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Catch crops as an alternative biomass feedstock for biogas plants

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INTRODUCTION

The increase of manure biogas yield and the search of new cheap co-substrates, with high biogas yield, are nowadays major issues in order to obtain a more economically feasible process in biogas plants in Denmark. Energy from renewable sources is being promoted and by the end of 2020, 35% of Denmark's energy is expected to come from renewable sources (1). Catch crops are grown after harvesting the main crop to stabilize the soil particles avoiding nutrient leaching into the aquatic environment. Therefore, besides its primary function, the post-harvest biomass of catch crops is a potential source of renewable energy in the form of biogas, without interfering with the production of food and fodder crops. At the same time, finding new co-substrates is also necessary in Germany. The reform of the Germany's Renewable Energy Source (EEG) towards the compensation of the production costs of biogas production has led to an expansion of maize cultivation area during 2012. Although the high methane yield and the easy harvest, silage and storage of maize make this crop very suitable as co-substrate for biogas plants, some drawbacks have been reported lately (2). The over fertilization of the soil, and the consequent harmful environmental effects on water and biodiversity, together with the current increase in the price of maize makes it necessary to look for alternative biomass feedstock for biogas production. In this sense, catch crops could function as an alternative feedstock also for biogas plants in Germany.

The biogas potential of catch crops depends mainly on the plant species and the maturity of the plant and a range of 250-450 ml CH₄ /g volatile solids (VS) has been previously reported. (3,4). However, when using catch crops as substrate for anaerobic digestion the key parameter to consider is the net energy yield per hectare, m³ CH₄/ha, (5), which is dependent not only on the specific methane yield, but also on the biomass yield per hectare.

The aim of this study was to obtain the most suitable strategy to maximize the net energy yield per hectare of catch crop. For this purpose, the specific methane yields of fourteen catch crop species were studied and the main parameters affecting biomass yields were investigated to identify the most promising catch crops from both agricultural and energetic points of view.

MATERIALS AND METHODS

Sixty-six samples of fourteen different catch crops were grown during the years 2010 (19 samples) and 2011 (47 samples) in four different locations of Jutland, Denmark, namely Holstebro (Hb), Horsens (Hs), Aabenraa (Aa) and Haderslev (Hd). The methane potential was studied in triplicated batch vials (117 ml total volume) filled with 30 ml of anaerobic sludge and approximately 1 g VS of each sample. The vials were incubated at 37 ± 2°C until no more gas production was observed. The biomass yield (ton VS/ha) of each catch crop in each experimental plot was measured using an experimental forage harvester. Soil samples were characterized according to Sørensen and Bülow-Olsen (6). The rainfall and temperature data were obtained from The Ministry of Climate and Energy of Denmark (7).

RESULTS AND DISCUSSION

Methane yields were in a range of 239-474 ml CH₄/g VS_{added}. As can be observed in Table 1, most of the methane yields achieved for the studied plant species were comparable to what has been observed in previous studies of the same species. It was noted that the catch crops belonging to Brassicaceae and Graminaceae families presented the highest methane yields, exception made for *Sinapis alba*, whereas *Cannabis* sp., *Helianthus* sp., *Lupinus* sp. and *Phaseolus* sp. presented low methane yield, regardless the location.

High standard deviations among the years and the catch crops species were observed for biomass yields (Table 1). It has been reported that biomass yield depends, among other parameters, on the climate conditions, the soil type and the availability of nutrients in the soil. Biomass yields for ten different catch crops were studied in two different locations of Denmark. Those locations presented very different soil types, namely clayey and sandy soils, and the rainfall during the growing season was much higher in one of the locations. It was observed that soil type and climate variations played a major role on biomass yield since the differences were up to 6 times greater when comparing the same catch crop growing in both locations (17). With regard to nutrients addition, Larsen (18) obtained up to 2.6 and 2.3 times increased biomass yield, for Italian ryegrass (*Lolium perenne*) and oil seed radish (*Raphanus sativus* var. *Oleiformis*), respectively, when applying 100 kg nitrogen per hectare. More than 90% of this nitrogen was then recovered with the harvest of the crop. Moreover, the stump and roots of the crops blinded many nutrients until mineralization to be used in a subsequent crop, which would represent an advantage for an environmental use of fertilizers. Therefore, the application of nitrogen should be considered to increase the biomass yield.

The variety of factors affecting biomass yield determined that the net energy yields per hectare presented high standard deviations (48-1077 ml CH₄/ha). According to the previous calculations reported by Hvid (19) for Italian ryegrass (*Lolium perenne*), a biomass yield of 2 g VS/ha would be the threshold to obtain an economically feasible process. With an averaged methane yield of 350 ml CH₄/g VS, a minimum net energy yield of 700 m³ CH₄/ha would be necessary. As it can be seen in Table 1, *Raphanus sativus*, *Sinapis alba*, *Lolium perenne* and *Lupinus arboreus* obtained net energy yields above that threshold, which demonstrates that biogas production from catch crops could be an economically feasible process.

Table 1. Methane yields of crops as obtained in Catchcrop2biogas and reported in the literature.

Crop	Methane potential			References	Biomass yield		Energy yield per hectare	
	2010	2011	Previous studies		2010	2011	2010	2011
	ml CH ₄ /g VS _{added}	ml CH ₄ /g VS _{added}	ml CH ₄ /g VS _{added}		ton VS / ha	ton VS / ha	ml CH ₄ /ha	ml CH ₄ /ha
<i>Raphanus sativus</i>	356-378	368-474	274-297	8,12	1.29-1.40	0.18-2.05	459-529	66-948
<i>Brassica napus</i>	362-377	368-448	334-420	14,15,16	0.62-0.66	0.13-1.05	224-249	48-470
<i>Brassica rapa</i>	289	n.d.	240-314	8,11	1.56	n.d.	451	n.d.
<i>Brassica oleracea</i>	373	n.d.	310-320	11	0.86	n.d.	321	n.d.
<i>Sinapis alba</i>	251-298	239-369	300	16	0.87-2.24	0.30-2.92	218-668	72-1077
<i>Avena sativa</i>	383-407	n.d.	250-527	10,11,12	0.34-0.4	n.d.	130-162	n.d.
<i>Lolium</i> sp.	413	335-450	410-499	12,15	0.19	0.36-1.59	78	121-716
<i>Secale cereale</i>	407	n.d.	280-410	9,11	0.24	n.d.	98	n.d.
<i>Cannabis sativa</i>	263	n.d.	239-290	13	0.82	n.d.	216	n.d.
<i>Helianthus annuus</i>	269	n.d.	154-454	3	0.40	n.d.	108	n.d.
<i>Lupinus arboreus</i>	n.d.	229-327	310-360	11	n.d.	1.67-2.44	n.d.	382-798
<i>Phaseolus</i> sp.	n.d.	289-319	n.r.	n.r.	1.20-2.12	n.d.	347-676	n.d.

n.d. not determined; n.r. not reported

CONCLUSIONS

Based on the previous screening, oil seed radish (*Raphanus sativus* var. *Oleiformis*), oil seed rape (*Brassica napus* ssp. *Oleifera*) and Italian ryegrass (*Lolium perenne*), were identified as the most suitable catch crops for biogas production in Denmark.

From these results it can be concluded that the plant species is of major importance when considering a catch crop for biogas production. Through the screening of the methane potential together with the data on the biomass yield it was identified that the biomass yield rather than the specific methane yield is a crucial parameter for the net energy yield. In order to obtain an economically feasible process, some parameters have to be considered when selecting a catch crop for biogas production, namely the crop species, the soil characteristics, the weather conditions and the nitrogen application.

This study indicates that catch crops could function as sustainable supplementary biomass for biogas plants based on manure and thus enhance the overall biogas production. Preliminary calculations on the economy in using catch crops for biogas production revealed that the economy is very dependent on the biomass yield per hectare and of the costs for harvesting, transportation to the biogas plant and biomass storage. Further investigation is necessary in order to assess the optimal process parameters for continuous anaerobic digestion of catch crops as well as the technical performance of harvest, storage, transport and feeding of the catch crops to a real biogas plant.

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