Scientific Papers. Series A. Agronomy, Vol. LX, 2017
ISSN 2285-5785; ISSN CD-ROM 2285-5793; ISSN Online 2285-5807; ISSN-L 2285-5785

THE EVALUATION OF BIOMASS OF THE *Sida hermaphrodita* AND *Silphium perfoliatum* FOR RENEWABLE ENERGY IN MOLDOVA

Victor ŢÎŢEI

Botanical Garden (Institute) of the Academy of Sciences of Moldova, Chişinău,
18 Padurii Street, MD 2002, Republic of Moldova

Corresponding author email: victitei@ gmail.com

Abstract

Perennial herbaceous crops can become the main basis for renewable energy production in agricultural ecosystems in future. To determine the plant species that are the most suitable for biomass production, their biological peculiarities and productivity, biochemical composition and thermophysical properties, social and ecological impact must be investigated thoroughly.
The local varieties of perennial energy crops: Energo, Sida hermaphrodita and Vital, Silphium perfoliatum registered in the Catalogue of plant varieties and patented in the Republic of Moldova, which were cultivated in the experimental land of the Botanical Garden (Institute) of the ASM served as subjects of study. Maize and sunflower (for biogas production) and wheat straw (for biosolid fuel) - control variants. It has been established that the gas forming potential of organic dry matter in silage varies from 458 l/kg in Sida hermaphrodita to 471 l/kg in Silphium perfoliatum. The best results of methane production were achieved by the silage of cv. Energo of Sida hermaphrodita – 4000 m^3/ha and cv. Vital of Silphium perfoliatum – 3675 m^3/ha, versus 3127 m^3/ha, maize silage, and 2881 m^3/ha, sunflower silage. The silage substrate of Sida hermaphrodita had higher content of methane (53.1%). The biomass of Sida hermaphrodita and Silphium perfoliatum was distinguished by high bulk density, moderate gross calorific values (18.3-18.7 MJ/kg.) and ash content (1.5-3.0%), but wheat straw – by low bulk density and low calorific value (17.0 MJ/kg) and high content of ash (5.1%). The potential of energy production of the local varieties of perennial energy crops was of 350-380 GJ/ha. The best results were achieved by cv. Vital, Silphium perfoliatum, due to its high productivity of dry biomass.

Key words: *biomass production, gas forming potential, Sida hermaphrodita, Silphium perfoliatum, thermophysical properties.*

INTRODUCTION

In the context of the increasing world population, which requires more and more resources, there comes a higher need of energy consumption that obligates us to look for alternative ways, to reduce the dependence on fossil fuels and to develop new technological processes of renewable energy production.
Biomass is a renewable energy source which is easily available around the world.
The increase in the biomass use for energy production can help reduce greenhouse gas (GHG) emissions and meet the targets established in the Paris Climate Conference (COP21), in December 2015. Energy from species plant biomass can be produced by different thermochemical (combustion, gasification, and pyrolysis), biological (anaerobic digestion and fermentation), or chemical (esterification) processes, where direct combustion can provide a near-term solution to the problem of energy (El Bassam, 2010).
Perennial herbaceous crops would be the main basis for renewable energy production in agricultural ecosystems and would play an important role in the reclamation of contaminated land in future. The investigation of local and introduced plant species, which are the most suitable as feedstock in an integrated multi-product biorefinery, is an important objective in the Botanical Garden (Institute) of the ASM (Teleuţă and Ţîţei, 2016; Ţîţei, 2015)
Some promising herbaceous perennial plant species belong to *Asteraceae* Bercht and *Malvaceae* Juss. families.
Sida hermaphrodita (L.) Rusby (Virginia mallow, Pennsylvanian malva, River mallow, Virginia fanpetals) fam. *Malvaceae* Juss., is a polycarpic perennial herb, originates from south-eastern parts of Northern America, where it naturally grows in moist riverine

habitats. It is bushy, has dense root system, a few dozen of stems with a length of 400 cm and diameter of 5 to 35 mm. The plant is reproduced by root cuttings, stem cuttings or seeds. The species lives for 15-20 years, providing a good harvest on all kinds of lands. Its multi-directional cultivation appears to be an advantage of *Sida hermaphrodita*, as well as its great capacity of adaptation to changing climate and soil conditions, including chemically degraded areas. *Sida hermaphrodita* is a fodder, fibre and energy crop (Thomas, 1979; Rakhmetov, 2011; Tarkowski and Truchliński, 2011; Stolarski et. al., 2014; Jablonowski et al., 2016).

Silphium perfoliatum L., fam. *Asteraceae* Bercht. & J.Pres, known by the common names Sylph or Cap plant, belongs to the genus *Silphium* L., which includes 23 species. It is native to North America, East Coast of United States of America and Canada. *Silphium perfoliatum* L. is an erect herbaceous perennial plant with strongly 4-angled (square) stem (150-350 cm), flowers very similar to sunflower, measuring about 2.5 cm in diameter, produces from 20 to 30 seeds in each flower head. The plant has an extensive root system, is able to establish colonies due to its central taproot system and shallow rhizomes. *Silphium perfoliatum* was introduced as an ornamental plant in the Botanical Gardens of France and the UK in the second half of the 18th century, in the 20-21th century – in Russia, France, Poland, Romania and in other regions of the Earth – as a fodder, melliferos, medicinal and energy plant (Niqueux, 1981; Puia and Szabo, 1985; Boe et. al., 2012; Šiaudinis et. al., 2012; Stolarski et. al., 2014).

A high aerial biomass productivity of *Silphium perfoliatum* and *Sida hermaphrodita* plants was mentioned in differ studies. So, Medvedev and Smetannikova (1981) mentioned that the green mass yield of *Silphium perfoliatum* cultivated in Kirgistan on irrigated land in was 234 t/ha and Moscow region, Russia - 70 t/ha; Rakhmetov (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.

Silages are the main feedstock for anaerobic digestion in European countries with a dynamic development of agricultural biogas plants (Klimiuk et. al., 2010; Kalac, 2011; Oleszek et al., 2013; Mast et. al., 2014)

The objective of this research was to evaluate silage as feedstock for biogas production based on the chemical composition and some thermophysical properties of the dry biomass from local varieties of introduced perennial species of *Silphium perfoliatum* and *Sida hermaphrodita.*

MATERIALS AND METHODS

The local varieties: *Vital* of cup plant, *Silphium perfoliatum*, and *Energo* of Virginia mallow, *Sida hermaphrodita*, created in the Botanical Garden (Institute) of the ASM, registered in the in the Catalogue of plant varieties (Catalogul soiurilor de plante, 2012; 2014) and patented by the State Agency on Intellectual Property (*BOPI 9/ 2016*) of the Republic of Moldova, which were cultivated in the experimental plot of the Botanical Garden (Institute) of the ASM, served as subjects of study. The most frequently used energy crops: maize – *Zea mays* and sunflower – *Helianthus annuus* (biogas production), wheat straw – *Triticum aestivum* (biosolid fuel) served as control variants.

The plant growth and development and their productivity were assessed according to methodical indications of Novoselov et al. (1983). The green mass of *Sida hermaphrodita* was harvested in the budding stage (the 1st mowing in June and the 2nd mowing in September), *Silphium perfoliatum* and *Helianthus annuus* – in the flowering stage (late July), maize – in kernel milk-wax stage (August). The yield was measured by weighing. The green mass was shredded and compressed in well sealed glass containers. After 45 days, the containers were opened, the biochemical composition of the silage was determined by Petukhov et al. (1989) and 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 mathe-matically appreciated, as 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 according to Baserga (1998) and the digestible index of nutrients according to Medvedev and Smetannikova (1981).
The dry stems of *Sida hermaphrodita* and *Silphium perfoliatum* were harvested manually in the first days of March. The stems of *Sida hermaphrodita* and *Silphium perfoliatum* and the wheat straw were chopped into chaff with the use of stationary forage chopping unit. The obtained chaffs of mean dimension from 7 to 35 mm, were milled in a beater mill equipped with a sieve with diameter of openings of 20 mm and 10 mm. Scientific researches on the dry biomass for the production of solid biofuel were carried out: the moisture content of plant material was determined by CEN/TS 15414 in an automatic hot air oven MEMMERT100-800; the content of ash was determined at 550 ºC in a muffle furnace HT40AL according to CEN/TS 15403; an automatic calorimeter LAGET MS-10A with accessories was used to determine the calorific value, according to CEN/TS 15400; the cylindrical containers were used to determine the 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; the mean compressed (specific) density of the briquettes was determined immediately after removal from the mould as a ratio of measured mass over calculated volume.

RESULTS AND DISCUSSIONS

We could mention that, in the conditions of the Republic of Moldova, in the first growing season, the cv. *Vital, Silphium perfoliatum,* passed 2 stages of ontogenetic development, the formation of plantlets and the juvenile phase, didn't develop shoots, but formed a rosette with 16-18 dark green triangular leaves, up to autumn frosts, the green mass productivity reached up to 23 t/ha of green mass. The cv. *Energo, Sida hermaphrodita,* in the first 45 days of vegetation had a slow rate of growth and development of aerial parts, and then, the rate accelerated. The development of flower buds started in mid-September and the stems were about 171 cm tall and 6-13 mm thick at base, the productivity of green mass was 28.3 t/ha or 6.2 t/ha dry matter, with high content of about 48 % leaves.
In the second year and in the further years of the vegetation, in spring, when the air temperature exceeded 6°C, plant development started from the generative buds of *Silphium perfoliatum* and *Sida hermaphrodita*, which went through all the stages of ontogenetic development, finishing with seed formation. A high growth rate of stems was observed during May and June (5-6 cm/day). In general, plants grew about 230-350 cm tall depending on the species. We observed that *Sida hermaphrodita* plants were significantly taller than *Silphium perfoliatum*. Our research data demonstrated that *Sida hermaphrodita* plants were characterized by intensive growth and development rates and harvesting stems in June allowed to obtain 59.5 t/ha of green mass. After the first harvest, *Sida hermaphrodita* plants had a high rate of revival and, in September, the stems reached 1.0-1.2 cm in diameter and 158-163 cm tall, the yield of green mass at the second harvest was 19.2 t/ha. The productivity of *Silphium perfoliatum* was of 79 t/ha natural fodder, *Zea mays* and *Helianthus annuus* yielded 40-45 t/ha green mass.
The quantities of biogas and the contained methane depend mainly on carbohydrates, fats and proteins contained in the substrate. Analyzing the results of the determination of the organic dry matter from the silage of the studied perennial species and its biochemical composition, we see how it differs from maize and sunflower (Table 1).

Table 1. Biochemical composition and gas forming potential of the silage from perennial species

	Zea mays	*Helianthus annuus*	*Sida hermaphrodita*	*Silphium perfoliatum*
Organic dry matter (ODM), g/kg	957.4	916.2	912.3	893.6
Digestible ODM, g/kg	695.6	693.5	579.3	593.6
Digestible proteins, g/kg	34.6	53.6	75.6	48.4
Digestible fats, g/kg	23.3	34.0	14.4	13.9
Digestible carbohydrates, g/kg	637.7	605.9	489.3	531.3
Biogas, l/kg ODM	557	559	458	471
Biomethane, l/kg ODM	292	294	243	245
Methane, %	52.4	52.6	53.1	52.4
Methane production, m^3/ha	3127	2881	4000	3675

It has been found that the silage made from the studied perennial species is characterized by a low content of organic substances (893.6-912.3 g/kg). The content of organic dry matter from *Silphium perfoliatum* silage was low, but its digestibility was higher. The silage made from *Sida hermaphrodita* contained a high amount of digestible proteins and fats, but an inferior level of digestible carbohydrates in comparison with *Silphium perfoliatum*.

Organic dry matter is an important factor influencing biogas and methane yield. The gas forming potential of digestible organic dry matter from silage substrate varied from 458 to 559 l/kg. Maize and sunflower silage had higher potential - 557-559 l/kg, but *Sida hermaphrodita* - a lower one – 458 l/kg, being directly proportional with the content of digestible organic dry matter.

The calculated methane content in the biogas ranged from 52.4 to 53.1%. The best methane content was achieved by *Sida hermaphrodita* silage, a lower one - by maize and *Silphium perfoliatum* silage.

The best results of calculated methane production were achieved by the silage from the cv. Energo of *Sida hermaphrodita* – 4000 m^3/ha and cv. Vital of *Silphium perfoliatum* – 3675 m^3/ha versus 3127 m^3/ha obtained from maize silage and 2881 m^3/ha from sunflower silage.

The literature suggests that for maize silage. silage the methane value is 330 l/kg VS (Klimiuk et al., 2010) and for sunflower silage 285-340 L/kg VS (Dandikas et al., 2014).

The biogas batch-tests of *Sida hermaphrodita* showed a potential of 435 l/kg ODM from silage made from biomass harvested in July (Oleszek et al., 2013), the Hohenheim Biogas Yield Test showed a specific methane yield of *Silphium perfoliatum* of 232-274 l/kg ODM depending on harvest time, methane yield per hectare was up to 4301 m^3/ha^{-1} (Mast et. al., 2014).

The stems of the studied perennial species dried quickly in autumn-winter. They were resistant couldn't be flattened easily and could be used to produce solid biofuels with high heating value. It is known that the heating value of solid biofuel depends on the 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 temperatures below 0 C, the studied species differed in the rate of leaf fall and dehydration of tissues. The degree of foliage of *Silphium perfoliatum* at the end of the growing season (October) was about 35 %, while the degree of foliage of *Sida hermaphrodita* – 20 % (Table 2). Over 15-35 days, the stems of *Sida hermaphrodita* were completely defoliated, while the leaves of *Silphium perfoliatum* were kept for a long period of time (in March, dry leaves on the stems constituted 8 % of the biomass). The stems of *Sida hermaphrodita*, in the field, dehydrated faster than *Silphium perfoliatum.*

The bulk density of the chopped stems reflects on transportation and storage expenses. It was established that the bulk density of the chopped material of *Silphium perfoliatum* was higher (165 kg/m^3) but - of *Sida hermaphrodita* was lower (122 kg/m^3). The wheat straw was characterized by the lowest bulk density – 83 kg/m^3 (Table 3).

Table 2. Plant material moisture and leaves contents of the biomass *Sida hermaphrodita* and *Silphium perfoliatum*

Period	*Sida hermaphrodita*		*Silphium perfoliatum*	
	Moisture content, %	leaves content, %	moisture content, %	leaves content, %
7 October	58.37	20.12	71.25	30.94
27 October	58.37	8.00	68.92	26.96
10 November	33.69	0	59.10	15.25
20 November	25.10	0	45.00	13.03
18 December	21.30	0	23.82	11.57
30 December	21.03	0	21.70	10.03
16 January	16.89	0	19.60	9.00
5 March	15.89	0	11.63	8.14

Table 3. Bulk density of biomass and specific density of briquettes of *Silphium perfoliatum* and *Sida hermaphrodita*

Variants	*Triticum aestivum*		*Sida hermaphrodita*		*Silphium perfoliatum*	
	bulk density of biomass, kg/ m^3	specific density of briquettes, kg/ m^3	bulk density of biomass, kg/ m^3	specific density of briquettes, kg/ m^3	bulk density of biomass, kg/ m^3	specific density of briquettes, kg/ m^3
Chopped chaffs 7 -35 mm	83	715	122	553	165	594
Milled chaffs 20 mm	86	733	160	642	195	869
Milled chaffs 10 mm	93	740	173	747	208	882

Table 4. Ash content and calorific value of biomass of *Silphium perfoliatum* and *Sida hermaphrodita*

Indices	*Triticum aestivum*	*Sida hermaphrodita*	*Silphium perfoliatum*
ash content,%	5.08	1.52	3.03
calorific value, MJ /kg	17.0	18.7	18.3

Distinct differences in bulk density between chopped and milled chaffs were found. These differences amounted to 13-38 kg/m^3 in *Sida hermaphrodita* and 13-30 kg/m^3 in *Silphium perfoliatum,* but 3-10 kg/m^3 in wheat straw.

The specific density of briquettes made from chopped material of *Sida hermaphrodita* and *Silphium perfoliatum* was low 553-594 kg/m^3, but it increased significantly if milled chaffs where processed into briquettes, reaching values of 642-747 kg/m^3 and 869-882 kg/m^3, respectively.

The ash content of different types of biomass is an indicator of slagging behaviour of the biomass. The greatest amount of this component was contained in *Triticum aestivum* – 5.08 %, while the lowest, 1.5 %, in the biomass of *Sida hermaphrodita* and a moderate one 3.0 % – in *Silphium perfoliatum* (Table 4). According to Stolarski et. al. (2014) the ash content decreased during the dehydration of stems, in *Sida hermaphrodita* – from 3.09 % to 2.69 %, and in *Silphium perfoliatum* - from 4.23 % to 3.49 %. The ash content of wheat straw pellets reached 6.33 % and negatively influenced the combustion efficiency (Ivanova et. al., 2015).

The investigation showed that the biomass of *Sida hermaphrodita* and *Silphium perfoliatum* had moderate gross calorific values between 18.7 MJ/kg and 18.3 MJ/kg respectively, but wheat straw - very low ones (17.0 MJ/kg), probably because of the high content of ash.

In Poland, the respective gross calorific values of the biomass of *Sida hermaphrodita* and *Silphium perfoliatum* were 18.8 MJ/kg and 18.7 MJ/kg (Stolarski et. al., 2014).

The potential of energy production of local varieties of *Sida hermaphrodita* and *Silphium perfoliatum* was around 350-380 GJ/ha.

Similar results were presented by other authors (Franzaring et al., 2014; Stolarski et. al., 2014).

The energy yield for *Sida hermaphrodita* as a solid fuel accounts for a net calorific value of 440 GJ ha-1 (Jablonowski et.al., 2016).

CONCLUSIONS

The studied perennial species differed 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 organic dry matter in silage varied from 458 l/kg in *Sida hermaphrodita* to 471 l/kg in *Silphium perfoliatum*.

The best results of methane production were achieved by the silage of cv. Energo, *Sida hermaphrodita*, 4000 m^3/ha and cv. Vital, *Silphium perfoliatum*, 3675 m^3/ha in comparison with maize silage 3127 m^3/ha and sunflower silage 2881 m^3/ha.

The dry biomass of the studied perennial species: *Sida hermaphrodita* and *Silphium perfoliatum* was distinguished by high bulk density, moderate gross calorific values (18.5-18.7 MJ/kg) and moderate ash content (1.5-3.0 %), but wheat straw *Triticum aestivum* – by low bulk density (163 kg/m^3) and calorific value (17.0 MJ/kg) and high content of ash (5.1 %).

The potential of energy production constituted 350-380 GJ/ha GJ/ha. The best results were achieved by cv. *Vital* of *Silphium perfoliatum*, due to its high productivity of dry biomass.

REFERENCES

Baserga U., 1998. Landwirtschaftliche Co-Vergärungs-Biogasanlagen – Biogas aus organischen Reststoffen und Energiegras. FAT-Berichte, 512: 1-11.

Boe A., Albrecht K., Johnson P. et. al., 2012.- Genetics, breeding, agronomy, and pest management of cup plant (*Silphium perfoliatum*), a potential new biomass crop for the north central USA http://ncsungrant.sdstate.org/upload/Boe-Sun-Grant-Ann-Mt-Indianapolis-2012.pdf

El Bassam N., 2010. Handbook of bioenergy crops: a complete reference to species, development and applications. Earthscan London; Washington, 516.

Franzaring J., Schmid I., Bäuerle L., Gensheimer G., Fangmeier A., 2014. Investigations on plant functional traits, epidermal structures and the ecophysiology of the novel bioenergy species *Sida hermaphrodita* Rusby and *Silphium perfoliatum* L. J Appl. Bot. Food. Qual., 87: 36-45.

Kalač P., 2011. The required characteristics of ensiled crops used as a feedstock for biogas production: a review. Journal of Agrobiology, 28(2): 85–96.

Klimiuk E., Pokoj T., Budzyński W., Dubis B., 2010. Theoretical and observed biogas production from plant biomass of different fire contents. Bioresour Technol, 101: 9527–9535.

Ivanova T., Kavalek M., Havrland B., Kolaríkova M., Skopec P., 2015. Comparison of technologic parameters of pellets and other solid fuels produced from various raw materials. Agronomy Research, 13(2): 303–310

Jablonowski N.D., Kollmann T., Nabel M., Damm T., Klose H., Müller M., Bläsing M., Seebold S., Krafft S., Kuperjans I., Dahmen M., Schurr U., 2016. Valorization of Sida (*Sida hermaphrodita*) biomass for multiple energy purposes. GCB Bioenergy. doi:10.1111/gcbb.12346

Mast B., Lemmer A., Oechsner H., Reinhardt-Hanisch A., Claupein W. Graeff-Hönninger S., 2014. Methane yield potential of novel perennial biogas crops influenced by harvest date. Industrial Crop and Products, 58, 194-203

Medvedev P.F., Smetannikova A.I., 1981. The forage crops of European part of the USSR. Ed. Kolos. Leningrad, 336. [in Russian].

Novoselov Y.K., Kharkov G.D., Shekhovtsova N.S., 1983. Methodical instructions for conducting field experiments with forage crops. Ed. VNNIK, Moscow, 198. [in Russian].

Niqueux M., 1981 Une nouvelle plante fourragère: le silfe (*Silphium perfoliatum* L.). Fourages. 87 :119-136

Oleszek M., Matyka M., Lalak J., Tys J., Paprota E., 2013. Characterization of *Sida hermaphrodita* as a feedstock for anaerobic digestion process. Journal of Food, Agriculture & Environment, 11, 1839–1841.

Petukhov E.A., Bessarabova R.F., Holeneva L.D., Antonova O.A., 1989. Zoo technical analysis of the feed. Edit. Agropromizdat, Moscow, 239[in Russian].

Pichard G., 2012. Management, production, and nutritional characteristics of cup-plant (*Silphium perfoliatum*) in temperate climates of southern. Chile. Cien. Inv. Agr. 39(1): 61-77

Puia I., Szabo A.T., 1985. Culture experimentale d'une nouvelle espece fourragere- Silphium perfoliatum- dans le Jardin agrobotanquie de Cluj-Napoca. Notulae Botanicae Horti Agrobotanici XV: 15-20.

Rakhmetov J., 2011. Energy malva or Virginia fanpetals (*Sida hermaphrodita* Rusby). J. Zerno 6: 36-39 [in Russian].

Šiaudinis G., Jasinskas A., Šlepetienė A. Karčauskienė D., 2012. The evaluation of biomass and energy productivity of common mugwort (*Artemisia vulgaris* L.) and cup plant (*Silphium perfoliatum* L.)

in Albeluvisol. Žemdirbystė (Agriculture) 99(4): 357–362.

Stolarski M.J., Krzyzaniak M., Snieg M., Slominska E., Piórkowski M., Filipkowski R., 2014. Thermophysical and chemical properties of perennial energy crops depending on harvest period. Int. Agrophys., 28, 201-211.

Tarkowski A., Truchliński J., 2011. Nutritional value of Virginia fanpetals (*Sida hermaphrodita* Rusby) protein in evaluation of nitrogen fertilization effect on environment. New Medicine, 15(1), 8-11

Thomas L.K., 1979. Distribution and ecology of Sida hermaphrodita. A rare plant species. Bartonia 46, 51-59.

Teleuţă A., Ţîţei V., 2016. Mobilization, acclimatization and use of fodder and energy crops. Journal of Botany. 2016, 1(12), 112-120.

Ţîţei V., 2015. Promising perennial plant species for bioenergy production in the Republic of Moldova. Journal of Botany, 2(11): 127-131.

SM 108:1995, 1996. Siloz din plante verzi. Condiţii tehnice. Moldovastandart. 10.