow, due to its high biomass productivity.

Key words: biomethane, briquettes, agrobiological peculiarities, *Inula helenium, cv.* Energo *Sida hermaphrodita*

The sources of renewable energy acquire considerable interest. In recent years, at global and national level, greater attention has been paid to the use of biomass for energy production, due to the depletion of fossil resources. Plant species are efficient users of solar energy for converting CO_2 into biomass (El Bassam N., 2010).

The Republic of Moldova has few fossil energy resources, so being forced to import near 86 %, depending entirely on the supplying countries. Therefore, the issue of renewable energy sources has been and remains an actual one. According to the Energy Strategy of the Republic of Moldova (2013), the total amount of energy produced from renewable sources should be increased to 20 % by the year 2020 and ¾ of this amount will make energy from biomass. Forests in Moldova cover less than 13 % of the territory; it becomes relevant to explore the suitability of using various types of biomass as renewable energy sources. The climatic conditions from the years 2007, 2012, 2015 which had serious consequences on the development of agriculture, revealed that only on the basis of agricultural remains – straw, sunflower stalks and corn cobs, the problem of biomass supply cannot be solved, which determined the orientation of the research and innovation policy towards identifying new plant species by analyzing their productivity, environmental impact, economic efficiency and ensuring that they didn't affect the food supply of the population. For biomass production on industrial scale, the most efficient crops that use, to a great extent, the photosynthetically active radiation (PAR) during the vegetation period, accumulate a considerable amount of dry matter and demand optimal expenses for the establishment of plantations and low expenses for maintenance, harvesting and processing should be selected and implemented.

Over more than half a century, as a result of the mobilization, introduction and acclimatization researches done in the Botanical Garden (Institute) of the ASM, collections and exhibitions of plants with multiple uses, necessary for the development of the national economy, were founded. The use of the gene pool of plant species for bioenergy production is a new research direction in the Academy of Sciences of Moldova.

Sida hermaphrodita (L.) Rusby. (Virginia mallow, Pennsylvanian malva, River mallow, Virginia fanpetals) fam. *Malvaceae* Juss., polycarpic

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perennial herb, originates from south-eastern parts of North America, where it naturally grows in moist riverine habitats, has a bushy shape, with densely branched root and with a few dozen of stems with the length of 400 cm and diameter of 5 to 35 mm. For the first time, *Sida hermaphrodita* was brought to Europe in 1930 and introduced in Ukraine as fodder and fibre crop (Rakhmetov J., 2011).

Inula helenium L., fam. *Asteraceae* Bercht. & J.Pres, commonly named elecampane, also called horse-heal or marchalan, is native to Europe and Asia, from Spain to China, and naturalized in some parts of North America. It is adapted well to different types of soils and habitats, highly resistant to frost and drought, used in medicine due to the inulin, volatile oil, alantolactone and helenin contained in its root (Spiridon I. *et al.,* 2013), polyphenol and flavone content in aerial part (Afemei M. *et. al.,* 2012), also became interesting for the production of fodder and energy (Medvedev P.F., Smetannikova A.I., 1981; Ivanova T. *et. al.,* 2013).

Currently, the species *Inula helenium* and *Sida hermaphrodita* are studied in different academic centres and universities and implemented as crops with multiple use (Oleszek M. *et al.,* 2013; Stolarski M. *et. al.,* 2014; Jablonowski N.D. *et al.,* 2016; Vronska L.V. *et al.,* 2016; Debowski M. *et al.,* 2017; Koc K. *et al.,* 2017).

In order to evaluate the potential bioenergy production, a research was carried out to determine the biological peculiarities of perennial herbaceous species and its biomass yields as the first objective, while the second objective was to estimate the gas forming potential and some energetic characteristics of biomass, that could be used for multiple energy purposes in Moldova.

MATERIALS AND METHODS

The local cv. *Energo* of Virginia mallow, *Sida hermaphrodita*, created in the Botanical Garden (Institute) of the Academy of Sciences of Moldova, registered in the in the Catalogue of Plant Varieties and patented by the State Agency on Intellectual Property of the Republic of Moldova and local ecotype, elecampane, *Inula helenium*, served as subjects of study. The most frequently used energy crops maize, *Zea mays* (for biogas production) and wheat straw, *Triticum aestivum* (for solid biofuel), were used as control variants.

The experiments were performed on experimental land in the Botanical Garden (latitude 46°58′25.7″ and longitude N28°52′57.8″E). The plant growth and development as well as their productivity were assessed according to methodical indications (Novoselov Y. K. *et al 1983*). The green mass was harvested in the flowering stage. The biomass yield was measured by weighing. The silage was prepared and evaluated in accordance with the Moldavian standard SM 108. The dry matter or total solid (TS) content was detected by drying samples up to constant weight at 105 °C. Crude protein – by Kjeldahl method, crude fat – by Soxhlet method, crude cellulose – by Van Soest method, ash – in muffle furnace at 550 °C. Nitrogen-free extractive substance (NFE) was mathematically appreciated, as the difference between organic matter values and analytically assessed organic compounds. Organic dry matter or volatile solids (VS) was calculated through differentiation, the crude ash being subtracted from dry matter. The biogas and biomethane, litre per kg of volatile solids (l/kg VS), were calculated using the gas forming potential of nutrients (Baserga U., 1998) and the digestible index of nutrients (Medvedev P.F, Smetannikova A.I., 1981). The content of ash was determined at 550 °C in a muffle furnace HT40AL, according to CEN/TS 15403. Automatic calorimeter LAGET MS-10A, with accessories, was used for the determination of the calorific value, according to CEN/TS 15400. The cylindrical containers were used for the determination of bulk density, calculated by dividing the mass over the container volume. The briquetting was carried out by hydraulic piston briquetting press BrikStar model 50-12 (Briklis). The mean compressed (specific) density of the briquettes was determined immediately after the removal from the mould as a ratio of measured mass over calculated volume.

RESULTS AND DISCUSSIONS

Analyzing the scientific results concerning the biological peculiarities of growth and development, we can mention that, in the first year of vegetation, the local ecotype *Inula helenium* passed 2 stages of ontogenetic development: the formation of plantlets and the juvenile phase; it did not develop shoots. *Inula helenium* plants developed up to 6-8 oblong leaves of intense green colour, the growth and development of the rosette lasted up to early autumn frosts, the green mass productivity reached up to 16 t/ha. The experimental results revealed that *Sida hermaphrodita*, in the first 45 days of the growing season, had a slow rate of growth and development of aerial parts, and then, the rate was accelerating and the formation of flower buds started in mid-September. The stems grew about 171 cm tall and 6-13 mm thick at the base, the productivity of green mass reached 28.3 t/ha or 6.2 t/ha dry matter, containing high amount of leaves – about 48 %.

In the second year and the in further years of vegetation, in spring, when the average air temperature exceeded 6 °C *Sida hermaphrodita*, and 12 °C *Inula helenium*, started the plant development from generative buds, which went

through all stages of ontogenetic development, finishing with seed formation and growth of a larger number of stems in a bush. A high rate of growth of stems was observed during May to June (3-6 cm/day). In general, plants reached a height of 210-350 cm, depending on the species. We observed that plants of cv. *Sida hermaphrodita* were significantly taller than the plants of *Inula helenium* species. Research data demonstrated that the studied perennial species were characterized by intensive growth and development that allowed obtaining annual up to 50.9-89.1 t/ha of green mass with 14-25 % dry matter. A high aerial biomass productivity of *Sida hermaphrodita* plants was also mentioned in other studies. So, Rakhmetov J. (2011) stated that, in the conditions of Ukraine, *Sida hermaphrodita* could have a productivity of 123.9-187.7 t/ha natural fodder depending on the genotype.

For the implementation of new plant species, it is necessary to assess their productivity and quality in comparison with traditional crops. Maize, *Zea mays*, is a well-known and appreciated energy crop (El Bassam N., 2010). Analyzing the results of the determination of the dry matter from the green mass of the studied perennial species and its biochemical composition, we saw that it differed from *Zea mays* (*table 1*).

Table 1.

Biochemical composition and gas forming potential of studied perennial species

Indices	*Sida hermaphrodita*		*Inula helenium*		*Zea mays*	
	green mass	silage	green mass	silage	green mass	silage
Organic dry matter (ODM), g/kg	926.9	912.3	887.9	861.4	954.5	957.4
Digestible ODM , g/kg	577.0	579.3	556.8	546.0	673.3	695.6
Digestible proteins, g/kg	95.4	75.6	88.2	88.9	41.5	34.6
Digestible fats, g/kg	15.1	14.4	18.6	20.5	17.4	23.3
Digestible carbohydrates, g/kg	466.5	489.3	450.0	436.6	614.4	637.7
Biogas, l/kg ODM	454	458	440	433	536	557
Biomethane, l/kg ODM	244	243	236	228	278	292
Methane, %	53.7	53.1	53.8	52.6	51.9	52.4
Methane production, m^3/ha	4050	4000	2443	2111	3296	3127

Table 2.

Characteristics of the dry matter and the potential of energy production of the studied perennial species

Indices	*Sida hermaphrodita*	*Inula helenium*	*Triticum aestivum*
Humidity of the stems December, %	17	13	10
Humidity of the stems January, %	13	11	9
Humidity of the stems March, %	9	10	9
Bulk density of the chopped stems, kg/m^3	268	259	163
Gross calorific value, MJ/kg	18.7	18.5	17.0
Density of briquettes, kg/m^3	1162	813	704
Ash of briquettes, %	1.5	2.6	5.1
Potential of energy production, GJ/ha	350	240	65
- equivalent coal, t	13	9	1.8
- equivalent to conventional oil, t	9	6	1.5

We can state that the dry matter of *Sida hermaphrodita* and *Inula helenium* had high content of digestible proteins and fats, but low amount of digestible carbohydrates as compared with *Zea mays*. The gas forming potential of digestible organic dry matter (proteins, fats, carbohydrates) green mass substrate of the studied perennial species varied from 440 to 454 l/kg ODM and 433-458 l/kg ODM of silage substrate; in maize – 536 l/kg ODM of green mass substrate and 557 l/kg ODM of silage substrate. The calculated methane content 52.6% -53.8 %. The best results of methane production 4000-4050 m^3/ha were achieved by *Sida hermaphrodita* biomass, in comparison with *Zea mays*, which produced 3127-3296 m^3/ha (*table 1*). The native species *Inula helenium* had a low biogas producing potential (433-440 l/kg), but it was distinguished by a higher content of methane (53.1-53.8 %). The biogas batch tests with *Sida hermaphrodita* showed a potential of 435 l/kg ODM from silage made from biomass harvested in July or 220 l/kg methane (Oleszek M. *et al.*, 2013). Jablonowski *et al.* (2016) achieved a biogas yield of 419.5 l/kg VS with methane concentration of 53.5 %, Debowski *et al.* (2017) noted lower results – 381.4 l/kg VS and 43.7 %, respectively.

The stems of the studied perennial species quickly dry in autumn-winter; they are resistant, cannot be flattened easily and can be used to produce solid biofuels with high heating value. It is known that the heating value of solid biofuel depends on humidity and mineral content. The leaves have higher ash content than the stems. The rate of tissue dehydration and fall of the leaves from stems were investigated in order to determine the optimal period of biomass

harvesting. At the end of the growing season and with the establishment of negative temperatures, the leaves of the studied species fell and the tissues dehydrated rapidly. The degree of foliage of *Inula helenium*, at the end of the growing season (October) was about 35 %, while the degree of foliage of *Sida hermaphrodita* – 20 %. Over 15-35 days *Sida hermaphrodita* stems were completely defoliated, while the leaves of *Inula helenium* were kept for a long period of time (in March, the leaves constituted 7-9 % of biomass). *Inula helenium*, in field, dehydrated faster than *Sida hermaphrodita* (*table 2*).

The bulk density of the chopped stems influenced the transportation and storage expenses. The briquettes from the biomass of the studied perennial species were characterized by high bulk density (813-1162 kg/m^3), moderate gross calorific value (18.5-18.7 MJ/kg) and moderate ash content (1.5-2.6 %), but wheat straw – by low bulk density (704 kg/m^3) and calorific value (17.0 MJ/kg) and high content of ash (5.1 %). The potential of energy production constituted 240-350 GJ/ha (*table 2*). The energy yield of *Sida hermaphrodita*, as a solid fuel, accounted for a net calorific value of 440 GJ/ha (Jablonowski N.D. *et. al.*, 2016), *Inula helenium* – 202 GJ/ha (Ivanova T. *et. al.*, 2013).

CONCLUSION

The studied perennial species differ in the rates of growth and development, productivity and chemical composition of the harvested mass, which have influenced the methane yield. The gas forming potential of digestible organic dry matter from green mass substrate varied from 440 to 454 l/kg ODM and 433-458 l/kg ODM of silage substrate, the methane content – from 52.6 to 53.8 %. The best results of methane production 4000-4050 m^3/ha were achieved by *Sida hermaphrodita*, in comparison with *Zea mays*, which produced 3127-3296 m^3/ha and the lowest – *Inula helenium* (2111-2443 m^3/ha).

The briquettes of *Sida hermaphrodita* and *Inula helenium* were distinguished by high bulk density (813-1162 kg/m^3), moderate gross calorific value (18.3-18.7 MJ/kg) and ash content (1.5-3.0 %), but wheat straw – by low bulk density (704 kg/m^3) and calorific value (17.0 MJ/kg) and very high content of ash (5.1 %). The potential of energy production constituted 240-350 GJ/ha. The best results were achieved by cv. *Energo* of *Sida hermaphrodita*, due to its high productivity of biomass.

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