Journal of Environmental Management 228 (2018) 260–266

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

# Cup-plant potential for biogas production compared to reference maize in relation to the balance needs of nutrients and some microelements for their cultivation

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ARTICLE INFO

*Keywords:*
Cup-plant
Maize
Specific methane yield
Nutrient balance
Trace elements
Digestate fertilizing

ABSTRACT

The study was focused on the assessment of cup-plant (*Silphium perfoliatum* L.) as a potential feedstock for biogas production in comparison to reference maize related to the balance needs of nutrients and some microelements for their cultivation, especially with use of digestate for fertilization. Field experiments were carried out in areas of the Czech Republic with less favorable conditions for the cultivation of maize. Obtained results confirmed that cup-plant can be considered a promising novel crop for biogas production due to high yields of biomass (12–18 t/ha DM) and methane (3600–4250 $Nm^3$/ha) competing with reference maize grown under the same soil and climatic conditions. The biochemical analyses characterizing the feed value of phytomass were conclusively better with maize than cup-plant. This corresponds with specific methane yields, which is about 5–10% higher in maize (269–319 $Nm^3$/t VS) than in cup-plant (254–298 $Nm^3$/t VS). On the basis of chemical analyses of tested crops, the uptake of basic nutrients (N, P, K, Ca, Mg and S) and selected trace elements (microelements B, Fe, Mn, Co, Cu, Mo, Ni and Zn) was determined. Then, using the element contents and average yields, it was possible to calculate the annual removal of each element from the field with cup-plant and reference maize as the basis value for the evaluation of compensatory fertilization needs. With respect to the cultivation of tested crops for biogas production, the possibilities of their compensatory fertilization were evaluated using digestate from biogas plants. The uptake of different nutrients and microelements on tested crops was verified. The experiment showed that cup-plant has higher requirements on all tested nutrients, except N, and microelements, except Cu and Zn. In the case of nutrients, the highest uptake differences between cup-plant and maize were at B (about 11× higher), followed by Mg (3.5×) and K (1.8×). In the case of microelements, the highest uptake differences were B at (about 9× higher), followed by Co (5×), Fe, and Mn (2×). Therefore, increasing yields of cup-plant after using these nutrients and microelements for compensative fertilizing can be expected. For the mixture of maize and cup-plant (1:1 of VS weight), the higher specific methane yield was obtained (292 $Nm^3$/t VS). It was more than expected of the average value (286 $Nm^3$/t VS). It cannot be explained by the improvement in the feed value of cup-plant and maize mixture, but a possible explanation could be the positive synergistic effect of cup-plant due to the better supply with biologically active essential nutrients and microelements. In any case, this phenomenon deserves more detailed research in the future.

## 1. Introduction

In recent years, most countries in the European Union have intensified the cultivation of agricultural crops for agricultural biogas production, which is associated by the support of renewable energy sources use. For this purpose, the cultivation and utilization of maize has achieved the largest expansion, which covers about 3/4 of the European biomass production for biogas (Amon et al., 2007; Gansberger et al., 2015; Weiland, 2010). Maize is a high-production crop, but its cultivation requires the use of intensive agro-technology, which combined with its slow growth in the first half of the vegetation period, makes this crop very dangerous during erosion, especially on sloping soils. Therefore, finding new alternative crops which are able to compete with maize as biogas feedstock is very desirable. One such prospective, non-traditional energy crop could be cup-plant (*Silphium perfoliatum* L.).

The utilization of cup-plant as an energy crop is in the initial phase. It is native in the north-eastern part of North America as a wild plant

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https://doi.org/10.1016/j.jenvman.2018.09.015
Received 15 November 2017; Received in revised form 27 August 2018; Accepted 3 September 2018
0301-4797/ 

(Tassel et al., 2017). In Europe, it has been cultivated since the 18th century as an ornamental plant in gardens and parks (e.g. Gansberger et al., 2015). The research on this crop for agricultural purposes, mainly as a fodder crop, took place mainly in the former Soviet Union (Sokolov and Gritsak, 1972), from where it was extended to former satellite countries, e.g., Poland, the Czech Republic, the former German Democratic Republic, etc. Currently, the research of cup-plant cultivation is being carried out for energy purposes, especially in the eastern regions of Germany (Franzaring et al., 2015). Therefore, the principal information sources about agricultural cultivation and use of this non-traditional crop can be found in Slavic or German languages and very little information has been published in English or in high impact magazines.

Considering that it is in practice not a very widespread and non-traditional crop, its cultivation and utilization requires more detailed research. The crucial issue for the successful cup-plant cultivation is the verification of its claims on essential nutrients and microelements, which can be determined and evaluated by the macro- and micronutrient uptake in this crop and their extraction from the field together with the yields of above-ground phytomass. In terms of the purpose of plant growing for biogas production, there is the possibility to return and use digestate from biogas plants as a cheap source of organic fertilizer. The use of digestate provides the possibility of compensatory fertilization and requires a balanced evaluation of inputs and outputs of individual nutrients.

The aim of this study was the assessment of cup-plant as a potential feedstock for biogas production in comparison with maize as the reference crop for these purposes related to the balance needs of nutrients and some microelements for their cultivation, especially with the use of digestate for fertilization.

## 2. Materials and methods

As suitable objects for study of prospective biogas feedstocks, cup-plant as a non-traditional crop and maize as a reference crop were selected. Unlike maize, cup-plant forms perennial vegetation. The tested plant samples came from parcel field trials conducted at the authors' workplace in order to determine the yield parameters of each crop depending on fertilization methods. The trials contained three different variants of nitrogen fertilization (50, 100, and 150 kg N per 1 ha) and at single fertilization of P and K (50 kg/ha of $P_2O_5$ and $K_2O$). However, the monitoring of tested crop yields is not a part of this study because chemical analysis and biogasification testing used mixed samples prepared by mixing the same weight parts of phytomass (in ratio of dry weight) from all experimental variants. Earlier results of agronomic tests of cup-plant cultivation for agricultural purposes have been published in the Practice Methodology (Ustak, 2012).

The chemical analyses of the essential nutrients and trace elements content in plant samples and digestate were performed according to standard procedures published in the methodological manuals of the Central Institute for Supervising and Testing in Agriculture (CISTA) (Zbiral, 2005; Zbiral et al., 2011), which are based on the world (ISO) or European Committee for Standardization (CEN) procedures.

The total content of nitrogen ($N_{tot}$) in phytomass and digestate was determined by digestion with concentrated sulphuric acid at 300 °C (Kjeldahl, 1883), using selenium as a catalyst and salicylic acid to improve the recovery of nitrate in the modification of CISTA (Zbiral, 2005). The manual steam distillation-titration method of determining ammonium nitrogen involved the liberation of ammonia with the flow of steam from the alkaline solution into the boric acid indicator mixture solution. The quantity of ammonium was estimated by titration of this indicator mixture with acid.

The total content of dry matter (DM) in wet samples, which is the same parameter as total solids (TS), was determined gravimetrically after drying at 105 °C to constant weight. The content of organic dry matter in biological samples, which is the same parameter as volatile solids (VS), was determined gravimetrically after combustion at 550 °C to the constant weight of ash. The term DM is usually used to express crop yields and chemical analysis results of phytomass, whereas the terms TS and VS are usually used to characterize feedstocks for anaerobic digestion and to express specific yields of biogas or methane from these feedstocks.

The total content of macronutrients, namely P, K, Na, Ca, Mg, S, and content of trace elements, which are B, Fe, Mn, Co, Cu, Mo, Ni and Zn, were determined in the mineralization solution after sample decomposition using aqua regia in a closed high pressure microwave system (microwave oven Milestone MLS-1200 Mega from Milestone Inc., Italy) with analytical determination by inductively coupled plasma optical emission spectroscopy (ICP-OES) instrumentation (namely Integra XL, GBC Scientific Equipment, Australia) according to CISTA methods (Zbiral et al., 2011) and common operation procedures of the equipment.

Anaerobic digestion tests for biogas production from biomass were carried out based on the guidelines of VDI 4630 (Friedmann et al., 2004). Laboratory batch tests were performed in triplicate with use of the assembly of 48 pieces of 3-liter glass anaerobic fermenters containing approximately 2 L of fermentation medium. The biogasification tests were conducted at a temperature of 37 ± 1 °C and stirred for 15 min every 2 h. For each reactor, the volume of biogas displaced by acidic solution was measured in a graduated cylinder. The basic composition of biogas (methane and carbon dioxide contents) was measured with a biogas analyzer and calculated to specific yields of biogas and methane at a standard temperature and pressure (STP) condition, namely at the temperature of 0 °C with a pressure of 100 kPa or 1 Ba (so-called normalized volume of gas, e.g. $Nm^3$). Therefore, the suitable unit for the expression of biogas or methane specific production from organic dry matter or volatile solids of anaerobic digestion feedstocks is $Nm^3$/t VS.

The input of the VS ratio of tested crops to an inoculum was 3:10. The inoculum was adjusted digestate from the agricultural biogas station (Ekoenergie Vyskov, FABE, Ltd., Bitozeves), which processes maize and grass silages and animal excrements in a ratio of 10:2:1. The total solids of inoculum was 69.8 g TS per 1 kg of wet weight (ww). The VS:TS ratio of inoculum was 65.6%, which corresponds to the value 45.8 g VS/kg ww. The total period of biogas digestion was uniformly set at 49 days. This is a sufficient time, during which the intensive phase of biogas production ended in all tested substrates. In the course of the experiments, the intensive phase of the biogas development lasted from about two to four weeks after the end of the start-up period (the so-called lag-phase), which usually takes about one to five days.

## 3. Results and discussion

### 3.1. Cup-plant suitability for biogas production

Table 1 reports the results of green phytomass testing for cup-plant and maize, cultivated in field trials which were carried out in the areas of the Czech Republic with less favorable conditions for the cultivation of maize, situated in the northwestern part of the country.

These are average values of cup-plant and maize yields achieved in long-term experiments by authors at cultivation under the same agro-ecological conditions and conventional agro-techniques. Similar results were achieved in neighboring areas of Germany by Vetter (2010) and Vetter et al. (2010), where a five year trial study also showed comparable dry matter yields for cup-plant and maize. However, the yields of both crops can also be significantly higher (up to 20–25 t/ha DM), but in case of worse soil and climatic conditions and extensive agro-techniques, they can be significantly lower as well (8–10 t/ha DM and less). For instance, according to the statistical values of the Czech Ministry of Agriculture, the long-term average yield of maize cultivated for silage is 13 t/ha DM. This value very well corresponds with the yields from the parcel trials, which are usually about 10–20% higher