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Original Research

Evaluation of the Biomass of *Arundo donax* L. in the Context of Regional Bioenergetics

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Abstract

In Slovakia, maize silage is preferred as the input material for biogas production whereas it should be used primarily as feed for cattle. The purpose of this paper is to point out the possibilities of using the fast-growing giant reed *Arundo donax* L. that is not used as fodder and can be grown on low-quality agricultural land. The experimental stand of *A. donax* L. used in the study provided a yield of 60.8 t ha^{-1} of fresh biomass in the third year of cultivation. Part of the biomass produced was ensiled as maize and later the silage was co-fermented with cattle excrements and pig slurry. The resulting biogas can be used as fuel for internal combustion engines. The average content of CH_4 and CO_2 is 52% and 44%, respectively. These values are very similar to the composition of maize silage biogas. The average hydrogen sulphide content in the biogas from *A. donax* L. was 730 ppm. The disadvantage is that the biogas production is 46% lower compared to maize silage.

Keywords: biogas, *Arundo donax* L., bioenergy, anaerobic digestion

Introduction

There is a high demand for electricity consumption in the world due to the increasing human population and its wealth. Part of the energy consumption can be replaced by renewable energy sources. The problem, however, is that raw material resources used in renewable energy production are also used in the food industry. Agricultural land is a limited natural resource with increasing economic value. Bioenergy crops grown on agricultural land represent one of the alternative strategies to reduce the dependence on fossil fuels and greenhouse gas emissions due to their low carbon footprint [1-5].

Biomass is considered to be an important source of renewable energy, especially in the EU [6]. Despite the generally declared support, the overall development of bioenergy in Slovakia is slow and is gradually lagging behind the more developed European countries. The commitment to gradually increase the share of renewable energy sources is stated in the National Action Plan for Energy from Renewable Energy Sources, which was approved by the Government of the Slovak Republic on 6 October 2010 by Government Resolution no. 677/2010. It was assumed that the use of renewable energy sources would achieve 15.3% of the gross final energy consumption in 2020. Among

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other things, this strategic document describes the need to increase biogas and/or biomethane (biogas modified to natural gas quality) production as promising alternative fuels from both waste and intentionally grown biomass.

An agreement for a new Renewable Energy Directive for the next decade was reached at the EU level in 2018. The new rules include a legally binding EU-wide target of 32% for renewable energy by 2030 [7].

The intentionally grown biomass represents the establishment of stands of fast-growing plants that are primarily intended for energy use [8]. The cultivation of energy plants (non-woody) is not regulated by the Slovak legislation, the legislation applies only to the cultivation of energy trees [9].

The development in the cultivation of fast-growing plants is linked to the development of biogas stations. There has been an intensive development of the biogas stations in Slovakia since January 2010, when the Act 309/2009 Coll. on the support of renewable energy sources and high-efficiency cogeneration and the amendment of certain laws came into force. There are approximately 113 active biogas plants in Slovakia and maize silage is preferred as the input material for biogas production [10, 11].

The major components of biogas are methane (CH_4) with a content of 48-75% and carbon dioxide (CO_2), (30-50%). In addition, we can also identify minor biogas components such as water vapor (H_2O) (1-10%), nitrogen (N_2) (0-5%), oxygen (O_2) (0-2%), hydrogen (H_2) (0-1%), ammonia (NH_3) (0-1%) and hydrogen sulphide (H_2S) (0-1%). The content of these substances depends on the composition of the input material, the course of the process and all parameters affecting the process [12].

The giant reed (*Arundo donax* L.) is considered a promising energy crop. It has been grown in Asia, southern Europe, North Africa and the Middle East for thousands of years. However, its origin is still discussed [13]. It has been found to grow spontaneously in many different environments (temperate and hot areas) around the world. It is a tall perennial grass with massive growth [14, 15]. The cultivation of *A. donax* for energy purposes is of particular interest in the Mediterranean environment [16]. There is little information on growth indicators and biomass production of *A. donax* species in the Slovak conditions [17]. There is also a lack of information on the possibilities of the species to produce electricity and heat.

Therefore, the paper aims to evaluate the biomass production of *A. donax* cultivated in the conditions of southwestern Slovakia and its use for energy purposes.

Materials and Methods

Biological Material

The above-ground biomass of *A. donax* was harvested at the research site of Slovak University of Agriculture (SUA) in Nitra. The site is located in the cadastral area of Kolíňany approximately 13 km from Nitra (48°21'20"N, 18°12'23"E). The main soil type is gley fluvisol and the soils are moderately heavy [18].

The experimental plot of giant reed was established in 2016. Inorganic fertilizer was applied (100 kg h^{-1} N, 60 kg ha^{-1} K, 30 kg ha^{-1} P) prior to the establishment. Seedlings were obtained from the Arundo cellulóz farming kft. Hungaria. They were treated with mycorrhizal preparations AEGIS SYM containing *Rhizophagus intraradices* and *Funneliformis mosseae* and acclimatized in the greenhouse of the Botanical Garden at the SUA in Nitra. Seedlings were planted by hand 1.0 m × 1.0 m on a total area of 200 m^2. Giant reed can reach a height of 2 to 10 m. The underground organs are rhizomes forming a polycormon with several spreading mats that penetrate deep into the soil. It belongs to C_3 plants that have higher photosynthetic rates than to C_4 plants [19].

Biomass Production and Silage

The above-ground biomass production was studied during the growing periods of 2016, 2017 and 2018. The biomass was cut by hand at the end of the summer seasons and transported to the laboratory where the fresh yield was determined.

Afterwards, the biomass was chipped to approximately 10 mm and ensiled without access to oxygen for 3 weeks.

Fermentation Process and Technology

The silage was processed by anaerobic fermentation. To carry out comparative tests of the yield of various mixtures of input biomass, experimental fermenters were designed and manufactured by the researchers of the SUA in Nitra.

The structural arrangement of the fermenters allows the so-called batch tests for determining the yield of biogas production from various types of input mixed materials A higher number of such devices allows to shorten the necessary research time. Fermenters are constructed from double-wall stainless steel and have a net volume of 100 l. They are equipped with electric heating of water with the power of 2 kW. It ensures very good stability of the set temperature inside the fermenter controlled by a temperature sensor pt 100 and electronically regulated with TLE 20 regulator to a temperature of 40ºC±0.5ºC.

The mixing of the fermenter content is provided by a slow speed stirrer controlled by a digital timer (12 cycles per day lasting 20 minutes). The amount of the produced biogas is continuously measured and recorded with a gas meter Ritter TG05. The fermenter contains sampling points for collecting the substrate as well as analysing the composition of the biogas. Biogas is analyzed using a portable biogas analyzer Sewerin 540 that measures 4 components of biogas

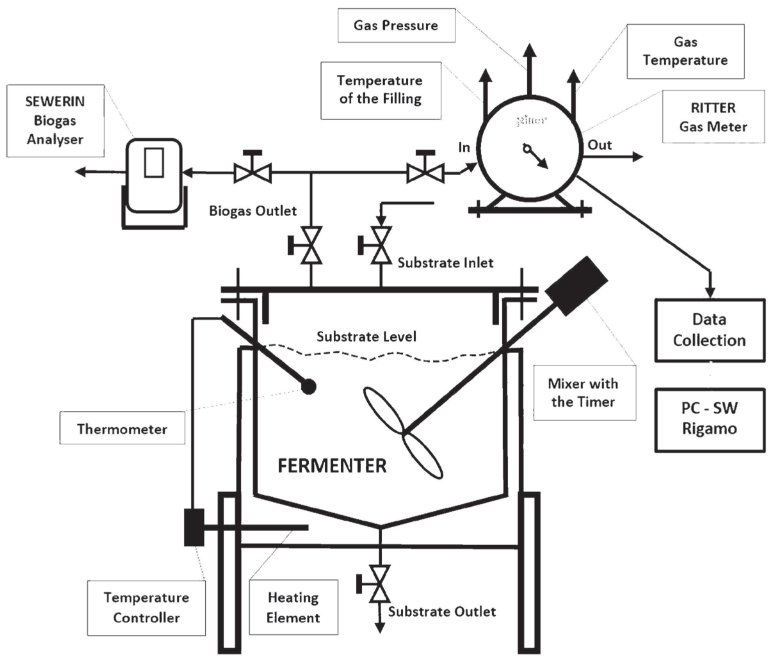

Fig. 1. Schematic representation of the technological process of the biogas production.

(CH_4, CO_2, O_2, H_2S). Altogether, 4 replicates were performed, each lasting 600 hours. Each replicate contained 97 litres of inoculum obtained from the biogas plant co-fermented with 3 kg of giant reed silage. A fermentate consisting of cattle manure and pig slurry was used as inoculum.

Fig. 1 shows a schematic representation of the technological process of biogas production.

Results and Discussion

Based on the results of the biomass production (Table 1), it can be stated that the cultivation of giant reed on the experimental field in Kolíňany proved to be promising. Our results correspond with the findings of other authors [20-24]. The biomass production of giant reed in Slovak conditions can vary from 40 to 70 t ha^{-1} which is significantly higher than other plant species grown for energy production [17].

[20] reported the biomass production of 12.1 t ha^{-1} of dry matter (DM) in the first year with the previous autumn establishment and 20 t ha^{-1} DM with the early spring establishment of a giant reed stand in Northern Italy. In a study conducted in Alabama (USA), giant reed achieved an average production of 35.5 t ha^{-1} DM

Table 1. Biomass production of giant reed at the experimental field in Kolíňany.

Year	2016	2017	2018
Total fresh biomass [t ha^{-1}]	2.3	24.4	60.8

[21]. Giant reed cultivated in San Piero and Grado (Pisa, Italy) reached production of 38 t ha^{-1} DM in the fifth growing season [22].

In a long-term field experiment in Central Italy, the average biomass production of giant reed was 37.7 t ha^{-1} year^{-1} DM over 11 years. The production could be characterized by maturity phase from the 3rd to 8th year of growth (with an average yield of 43.5 t ha^{-1} year^{-1} DM) and decreasing phase from the 9th to 12th year of growth (with an average yield of 25.5 t ha^{-1} year^{-1} DM). No fertilization and/or irrigation was provided [16]. It was reported that the biomass yield can be doubled under fertirrigated conditions [25].

The average yield of maize intended for silage is 31.2 t/ha over the last 10 years in Slovakia [26].

Based on full-scale ensilage trials, giant reed (although it does not contain starch) can be correctly ensiled and stored for a long period similarly to maize [27].

Data obtained on biogas production from the giant reed silage and maize silage compared to the inoculum are shown in Fig. 2.

The highest flow rate of the biogas was reached during the first 48 hours and the course of the biogas production was similar in all three types of mixture input. The peak flow rate of the biogas produced from the giant reed silage was 2.4 dm^3.h^{-1}. The maize silage produced a significantly higher amount of biogas compared to the giant reed silage and the inoculum. The flow rate of the maize silage biogas reached a peak of 4.4 dm^3.h^{-1}. After 48 hours, the production of biogas decreased and in the 264th hour, the biogas productions from giant reed and maize silage were almost the same. The results of cumulative biogas production show that

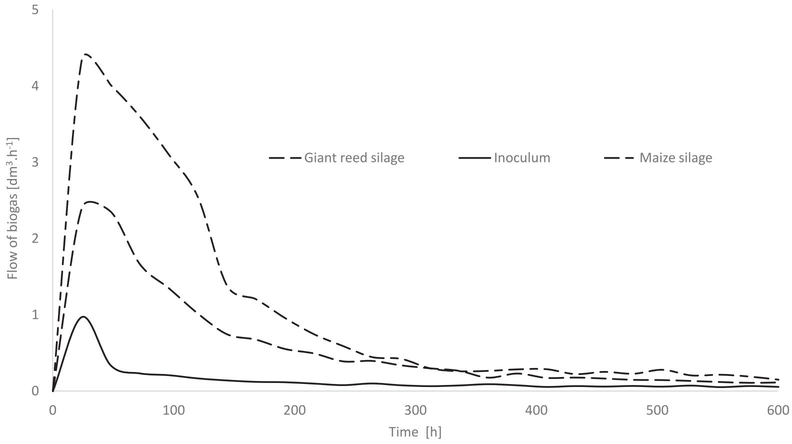

Fig. 2. Biogas flow production from individual types of input mixtures.

the maize silage produced an average of 641 dm^3 and giant reed silage 351.5 dm^3 of biogas in 600 hours. Therefore, the biogas production from the giant reed silage represented approximately 55% of the biogas production from the maize silage. However, taking into consideration the total biomass, *A. donax* has a similar production. This is in agreement with results obtained by [27] who also pointed out that low costs of giant reed production make it a valid alternative to traditional crops used for biogas production. Giant reed can be successfully grown on marginal soils and thus it does not compete with food production [28].

Fig. 3 shows the methane content of the biogas throughout the whole experiment. The average methane content of the biogas from giant reed, maize silage and inoculum was 52%, 53% and 48%, respectively. The highest average methane content was reached in the biogas produced from the maize silage after 48 hours of fermentation (59.1%). The biogas from giant reed silage reached the highest methane content after 72 hours (59.7%) and remained at a similar level for another 48 hours.

Carbon dioxide is the second major component in biogas and it is formed in the process of anaerobic fermentation. Increasing CO_2 concentration in biogas is related to the increased load and depletion of neutralization capacity. The CH_4 to CO_2 ratio is used as an indicator of the process stability [29]. The average CO_2 content in the biogas produced from the giant reed silage, maize silage and inoculum was 44%, 45% and 37%, respectively (Fig. 4.).

Fig. 5 shows the average hydrogen sulfide content of biogas. For the first 336 hours, the average H_2S content of the biogas produced from the giant reed silage was significantly higher than that from maize silage. After this time, the average H_2S content of the biogas produced from the giant reed silage was lower than that from maize silage. The total average hydrogen sulfide content in the biogas from the giant reed silage, maize silage and inoculum was 730 ppm, 430 ppm and 137 ppm, respectively. Hydrogen sulphide is an undesirable component in biogas causing corrosion of metal parts and degradation of engine oil due to the formation of acidic compounds. Therefore, it is necessary to remove H_2S from the biogas and/or to keep its content as low as possible. The most common methods of H_2S removal include adsorption on activated carbon and the addition of air to biogas [29, 30].

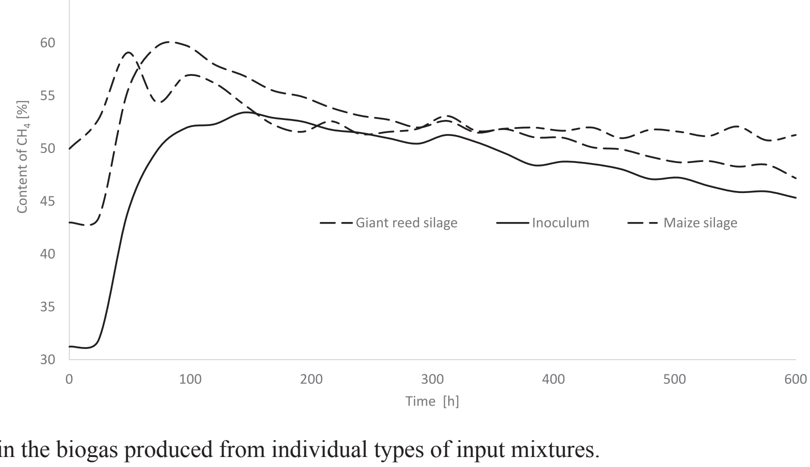

Fig. 3. Methane content in the biogas produced from individual types of input mixtures.

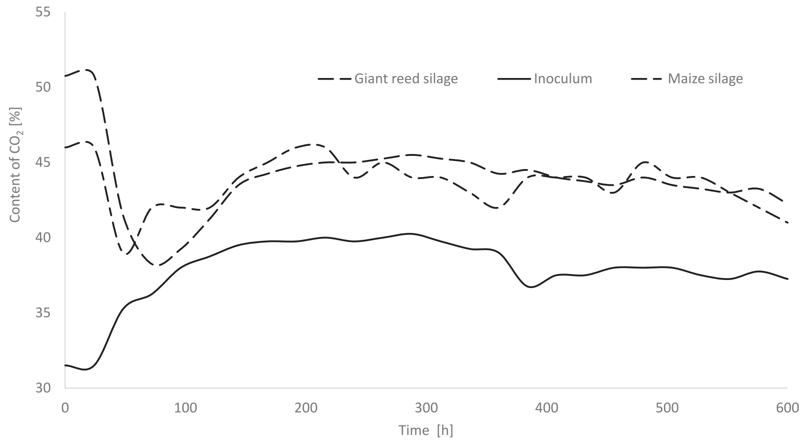

Fig. 4. Carbon dioxide content in the biogas of individual types of input mixtures.

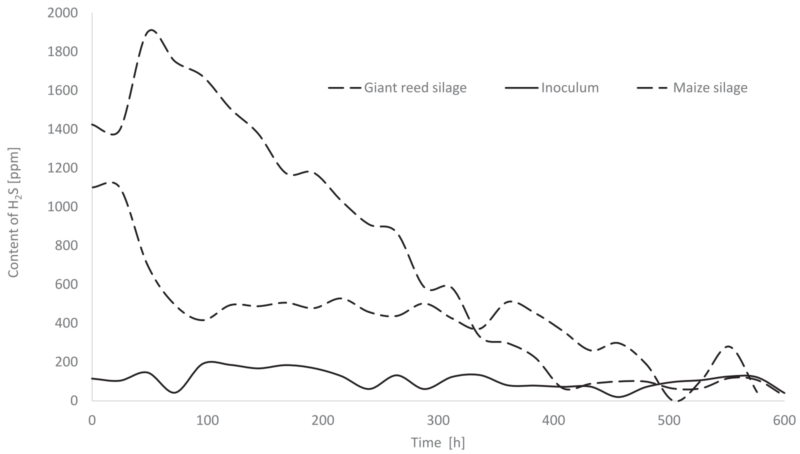

Fig. 5. Hydrogen sulphide content in the biogas of individual types of input mixtures.

Conclusions

Based on the biomass production results, it can be concluded that the cultivation of *Arundo donax* L. is perspective in the areas of southern Slovakia. The research was carried out from 2016 to 2018 under operating conditions, which is efficient from an economic and energy point of view. The biomass production was 60.8 t ha^{-1} of the fresh matter in the third growing season. The biomass production of giant reed is expected to increase in the following growing seasons, which would be advantageous in terms of energy and economic efficiency. The silage process of maize and giant reed was the same, which in practice means that it is possible to substitute the maize silage with giant reed silage without changing the technological process.

A disadvantage is that the amount of biogas produced from giant reed is approximately half that of maize silage. This means that when maize silage is replaced by *A. donax* silage a biogas plant with an electrical output of 1000 kW could be operated at an output of approximately 500 kW, which negatively impacts the economic performance of the facility. However, *A. donax* provides comparable yields to maize in the second growing season and the yield is already double compared to maize in the third growing season. Therefore the total biogas production is comparable.

Another advantage is that *A. donax* can be grown on lower-quality soil and its production does not affect the food industry.

The methane and carbon dioxide contents in the biogas produced from giant reed silage and maize silage are comparable. The operating parameters of cogeneration units are set based on the composition of the produced biogas. The average methane content in *A. donax* biogas is 52% and the methane content is similar to biogas from cattle manure, pig slurry, maize silage and grass silage. Therefore it is not necessary to intervene with the biogas plant technology and changing the operating parameters of the cogeneration unit would not be necessary.

The hydrogen sulfide content is higher than in the case of corn silage, but biogas plants have the technology to remove hydrogen sulfide from biogas. The hydrogen sulphide content of 730 ppm in the biogas from *A. donax* does not pose a risk in the operation of the biogas plant.

Acknowledgments

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Conflict of Interest

The authors declare no conflict of interest.

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