Factors influencing the feasibility of using catch crops for biogas production

B. Molinuevo-Salces*, B.K. Ahring* and H. Uellendahl*

*Section for Sustainable Biotechnology, Aalborg University Copenhagen, A C Meyers Vænge 15, 2450 Copenhagen SV, Denmark. (E-mail: *bms@bio.aau.dk; hu@bio.aau.dk*).

Abstract
In order to secure an economically feasible operation of manure-based biogas plants in Denmark there is a need for supplying the plants with high yielding biomass feedstock. The aim of this study was to investigate the biomass yield and the methane potential of three different catch crop species in three different locations of Jutland, Denmark. Differences in climate and soil conditions between locations determined mainly the biomass yield. Methane potentials were in the range of 252-435 ml CH_4/ g VS depending on catch crops species. The use of catch crops for biogas production has large perspectives since it would combine renewable energy production with agricultural and environmental benefits.

Keywords
Catch crops, Biomass yield, Methane potential, soil type.

INTRODUCTION

Nowadays, the increase of the biogas yield of manure and the search for new cheap co-substrates, with a high biogas yield, are major issues in order to obtain a more economically feasible operation of biogas plants in Denmark, which are based on manure as main substrate. Catch crops are grown as supplementary crops after the harvest of primary crops with the primary purpose of binding nutrients in the soil. Since the implementation of the Nitrates Directive in Denmark (91/676/CEE), it is mandatory to grow them on farms bigger than 10 ha. Catch crops protect the aquatic environment and reduce the need of application of fertilizer in the following growing season. On the other hand, catch crops constitute a by-product of sustainable crop production that can potentially be used as a biomass source for bioenergy production without interfering with the production of food and fodder crops. Previous studies have investigated the biogas potential of different catch crops obtaining methane yields in the range of 250-450 ml CH_4 /g volatile solids (VS) (Amon et al., 2007; Raposo et al.; 2011). However, when using catch crops as substrate for anaerobic digestion the key parameter to consider is the net energy yield per hectare, m^3 CH_4/ha, (Seppäla et al., 2008), which is dependent not only on the specific methane yield, but also on the biomass yield per hectare.

Identifying the most suitable strategy to maximize catch crop biogas conversion together with a favourable regime of cultivation would improve the biogas plant’s economy while obtaining agricultural benefits such as pesticides and fertilizer reduction or aquatic environment protection. The objective of this study is to investigate the biomass yield and methane potential of three different catch crop species grown in three different locations of Denmark.

MATERIALS AND METHODS

Catch crop characteristics and agricultural practices

Three different catch crops, namely Italian ryegrass (IR) (*Lolium multiflorum*), Oil seed radish (OSR) (*Raphanus sativus)* and White mustard (WM) (*Sinapis alba*), were sown in three different locations of Jutland, Denmark. One of those locations, namely Holstebro (Hb), is sited in Middle Jutland whereas the other two, namely Haderslev (Hd) and Aabenraa (Aa), are located in South Jutland. Table 1 presents seed rates, sowing and harvesting times and soil type for the different catch crops in the different locations.

After harvest of the main crops, the fields were ploughed and tilled prior to sowing the catch crops. Plant cover (%) and plant height (cm) were evaluated just prior to the harvest of the catch crops. The biomass yield (ton fresh/ha) of each catch crop was and a representative biomass sample was taken from each plot for analysis of methane potential. All samples were frozen at -18ºC after harvest and until analysis of methane potential.

Methane potential

Batch vials (117 ml total volume) were filled with 30 ml of anaerobic sludge (AS) and approximately 1 g VS of each sample. The batch tests were performed in triplicates. Blanks containing 30 ml of AS were run in triplicate to determine the endogenous methane production of the AS. The vials were gas tight sealed with a rubber stopper and a metal cramp and flushed with a mixture of 80% N_2 and 20% CO_2 in order to ensure anaerobic conditions. The vials were then incubated at 37 ± 2°C. The anaerobic degradation process was monitored by measuring the methane production in the head space of each vial. Methane production was measured until no more gas production was observed. Total solids (TS) and VS of the AS were 2.92 ± 0.08% and 1.39 ± 0.09%, respectively.

Analyses

The rainfall and temperature data were obtained from The Ministry of Climate and Energy of Denmark (Cappelen, 2011). JB number classification is a Danish system to classify soils which is based on the analysis of soil texture. Biomass samples were analyzed for TS, VS (APHA, 2005). Biogas composition was analyzed using a Shimadzu gas chromatograph GC-8A, equipped with a Porapak Q 80/100 column (length: 6 ft., inner diameter: 3 mm) and a flame ionization detector. N_2 was used as carrier gas with a pressure of 2.0 kg/cm^2. The injector, detector and oven temperatures were 80°C. As standard gas, a mixture of 30% CH_4 and 70% N_2 was used.

Table 1. Seed rate, sowing and harvesting times and soil type for the different catch crops.

	Seed rate (kg/ha)	Sowing (Date)			Harvesting (Date)			Soil type (JB number*)		
		Hb	Hd	Aa	Hb	Hd	Aa	Hb	Hd	Aa
IR	15	09-05-2011	08-04-2011		24-10-2011	25-10-2011		5	5	
OSR 1	12	19-07-2011	18-07-2011		24-10-2011	25-10-2011		5	5	
OSR 2	14	09-08-2011		06-08-2011	07-11-2011		25-10-2011	4		1
WM	10	30-07-2011		28-07-2011	07-11-2011		25-10-2011	4		1

* JB number classification is a Danish system to classify soils based on soil texture.

RESULTS AND DISCUSSION

Climate conditions and agricultural parameters

The average rainfalls registered in Middle Jutland and South Jutland from July to November of 2011 were 88 mm and 100.2 mm, respectively. The average temperatures were 12.4°C and 12.5°C for Middle Jutland and South Jutland, respectively. While average temperature was in the same range for both locations, average rainfall was higher in South Jutland, registering a maximum in August with 180 mm. The different catch crops were sown between July and August of 2011 and harvested between October and November of 2011. It is worth to mention that an exception was made for the sowing time of Italian ryegrass; this crop was sown together with the main crop, between April and May of 2011, and the harvesting data presented here correspond to the second harvest (Table 1).

Two different plots were sown in Hb with JB numbers of 5 (sandy clay loam) and 4 (fine loamy sandy). The soils of Hd and Aa presented JB numbers of 5 and 1 (coarse sand), respectively (Table 1). It was reported that the risk of nitrate leaching is higher on coarse sandy soils with high humidity than in loamy soils (Askegaard et al., 2011). A more sandy soil implies an increase in risk of nutrient leaching and also a decrease in plant grip, thus the soil conditions for harvesting in Aa were not so suitable as those conditions registered in Hb and Hd.

Table 2. Agricultural parameters and methane potential for the different catch crops.

	Location	Biomass yield	Plant cover	Plant height	Methane potential	TS	VS
		(ton fresh/ha)	(%)	(cm)	(ml CH_4/g VS)	(%)	(% TS)
IR	Hb	1.7	80	14	339.04	24.0	89.6
IR	Hd	7.9	81	31	322.89	26.2	89.9
OSR 1	Hb	5.6	82	37	386.26	19.8	85.0
OSR 1	Hd	8.9	42	76	372.80	19.3	89.3
OSR 2	Hb	23.3	97	40	349.58	10.4	83.9
OSR 2	Aa	1.2	60	14	435.19	17.2	82.7
WM	Hb	14.4	88	108	238.95	22.3	90.5
WM	Aa	3.0	24	48	252.43	26.7	87.2

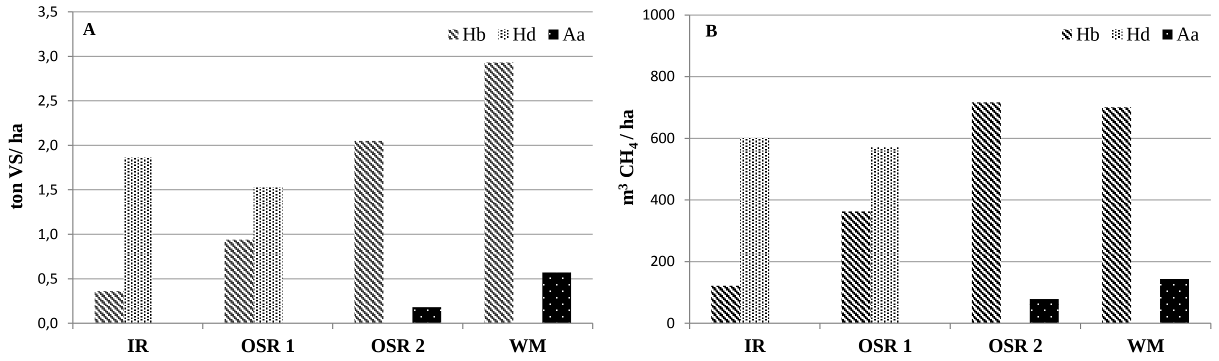
The biomass yield (ton fresh/ha) presented a wide variation among the different species and locations. When comparing results obtained for IR and OSR1, both catch crops grown in Hb and Hd, it was observed that both the biomass yield and plant height were greater in Hd than in Hb. On the contrary, biomass yield, plant cover and plant height were significantly greater in Hb compared to Aa, for OSR2 and WM (Table 2; Fig. 1A). The biomass yield of a catch crop depends on many parameters. These may include temperature, rainfall, time of sowing, time of harvest, type of soil and the availability of nutrients in the soil. Temperature, time of sowing and time of harvest were very similar in all the locations and may only have contributed little to the differences in biomass yield between locations. It was observed that the higher rainfall registered in South Jutland compared to Middle Jutland affected plant growth in a different way depending on soil type. In this manner, the high rainfall in a sandy clay loam soil (Hd) could have retained nutrients, which were efficiently used by the catch crops increasing biomass yields and plant heights. On the other hand, high rainfall coupled with a more sandy soil (Aa) may have increased nutrient leaching and hence diminishing nutrient availability for the plants (Askegaard et al., 2011). This combined with a generally lower fertility of sandy soils may have resulted in low biomass yields and low plant heights (Askegaard et al., 2011). Indeed, this fact could explain the high differences in biomass yield between locations for the different catch crops evaluated (Fig. 1A).

Methane potential

The highest methane yields were obtained for OSR (350-435 ml CH_4/g VS) while the lowest were obtained for WM (239-252 ml CH_4/g VS) (Table 2). High differences in methane potential were observed among the different catch crops species while the differences among locations were very low, exception made for OSR2. Although it has been widely reported that the stage of the plant is of major importance for methane yield since it determines biomass composition (Kaparaju et al., 2002; Gunaseelan et al., 2004; Amon et al., 2007), results obtained in the present study indicate that methane potential may be mainly related with the crop species. Further investigation on biochemical composition of the different crops and the different stages of the plant is necessary to clarify this point.

Fig. 1B shows net energy yields per hectare (m^3 CH_4/ha) for the catch crops evaluated in the different locations. The main parameter to consider when digesting catch crops is the net energy yield per hectare (m^3 CH_4/ha) (Seppäla et al., 2008; Lentomäki et al., 2008). In this case, net energy yields per hectare of catch crop were higher in Hd for IR and OSR1 while they were higher in Hb for OSR2 and WM, on account of their high biomass yields. The net energy yield threshold to obtain an economically feasible process was around 700 m^3 CH_4/ha (Hvid, 2012), only the net energy yields obtained for OSR2 and WM in Hb were in the range of that threshold with values of 716 and 700 m^3 CH_4/ha, respectively.

Figure 1. Biomass yield (A) and methane yield per hectare (B) in the different catch crops and locations.



CONCLUSIONS

Catch crops could function as sustainable supplementary biomass for biogas plants based on manure and thus enhance the overall biogas production. Differences in conditions and soil type determined the biomass yield and therefore the net energy yield per hectare. This study indicates that the combination of catch crops cultivation with biogas production looks promising and economically feasible if a previous study of the soils is carried out.

ACKNOWLEDGEMENTS

The authors would like to acknowledge financial support by Energinet.dk through the project Catchcrop2biogas.

REFERENCES

Amon T., Amon B., Kryvoruchko V., Machmuller, A., Hopfner-Sixt, K., Bodiroza, V., Hrbek, R., Friedel, J. et al. 2007. Methane production through anaerobic digestion of various energy crops grown in sustainable crop rotations. *Bioresource Technology* **98** (17), 3204–3212.

APHA 2005. Standard Methods for the Examination of Water and Wastewater. 21th ed. Washington. D.C.: American Public Health Association. American Water Works Association. and Water Environment Federation.

Askegaard, M., Olesen, J.E., Rasmussen, I.A., Kristensen, K. 2011. Nitrate leaching from organic arable crop rotations is mostly determined by autumn field management. *Agriculture, Ecosystems & Environment* **142** (3-4), 149–160.

Cappelen 2011. Danmarks klima 2011 med Tórshavn, Færøerne og Nuuk, Grønland. Danmarks Meteorologiske Institut. www.dmi.dk/dmi/tr12-01

Council Directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources.

Gunaseelan, N. 2004. Biochemical methane potential of fruits and vegetable solid waste feedstocks. *Biomass and Bioenergy* **26**. 389–399.

Kaparaju P., Luostarinen S., Kalmari E., Kalmari J., Rintala J. 2002. Co-digestion of energy crops and industrial confectionery by-products with cow manure: batch-scale and farm-scale evaluation. *Water Science and Technology* **45** (10) 275-280.

Hvid, S.K. 2012. Efterafgrøder til biogas er ikke rentable med aktuelle priser på biogas. *Planteavlsorientering* **092**. Videncenter for Landbrug (in Danish).

Lentomäki, A., Viinikainen, T.A., Rintala, J. 2008. Screening boreal energy crops residues for methane biofuel production. *Biomass and Bioenergy* **32**, 541–550.

Raposo, F., De la Rubia, M.A., Fernández-Cegrí, V., Borja, R. 2012. Anaerobic digestion of solid organic substrates in batch mode: An overview relating to methane yields and experimental procedures. *Renewable and Sustainable Energy Reviews* **16** (1), 861–877.

Seppäla M., Paavola T., Lehtomaki A., Pakarien, O., Rintala, J. 2008. Biogas from energy crops-optimal pre-treatments and storage, co-digestion and energy balance in boreal conditions. *Water Science and Technology* **58** (9), 1857–1863.