BIOGAS PRODUCTION FROM GREATER BURDOCK, LARGELEAF LUPIN AND SOSNOVSKY COW PARSNIP

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Abstract. There is a need to find acceptable crops for energy production for the climatic and soil conditions in Latvia. Greater burdock (*Arctium lappa* L) and largeleaf lupin (*Lupinus polyphyllus* L.) are growing in Latvia for years. Sosnovsky cow parsnip *(Heracleum sosnowskyi* MANDEN.) was introduced around 50 years ago as the fodder crop, but it was labelled as an invading plant spreading over 10 230 ha in Latvia in 2010. Green fresh plant biomass was investigated for biogas production in six 5 l digesters operated in batch mode at temperature 38 ºC. Average biogas yield 480 $l \cdot kg_{vos}^{-1}$, 520 $l \cdot kg_{vos}^{-1}$ or 296 $l \cdot kg_{vos}^{-1}$ was obtained from greater burdock, largeleaf lupin or sosnovsky cow parsnip biomass respectively. The estimated average energy potential per unit of area is 87 $GJ \cdot ha^{-1}$ or 82 $GJ \cdot ha^{-1}$ for greater burdock or largeleaf lupin biomass cultivated on not used agricultural land area respectively, and energy potential is 38 $GJ \cdot ha^{-1}$ for sosnovsky cow parsnip during its elimination period.

Keywords: anaerobic digestion, greater burdock, largeleaf lupin, sosnovsky cow parsnip.

Introduction

According to the EU directive the renewable energy share in gross energy consumption should increase from 32 % to 40 % in 2020 in Latvia. Biogas production from local plant biomass is an important type of alternative energy for Latvia, capable to produce electricity, heat or gaseous fuel for mobile machines. An economically feasible source of biomass feedstock can be perennial grasses covering around 800 000 ha or 45 % of agricultural land area. There were also 368500 ha of unused agricultural land or 15.7 % of all agricultural land area in Latvia in 2010, Table 1.

Table 1

Not used agricultural land area in regions of Latvia [1]

Planning region	Not used agricultural land, ha	Percent of agricultural land, %
Riga	63 680	20
Latgale	110 310	18
Kurzeme	68 050	15
Vidzeme	75 050	15
Zemgale	51 801	13
Sum (Latvia)	368 900	16

Most of unused agricultural land areas have soils with low fertility index, the soils are acidic and less suitable for feed or fodder production compares to the rest of agricultural land. Wild plants, like lupin (*Lupinus polyphyllus* L.), greater burdock (*Arctium lappa* L.) or sosnovsky cow parsnip *(Heracleum sosnowskyi* MANDEN.) have long roots capable to improve the soil structure and to transfer plant nutrients from sub-arable layers to the soil. Sosnovsky cow parsnip was introduced as a fodder plant in Latvia in the middle of the 20th century due to high green biomass yields up to 80-90 $t \cdot ha^{-1}$ during intensive fertilization [2] and spreading over 10 230 ha in Latvia in 2010 [3]. Sosnovsky cow parsnip is labelled as an invasive plant now and should to be removed from the ecosystem in Latvia. The possible removal technology includes frequent cutting and usage of Sosnovsky cow parsnip biomass for biogas production purposes during 4 - 6 years period until its complete extinction. Other energy plants should be cultivated in areas where sosnovsky cow parsnip was eliminated, so providing stable biomass supply for bioenergy production. Especially favourable for this purpose is perennial largleaf lupin (*Lupinus polyphyllus* Lindl.) cultivated for green manure and forage production in Belarus, Russia, and Finland, and also in Latvia. Largleaf lupin can be cultivated on low-fertile sandy and acid soils, unprofitable for cultivating other crops. Under such conditions lupin can be grown and harvested during up to 10 years period without reseeding, providing green mass yield of 30-50 $t \cdot ha^{-1}$ or dry matter yield 6-10 $t \cdot ha^{-1}$ in a year [4]. In other investigations the green mass weight of largleaf lupin was found on the average 60.2 t·ha^{-1} over three years for two cuts management [5]. Low alkaloid (sweet) forms of this species, for example, *cv. Pervenec* were obtained and used for fodder production [6]. Large leaved lupin (*Lupinus polyphyllus* Lindl.) is capable not only to sustain in drought conditions in sandy, acidic soils but also to provide soil enrichment by nitrogen up to 200 kg·ha^{-1} [6] or 250-300 kg·ha^{-1} [5] accumulated from air help by symbiosis of lupine with nodule bacteria. Greater burdock is considered as a weed plant in Latvia at the moment, but it is used as an edible vegetable in Japan, where its consumption is around 260 000 t in a year. Overground dry matter yield is investigated up to 14.5 t·ha^{-1} [7] under agro ecological conditions in Brazil. Great burdock is considered as a weed plant in Latvia. Great burdock originated in Europe and can be found in uncultivated areas such as roadsides, stream banks, waste places, abandoned farmsteads, and pastures. Great burdock grows in a wide range of soils from sandy clay to moist loam. In perspective great burdock can be raised for harvesting of edible roots, but its tops biomass can be utilised for bioenergy purposes at the same time. The aim of the investigation is evaluation of the biogas yield obtainable from largeleaf lupin, sosnovsky cow parsnip and great burdock for estimation of biogas energy obtainable from unit of area under the agro ecological conditions in Latvia.

Materials and methods

The green biomass samples were cut in 5-10 mm pieces, mixed with water and inoculums in proportions shown in Table 1. Fermented cow manure was added as the microbial inoculums in all substrates to provide the anaerobic fermentation process. The anaerobic fermentation process was provided in 6 digesters (two digesters for each type of biomass) operating in batch mode at temperature 38 ºC without mixing or recirculation of substrates. The digesters were equipped with sensors for automated registering of the temperature, pH value and gas volume data in computer. The substrates were analyzed for organic matter, total solids, organic solids and moisture content before filling in and after extracting out of the digesters. The accuracy of the measurements was ±0.02 for pH value, ±0.0025 l for gas volume and ±0.5 ºC for temperature. The total solids in substrate and organic matter in the total solids were measured by using of standardized methods. Anaerobic fermentation was provided within a 2 - 3 month period, until the biogas production ceases. The results of anaerobic fermentation of biomass for all digesters are shown in Table 1.

The energy output obtainable in the anaerobic digestion process from the energy crops area calculates as following:

$$E = m_F\ k_{DM}\ k_{OM}\ k_D\ V_{BN}\ LHV_{BN}\ , \tag{1}$$

where E – energy obtainable from unit of energy crop area, kJ·ha^{-1};
m_F – fresh biomass harvested per unit of area, kg·ha^{-1};
k_{DM} – fraction of dry matter in harvested fresh biomass;
k_{OM} – fraction of dry organic matter in dry matter of biomass;
$_D$ – biodegradation ratio of organic matter during anaerobic digestion process;
$_{BN}$ – volume of biogas (temperature T=0 ºC, pressure P=101.3 kPa, dry gas) obtainable in anaerobic digestion process from organic matter, Nm^3·kg^{-1};
HV_{BN} – lower heat value for 1 m^3 of biogas at normal conditions, kJ·Nm^{-3}.

The lower heat value for 1 m^3 of biogas at normal conditions roughly calculates according to equation:

$$LHV_{BN} = LHV_{MN}\ k_M\ , \tag{2}$$

where LHV_{MN} – lower heat value of 1 m^3 of methane at normal (temperature T=0 ºC, pressure P=101.3 kPa, dry gas) conditions, kJ·Nm^{-3} (LHV_{MN} = 36 000 kJ·Nm^{-3});
k_M – fraction of methane in biogas (k_M = 0÷1).

Results and discussion

While hydrolysis and acidification processes were ongoing, the pH value declines after the start period, and rises again after 5-6 days in substrates with largleaf lupin and greater burdock. In substrates with sosnovsky cow parsnip the pH value lowered below 5.2 just after the start period and remained unchanged during a six week period, until acid environment was interrupted manually by help of addition of a small amount of soda in these digesters, resulting in restoration of the anaerobic fermentation process. Anaerobic fermentation was successful and biogas release was registered from all digesters. The results of the anaerobic fermentation process of biomass are shown in Table 1.

Table 1

Average substrate and biogas parameters

Parameter	Unit	Greater burdock	Largeleaf lupin	Sosnovsky cow parsnip
Substrate composition	%	12 gb 12 in 76 w	12 ll 12 in 76 w	44 scp 11 in 45 w
Total substrate weight	kg	4.117±0.002	4.081±0.020	3.372±0.024
Substrate organic solids in total solids	%	86.9±0.9	89.7±1.2	70.2±0.8
Biogas yield	$l_c \cdot kg_{VOS}^{-1}$	480.4±11.0	520.0±2.0	295.1±28.1
Average methane content	%	57.4±1.1	61.9±0.5	76.4±1.2
Methane yield	$l \cdot kg_{VOS}^{-1}$	275.6±11.9	321.6±3.8	226.1±18.1
Conversion rate	%	78.0±1.6	77.2±0.6	56.4±1.5

Remarks: gb – greater burdock; ll – largeleaf lupin; scp – sosnovsky cow parsnip; w – water; in – inoculum (fermented cow's manure).

The average biogas yields from different substrates are shown in Fig. 1. High biogas yield 520 $l \cdot kg_{VOS}^{-}1$ was obtained from largeleaf lupin, that was by 36.6 $l \cdot kg_{VOS}^{-1}$ or 135 $l \cdot kg_{VOS}^{-1}$ higher compared to biogas released from greater burdock or sosnovsky cow parsnip respectively.

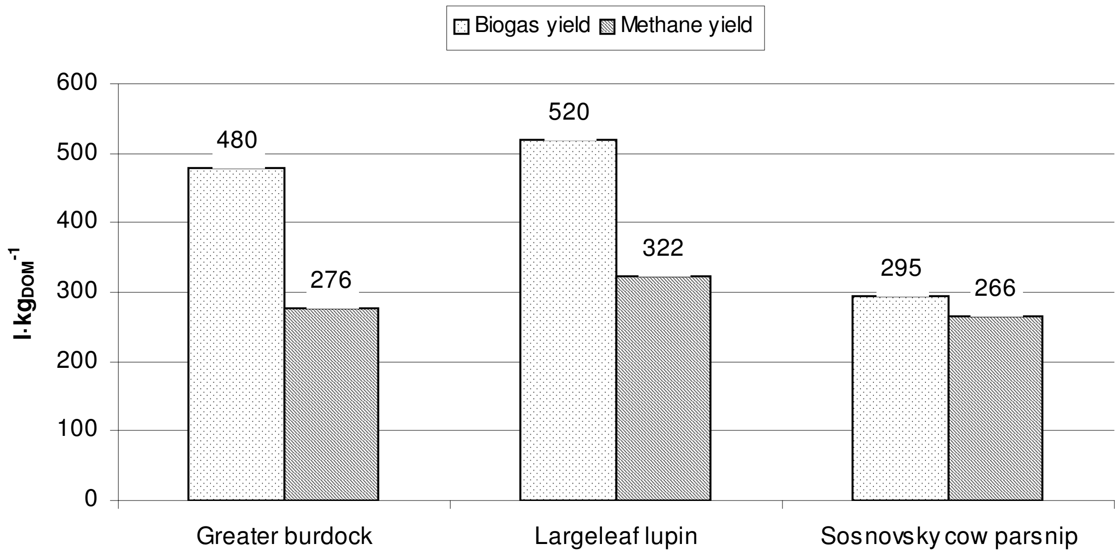

Fig. 1. **Average biogas and methane yields from investigated biomass**

The methane yield in amount of 322 $l \cdot kg_{VOS}^{-1}$ obtained from largeleaf lupin was by 14 % or by 30 % higher compared to that from greater burdock or sosnovsky cow parsnip respectively. The substrates with sosnovsky cow parsnip were processed at optimal pH range (5.5 ÷ 7.5) within a 45-day period, instead of a 60-day period of favourable fermentation of greater burdock and largeleaf lupin biomass, that results in lower biogas, methane yields and conversion rate of sosnovsky cow parsnip organic matter.

The methane content in biogas from all substrates was relatively high and biogas can be successfully utilized in cogeneration engines for electricity production.

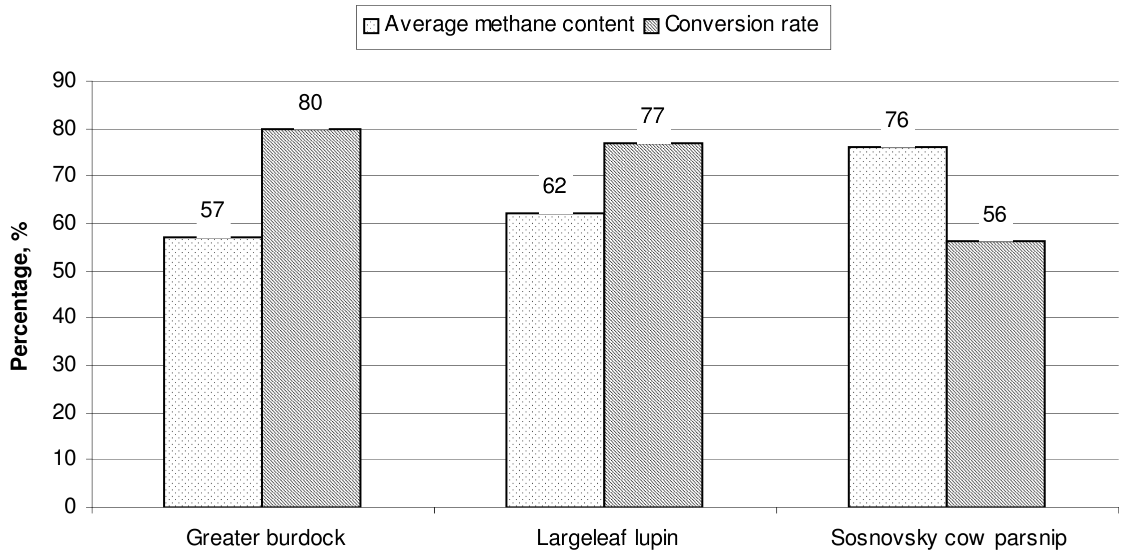

Fig. 2. **Average methane content and conversion rate of organic solids**

The average energy obtainable from 1 ha of energy plants area, was calculated according to equations (1, 2) using the experimental data on biogas output, methane fraction in biogas, organic solids degradation ratio. The average yields used in calculations were 12 $t\cdot ha^{-1}$, 10 $t\cdot ha^{-}1$ and 9 $t\cdot ha^{-1}$ for greater burdock, largeleaf lupin and sosnovsky cow parsnip respectively. Average organic solids content 92 % in dry plant biomass was accepted for calculations. The average energy per unit of area obtainable from different plant biomass is shown in Fig. 3.

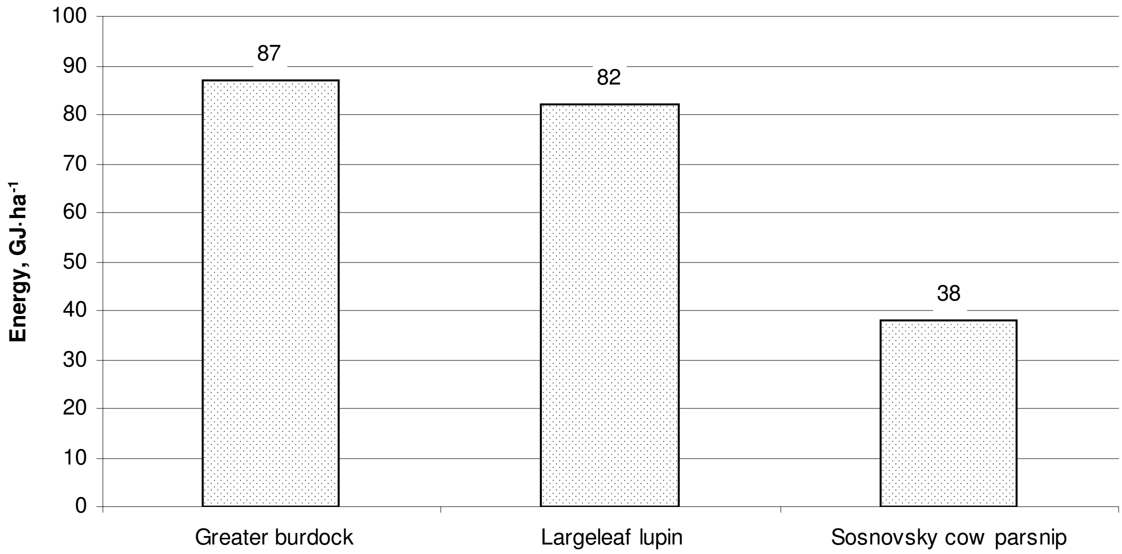

Fig. 3. **Average energy from plant biomass per unit of area**

The highest energy yield 87 $GJ\cdot ha^{-1}$ can be obtained from greater burdock. Greater burdock vegetates as a weed plant on scattered locations on not used agricultural land areas in Latvia; however, special cultivating of greater burdock for energy production involves deep soil tillage down to 0.9 m, resulting in increased energy consumption for this plant growing. Intensive cultivation of greater burdock can be economically justified, if the greater burdock roots can be marketed as a valuable raw material for production of medical or food additives, like this is practiced in Indochina countries widely. Sosnovsky cow parsnip should be harvested 2 ÷ 3 times or more times in a year, aiming to preserve ripening of the seeds and to perform complete elimination of this plant during 4 ÷ 5 years period. Therefore, from sosnovsky cow parsnip can be obtained low energy yield 38 $GJ\cdot ha^{-1}$ calculated as average from a 4-year elimination period, supposing, that the maximal yield is at the beginning, and the yield decreases to minimal at the end of the elimination period, when sosnovsky cow parsnip will be removed and replaced by another plant(s) completely. Great largeleaf lupin provides the average energy yield of 82 $GJ \cdot ha^{-1}$ and can be cultivated on most of not used agricultural land areas, including acid, sandy soils or on soils with low organic matter content, unsuitable for other legumes. Moreover, the soil organic matter content and soil nitrogen content increases during the lupine growing period, so lupine can be an excellent precursor for other energy crops, cereals or root crops.

Conclusions

1. Average biogas yield 480 $l \cdot kg_{vos}^{-1}$, 520 $l \cdot kg_{vos}^{-1}$ or 296 $l \cdot kg_{vos}^{-1}$ was obtained from greater burdock, largeleaf lupin or sosnovsky cow parsnip biomass respectively.
2. The investigated average methane content was 57.4 %, 61.9 % or 76.4 % in biogas from greater burdock, largeleaf lupin or sosnovsky cow parsnip respectively.
3. Sosnovsky cow parsnip harvesting 2 - 3 or more times in a year and biomass utilization for biogas production should be implemented as an environmental method for elimination of this invasive plant in Latvia.
4. Largeleaf lupin cultivation on not used agricultural areas can be an effective method for enrichment of soils with nitrogen and soil organic matter, providing feedstock for biogas production not competing with food or fodder production in Latvia.
5. The estimated average energy potential per unit of area is 87 $GJ \cdot ha^{-1}$ or 82 $GJ \cdot ha^{-1}$ for greater burdock or largeleaf lupin biomass cultivated on not used agricultural land area respectively, and the energy potential is 38 $GJ \cdot ha^{-1}$ for sosnovsky cow parsnip, calculated as average for a 4-year period of complete elimination of this invasive plant.

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