BIOGAS PRODUCTION FROM MEDITERRANEAN CROP SILAGES

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SUMMARY: Anaerobic digestion has proven to be an efficient way for the production of a renewable fuel. The aim of this work was to study the potential use of two crop silages, yellow lupine (*Lupinus luteus* L.) and oilseed radish (*Raphanus sativus* var. *oleifera* cv. Pegletta), for the production of biogas through the process of anaerobic digestion. The use of yellow lupine was due to its capacity for nitrogen fixation, reducing the fertilization needs for the succeeding crop cycle and reducing also the GHG emissions due to the fertilizer production and its field application. The utilization of the oilseed radish was due to its root exudates with nematicide effect, reducing the needs for soil disinfection, working as a biological weapon and also due to the effect on soil compaction of its large roots, working as a bio-driller. The yellow lupine gave rise to 400 m^3 of $CH_4.t^{-1}$ VS and the oilseed radish silage produced approximately 300 m^3 of $CH_4.t^{-1}$ VS, proving to be good anaerobic substrates. The inoculum used for the batch digesters was sludge from an anaerobic digester of a WWTP.

1 INTRODUCTION

The production of biogas reduces the need for fossil fuels importation and the gases released from its combustion will not contribute to the increase of greenhouse gas (GHG) atmospheric emissions. When biogas is produced in a farming system, from livestock manure and/or agricultural waste, it is regarded as an energy source that will reduce costs and at best make a profit from the sale of energy surplus. The cost reduction is possible using biogas to produce electricity and heat and also by its use as fuel in vehicles (Holm-Nielsen et al., 2009). The agricultural valorisation of the effluent coming from the digester (digestate) will reduce the need for fertilizers application, reducing the costs associated with the establishment of future crops (Lukehurst et al., 2010). On the other hand it can also be a way to make profits by selling the surplus biogas to the natural gas distribution network or by selling electricity to the national grid.

Performing cover crops between the main crops cycles, normally in the autumn/winter season, further reduces the risk of erosion caused by rain and wind, due to the protection that the presence of vegetative biomass offers (Prochnow et al., 2009), holding also the prevailing biodiversity. This cultivated land in situations of flooding will have better water absorption, reducing the effects that its accumulation causes, such as the release of CH_4 due to the anaerobic environment created in the submerged soil. Using plants like yellow lupine as cover crops has the advantage of enriching the soil with nitrogen (N), since these plants from the legume family

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have the ability to create symbiotic relations with nitrogen fixing bacteria, as *Rhizobium* species, which are able to fix the atmospheric nitrogen (N_2) into the soil. Yellow lupine can fix in one year between 150 to 169 kg of N_2 per hectare, although the amount of N_2 fixed by the consortium Legume – *Rhizobium* depends on the species associated and the environmental conditions (Lança, 1993). Other type of cover crops can work as biological weapons against some pests, as the case of certain species from the Cruciferae family like oilseed radish, which produce glucosinolates as secondary metabolites. The breakdown of these metabolites produces volatile compounds with toxic properties, affecting nematodes, diseases and weeds (Ngouajio and Mutch, 2004 & Weil et al., 2009), being its cultivation performed on European agriculture systems mainly to fight against the soil dissemination of nematodes from the *Heterodera schachtii* species, which attack the plant roots affecting the agricultural crops (Gardner and Caswell-Chen, 1994). This crop produces large roots which will promote the soil aeration and water infiltration by diminishing its compaction, working as a bio-driller (Ngouajio and Mutch, 2004 & Weil et al., 2009).

Ensiling can be used as a way to storage biomass in order to avoid losses in terms of quality but it also can be considered a biological pre-treatment, since it will promote the biodegradation of the complex vegetable structures, releasing intermediary products more easily used by the microorganisms during the anaerobic digestion process (Pakarinen et al., 2008). The silage quality depends on many factors, being the most important one the duration of the period on which the biomass is under ensiling conditions (Prochnow et al., 2009).

Both crops were selected due to their great utility as cover crops, conferring the above mentioned benefits to the soil nutritional, structural and sanitary conditions. Furthermore, their utilization as substrates for anaerobic digestion and biogas production will also contribute to the reduction of the GHG emissions, not only by the replacement of fossil fuels through biogas, but also by the savings they provide by reducing the need for fertilizers and soil disinfectants application. This approach to the production of biogas from cover crops silages does not interfere with the food supply chain and has positive environmental impacts.

The main objective of the present work was to assess the methane yield obtained in the anaerobic digestion of yellow lupine and oilseed radish silages under mesophilic conditions in batch experiments, using as inoculum digested sludge from a mesophilic anaerobic digester operating in one WWTP from Lisbon (Chelas).

2 MATERIAL AND METHODS

2.1 Substrates and inoculum

To assess the production yield of both crops studied, two spots of $4m^2$ per crop were harvested manually and all the resulting biomass was weighted, performing a total sampling area of $8m^2$ for each one of the crops. The harvesting was done after the flowering stage.

Both substrates were stored under silage conditions, inside black plastic bags to avoid the light penetration and were involved by a plastic film to keep the environment free of oxygen. The substrates were storage under those conditions inside a barn for approximately two months. Before the beginning of the batch assays the substrates were manually chopped with a stainless steel knife to dimensions between 1 and 2 cm, those typical produced by a regular silage machine. The inoculum was collected from one mesophilic digester operating in a WWTP. The characteristics of the silages and inoculum are presented on Table 1.

Table 1 – Substrates and inoculum characteristics. **TS**: Total Solids; **VS**: Volatile Solids; **VSS**: Volatile Suspended Solids; **TKN**: Total Kjeldahl Nitrogen.

Substrates	pH	TS (%)	VS (%)	VSS (%)	TKN (g/L)
Inoculum	7,56	2,2	1,6	1,7	1,05
Oilseed radish	7,64	14,7	12,8	n.a	30,02
Yellow lupine	5,17	18,7	14,7	n.a	22,61

n.a. – not analysed

2.2 Batch assays

The assays were performed in triplicate in 1L batch reactors placed inside a water basin with controlled temperature (35 ± 1°C). The reactors were mixed manually twice a day and the biogas produced was measured by liquid displacement in a column filled with a saline solution, to minimize the biogas dissolution. The reactors were filled with 480 mL of inoculum which will add 8,2 g/L VSS, value little superior to the one recommended by Field et al. (1988) for sludge used as inoculum. For the substrates were added 50g for both cases, which will add 6,4 g/L VS in the case of oilseed radish and 7,4 g/L VS for yellow lupine. The final volume was adjusted to 700 mL by adding distilled water and the solution pH was fit to values between 7 and 7,5 through the addition of NaOH 10M. Reactors only with inoculum and distilled water were used as controls, to assess the biogas produced by the inoculum, in order to discount that volume on the final volume of the crops under study. Anaerobic conditions were created by flushing nitrogen gas during 2/3 minutes before closing the reactors.

2.3 Analytical methods

Total, volatile and volatile suspended solids, pH and total kjeldahl nitrogen were measured as described in Standard Methods 20th edition (1998). Methane and carbon dioxide concentration in the biogas were measured with a Varian-3800 chromatograph fitted with a Porapack S column (3m x $^{1}/_{8}$ inches) and a thermal conductivity detector. Operating conditions were: oven 50ºC; detector 150ºC and injector 60ºC. The biogas was analyzed once a week, during the 7 week assay. The specific methane yield was measures as m^3 $CH_4.t^{-1}$ VS with methane from inoculum (control) subtracted.

3 RESULTS AND DISCUSSION

During the batch experiment period the biogas produced was recorded every day and Figure 1 shows the evolution of the daily biogas production during that period, showing that the adaptation phase (lag-phase) was almost inexistent, since on the 2nd day of the assay there was already biogas formed. The first 4/5 days were those on which more biogas was produced, and then the daily production started to decrease slowly. This short adaptation period is probably due to the good quality of the inoculum, even being from a WWTP digester, normally not used to digest lignocellulosic biomass and also due to the enhanced biodegradation of the substrate vegetable structures, promoted by the ensilage storing conditions.

The biogas cumulative production is represented on Figure 2 for both the crop silages and the inoculum. There is a substantial difference between the biogas productions among the two silages, with the yellow lupine (YL) having best biogas yield compared with the oilseed radish (OSR).

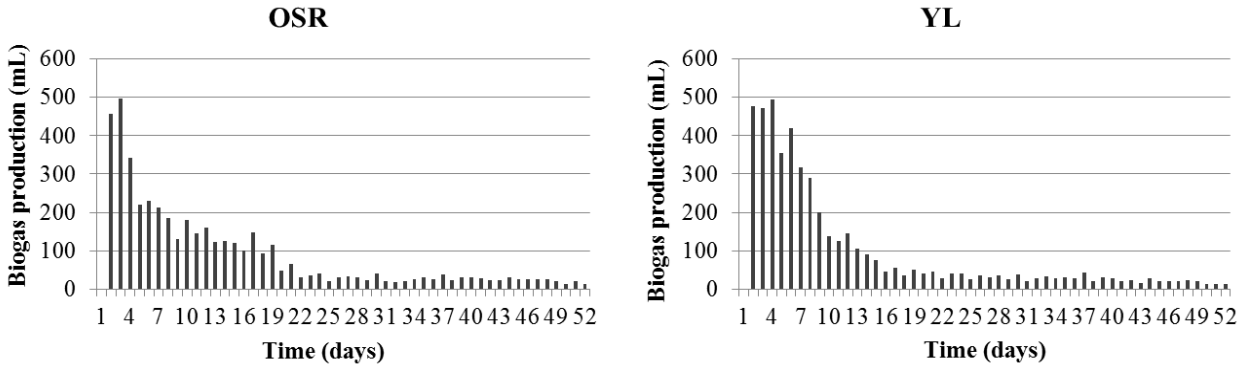

Figure 1 – Daily biogas production during the essay period. **OSR**: Oil seed radish; **YL**: Yellow Lupine

During the first 10 days both crops had more than 50% of the total biogas produced and after 25 days more than 80% of the total biogas was already produced in both cases.

The biogas production yield is not the only factor with influence on the final calculations of the methane potential yield of a given substrate, its qualitative composition is also an important aspect. The biogas quality varies according to the substrates used in the anaerobic digestion process (Rasi et al., 2007). Throughout the batch assays the methane content of the biogas produced by both crop silages evolved and stabilized after some days (data not shown). For the calculation of the methane potential yield (Table 2) the average values determined on the last week measurements were used, which resulted on 66 and 61% methane content on the biogas produced from YL and OSR, respectively. These are quite good results, since the value normally defined as fine for the methane concentration on biogas is about 65%, being superior in the case of YL and a bit lower on OSR situation.

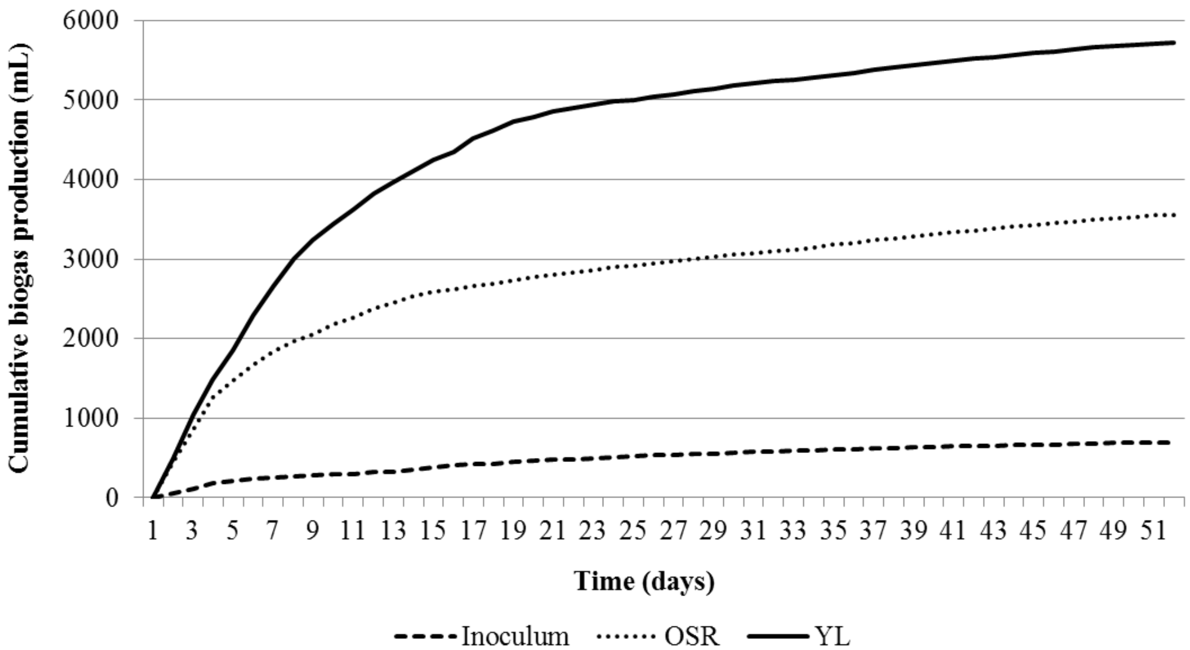

Figure 2 – Cumulative biogas production during the batch experiment period.

Table 2 – Potential biogas and methane (CH_4) yield for both crop silages (inoculum subtracted).

	OSR	**YL**
Biogas ($m^3.t^{-1}$ VS)	447	665
CH_4 ($m^3.t^{-1}$ VS)	294	409

YL had a better biogas production potential in the batch experiments and also with a better quality, since its methane content was 8% higher when compared with the OSR. Compared to results available from the literature and presented in Table 3, YL can be considered as one of the most favourable agricultural crops for anaerobic digestion application.

The production of these cover crops silages has some costs associated, connected to the land preparation, seeding, ensilage and transport. However, these crops are normally produced by farmers due to the benefits they provide to the soil, which will improve the following crop production. So, the costs inputted to the silage production can only be related to the ensiling process, transportation to the biogas plant and transport and spreading of the digestate again on the field, to avoid the loss of organic matter. The digestate can also be seen as a way to have some profits, by selling it, or part of it, to the neighbouring farmers.

Table 3 – Literature references for the potential methane production from different agricultural substrates. **1** – Braun et al., (2009); **2** – Kaparaju et al. (2002); **3** - Lehtomäki (2006).

Substrate	**m^3 CH_4 .t^{-1} VS**	**Ref.**	**Substrate**	**m^3 CH_4 .t^{-1} VS**	**Ref.**
Oats	250 – 260	2	**Lupine**	360	3
Ryegrass	390 – 410	1	**Alfafa**	340 – 500	1
Potato	276 – 400	1	"	320 – 410	3
Fodder beet	420 – 500	1	**Maize**	205 – 450	1
"	360 – 460	3	"	410	3
Sugar beet	236 – 381	1	**Turnip**	314	1
"	230	3	**Straw**	250 – 300	3
Sugar beet tops	360 – 380	3	**Grass**	298 – 467	1
Barley	353 – 658	1	"	270 – 410	3
"	360	3	**Sorghum**	295 – 372	1
Oilseed rape	240 – 340	1	"	410 – 420	3
"	340	3	**Clover**	345 – 350	1
Sudan Grass	213 – 303	1	"	140 – 210	2
Peas	390	1	**Wheat**	390	3
Sunflower	154 – 400	1	**Triticale**	337 – 555	1

4 CONCLUSIONS

Cover crops are used in agricultural systems in the period between the major crop cycles, not only to prevent soil erosion by wind and rain due to the prevailing biomass, but also to improve the soil properties, which depend on the plant species used. In general the cover crops are plough into the soil before the beginning of another major crop cycle, to maintain the organic matter content of the soil.

Using cover crops like YL with capacity to promote soil nitrogen (N) enrichment, as substrate for anaerobic digestion or co-digestion allows a considerable production of biogas, corresponding to about 400 m^3 of $CH_4.t^{-1}$ VS. On the other hand OSR, which alleviate soil compaction and have nematicide properties, allows the production of nearly 300 m^3 of $CH_4.t^{-1}$ VS. These results show that YL is more attractive in terms of biogas production. However OSR maintains a value on the range of the literature reported results for other types of crop biomasses (Table 3).

When the methane yield is compared in terms of m^3 of CH_4 per hectare the difference between both crop silages becomes higher, with 4468 $m^3CH_4.ha^{-1}$ and 1600 $m^3CH_4.ha^{-1}$ for YL and OSR, respectively. These calculations were done with the production yield values (t/ha) obtained in our field trials. However the production yield values can be different among regions, so the best way to report methane yields from crop digestion is by m^3 produced per tons of VS.

The difference between the achieved methane yields on both silages is probably due to the lower biodegradability of the OSR vegetable structure, making its digestion more difficult to the consortium of different microorganisms operating during anaerobic digestion, having as main consequence lower biogas production.

The main conclusion achieved in the end of the reported study is that cover crops as YL and OSR work well for the production of biogas, contributing for the reduction of GHG emissions, not only due to the replacement of fossil fuels consumptions by a renewable resource, but also by the savings they provide in GHG emissions due to the reduced needs for soil fertilization, tillage and disinfection, since all this operations are done with heavy machinery.

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