Industrial Crops and Products 58 (2014) 194–203

Contents lists available at ScienceDirect

Industrial Crops and Products

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

Methane yield potential of novel perennial biogas crops influenced by harvest date

Benjamin Mast[a,*], Andreas Lemmer[b], Hans Oechsner[b], Annett Reinhardt-Hanisch[b], Wilhelm Claupein[a], Simone Graeff-Hönninger[a]

[a] Institute of Crop Science, University of Hohenheim, Fruwirthstrasse 23, 70599 Stuttgart, Germany
[b] State Institute of Agricultural Engineering and Bioenergy, University of Hohenheim, Garbenstrasse 9, 70599 Stuttgart, Germany

ARTICLE INFO

Article history:
Received 10 December 2013
Received in revised form 3 April 2014
Accepted 12 April 2014

Keywords:
Biogas
Methane yield
Dry matter yield
Dry matter content
Perennial crops
Maize

ABSTRACT

In the past decade biogas production has experienced a strong increase in Germany, and along with that the demand for biogas substrate increased equally. In most cases, maize is used as feedstock for biogas production due to its high biomass and methane yields; however, by now, different alternative crops have been considered as potential feedstocks for biogas production. In the present study, four novel perennial crops – cup plant (*Silphium perfolatium*), energy dock (*Rumex schavnat*), giant knotweed (*Falopia sachalinensis* var. Igniscum) and Szarvasi (*Elymus elongatus* ssp. *ponticus* cv. Szarvasi-1) – were investigated in a field experiment located in Southwest Germany for their suitability as biogas crops. The study focused on the impact of different harvest dates on biogas potential expressed by the specific methane yield (SMY). Moreover, further parameters such as dry matter yield (DMY), dry matter content (DMC) and methane hectare yield (MHY) were determined. Each crop was harvested several times over a certain period; methane yields were determined by batch fermentation experiments. The results showed that harvest date influenced the tested crops and parameters in the most cases significantly. Szarvasi was found to provide the highest SMY, which decreased over the harvest period in summer (0.376–0.311 Nm^3 kg oDM^{-1}). In contrast SMY of energy dock (0.297–0.187 Nm^3 kg oDM^{-1}) and cup plant (0.274–0.232 Nm^3 kg oDM^{-1}) showed a lower biogas potential on a medium level. An overall low potential regarding SMY was found for Igniscum. In general, the results indicated an adequate biogas potential of all tested crops with exception of Igniscum.

1. Introduction

Since several years, the bioenergy sector occupies an important position within the field of renewable energies in Germany, and particularly the anaerobic fermentation of biomass (*e.g.* agricultural crops) into biogas (methane) experienced a significant expansion over the past decade. Since 2008, the number of biogas plants increased to a considerable extent and has almost doubled to approximately 7700 plants in 2013 (German Biogas Association, 2013). Consequently, along with this trend, the demand for agricultural crops as biogas substrate increased in a significant way resulting in the fact that 8% (962,000 ha) of the total agricultural land in Germany is currently used for the production of crops for biogas purposes (FNR, 2012a); whereas, almost 80% of the biogas substrate is comprised by maize (FNR, 2012b). Maize, used as silage maize, currently represents the most suitable crop for biogas purpose considering its biomass and methane yields (Vetter, 2010). Hence, a high concentration of maize cultivation occurs particularly in regions where a large number of biogas plants and moreover, traditionally intensive animal husbandry coexist (Herrmann, 2013; Vetter, 2009a). However, the increase of silage maize cultivation over the past decade is almost exclusively caused by the increase of biogas production over the same period. Furthermore, the implementation of a centralized biogas plant led to a significant increase of the area used for maize cultivation in the region concerned (Kruska and Emmerling, 2008; Möller et al., 2011). By now, this development is being considered critical, particularly due to the potential negative environmental impacts and arising phytosanitary issues caused by high maize densities. Various studies investigated the effect of high maize densities on different environmental parameters, whereas a higher risk for soil

Abbreviations: DMY, dry matter yield; DMC, dry matter content; SMY, specific methane yield; MHY, methane hectare yield; Nm^3, standard cubic meter; oDM, organic dry matter.

* Corresponding author. Tel.: +49 711 459 22380.
E-mail address: benjamin.mast@uni-hohenheim.de (B. Mast).

http://dx.doi.org/10.1016/j.indcrop.2014.04.017
0926-6690/

erosion and nitrate leaching, as well as negative long-term effects on soil organic matter, could be found as a consequence of high maize cultivation (Möller et al., 2011, Weidanz and Mosimann, 2008; Willms et al., 2010), since maize, as row crop, has generally shown a higher potential for soil erosion and nitrate leaching when compared to other crops (Fiener and Auerswald, 2007; Svoboda et al., 2013). Furthermore, a concentration of maize cultivation in biogas production regions may also cause a reduction of the (agro)biodiversity and an alteration of the characteristic landscape of such a region (Herrmann and Taube, 2006; Schöne, 2007; SRU, 2007). Apart from these ecological and environmental relevant impacts, a further limitation of high maize densities arises from the spread of maize-specific pests and diseases. In particular, *Diabrotica virgifera virgifera* has become increasingly important in Germany and has the potential to restrict the future biogas production when it is solely based on maize (Deuker et al., 2012; Schwabe et al., 2010). Considering these aspects, the enlargement of the feedstock base for biogas production to improve the suitability of the biogas production and to overcome the above-mentioned restrictions is one of the main challenges associated with the future biogas production in Germany. In this context, perennial crops may represent a promising alternative to the conventional biogas substrates, such as maize, when providing a similar suitability and performance regarding biomass and methane yield as well as ensiling and fermentation quality. Moreover, taking ecological and economical aspects into account perennial crops for biogas purpose may provide several essential benefits. Due to the year-round soil cover and the long lifespan, perennial crops provide a lower risk for soil erosion and nutrient leaching, and moreover, long-term positive effects on humus balance and carbon sequestration can be expected (Blanco-Canqui, 2010; Zegada-Lizarazu et al., 2010; Zhang et al., 2011). Thus, perennial crops may particularly serve, in the short-term, as a favorable option for erosion-prone and water protection areas, which were increasingly cultivated in response to an expanding biogas production. In addition, economic benefits may be associated with the cultivation of perennial crops due to the fact that soil tillage and sowing/planting is only required in the first year and the need for plant protection is usually low, which reduce the overall production costs and energy input for cultivation (Boehmel et al., 2008; Ust'ak and Ust'akova, 2004; Zegada-Lizarazu et al., 2010). Up to now, the utilization of perennial crops, except for grassland, as biogas substrate has been low in Germany; however, some new perennial crops from different parts of the world are being intensively discussed at the moment and might be able to serve as alternative biogas substrate. Some of these new perennial crops are cup plant (*Silphium perfolatium*), energy dock (*Rumex schavnat*), giant knotweed (*Falopia sachalinensis* var. Igniscum) and Szarvasi (*Elymus elongatus* ssp. *ponticus* cv. Szarvasi-1).

So far, among the four mentioned perennial crops cup plant (*S. perfolatium*) has been investigated most extensively as feedstock for biogas purpose, and relatedly, the information based on field experiments regarding cultivation and potential yields are relatively large in comparison with the other three crops. Cup plant and other *Silphium* species belong to the family of *Asteraceae*, which are natively located to the temperate regions of eastern North America (Stanford, 1990). In North and South America, some research activities focus the use of cup plant as alternative crop for animal feeding (Albrecht and Goldstein, 1997; Pichard, 2012). For the same purpose, cup plant was introduced to Russia and Europe in 1970 and 1980, however, cup plant did not gain any importance as a fodder crop in Germany. For several years, the yellow flowering cup plant is highly investigated as alternative biogas substrate in Germany, and the experiments conducted so far showed a DMY potential between 12 and 20 t ha^{-1} from the second year of cultivation (Strauß et al., 2013). The harvest of cup plant is determined by the optimal dry matter content for ensiling and is usually carried out once in late summer or fall; however, Pichard (2012) tested also a two-cut regime for cup plant as a fodder crop.

Energy dock (*R. schavnat*), also known as sorrel or Rumex, is a crossbreed of *Rumex patencia* and *Rumex tianschaicus* and originated in the Ukraine. In general, there is little information available on the cultivation of energy dock, but it is reported that energy dock provides an expected lifetime of 15–20 years. When used as biogas substrate, energy dock should be harvested twice a year (Strauß et al., 2013). A 10-year field experiment conducted in the Czech Republic revealed a DMY-potential of energy dock up to 16 t ha^{-1} depending on the used fertilizer level, however, only one cut per year was carried out in this investigation. A consistently high level of DMY can be achieved from the third year of cultivation (Ust'ak and Ust'akova, 2004).

The region of origin of giant knotweed (*Falopia sachalinesis*), the wild type of Igniscum (*F. sachalinesis* var. Igniscum), are the North Eastern part of Asia including Japan, Korea and the Russian island Sakhalin. The breeding Igniscum is bred with a less invasive potential compared to the wild type, whereas the cultivar Igniscum Candy is especially for biogas purpose and therefore used in the present study (Lebzien et al., 2012). Data regarding DMY or SMY of Igniscum are not available so far, but other knotweed species are known to achieve DMY of 25 t ha^{-1} (*Polygonum sachalinesis*) (Vetter, 2009b) and approximately 21 t ha^{-1} (*Reynoutria x bohemica*) (Strasil and Kara, 2010).

Tall wheat grass (*Elymus elongatus* ssp. *ponticus* cv. Szarvasi-1 or *Agropyron elongatum* cv. Szarvasi-1) is the only grass species among the four new perennial energy crops. Szarvasi represents a breeding of tall wheat grass for agronomic and energy purpose conducted in Hungary, whereas, native populations of tall wheat grass are located in the southern area of the Black Sea (Csete et al., 2011). Csete et al. (2011) reported DMY up to 15 t ha^{-1} with Szarvasi in Hungary, however, in Hungary, Szarvasi is more commonly used for solid fuels with a higher DMC as typically for biogas production. First results in Germany from a 3-year field experiment showed DMY between 17.6 and 19.3 t ha^{-1}, as well as most favorable SMY (Geißendörfer, 2012).

These novel perennial crops are increasingly involved into the discussion of alternative feedstock for biogas purpose, and hence, an enhancement of the research activities regarding these crops is required. Because an essential factor is, that for the majority of these crops hardly or no long-term cultivation experiences and data are available, which impedes the introduction of these crops into large-scale cultivation and the commercial use for biogas production. To close the gap of knowledge, which exists concerning the biogas potential, ensiling and fermentation quality, as well as cultivation and crop management (*e.g.* sowing/planting, fertilization and harvest), various investigations using these crops are required. The focus of the present study was to investigate the impact of harvest date on the biogas potential, primarily expressed by the specific methane yield (SMY), and further parameters such as dry matter yield (DMY), dry matter content (DMC) and methane hectare yield (MHY) drawing conclusions on the optimal harvest date of these crops under the pedoclimatic conditions of southern Germany

2. Material and methods

2.1. Experimental site

The field experiment including the four perennial crops and the reference crop maize was established at the experimental station of the University of Hohenheim, Ihinger Hof in spring 2011. The experimental station is located West of Stuttgart (48.75°N latitude, 8.92°E longitude); the average altitude of the experimental station is 490 m above sea level. Furthermore, the experimental site is