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Potential application of anaerobic digestion to tobacco plant

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HIGHLIGHTS

- Results of anaerobic digestion (AD) of the tobacco plant are presented.
- Energetic benefits of AD are quantified and compared with other energy crops.
- The amount of water recovered by biomethanation of the tobacco plant is quantified.
- AD is an appropriate process to treat tobacco plant.

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ABSTRACT

In this work, the energetic feasibility of using tobacco (not tobacco waste materials) as a raw material in the process of anaerobic digestion has been studied in terms of methane production, in order to demonstrate the potentiality of tobacco plant to be used as an energy crop.

Long-term experiments have been performed at the laboratory scale with and without a regulation of the substrate pH and within the mesophilic range (38 °C). Methane production and the parameters that control the anaerobic digestion process have been monitored periodically. The highest methane production, 53.84 Nm^3 methane/tonne of fresh tobacco, and a chemical oxygen demand reduction of 53.26% were achieved when the substrate with 15% tobacco (m/m) was treated with a hydraulic retention time of 16 days.

In addition, biomethanisation of this substrate can recover 57% of the water contained in the mixture, which can be used for irrigation of the tobacco crop.

It should be noted that pH regulation is essential to ensure the stability of the biological process, since all the experiments was carried out with the natural pH showed signs of inhibition.

These outputs of methane are on the same order as those obtained from other substrates, such as Sudan grass, fodder beet, and millet and place an industrial plant for tobacco biomethanation at the edge of economic profitability.

1. Introduction

Extremadura is a region, located in the south-west of Spain and border Portugal, where tobacco has been traditionally cultivated for decades, in fact, more than 93% of the dried tobacco of Spain is produced in Extremadura [1]. It has been a highly profitable crop because of the Common Agricultural Policy (CAP) (a European subsidy) has retained large expanses of fertile land unusable for the production of substrates or consumer products. Nevertheless, in recent years this subsidy to the tobacco cultivation has been reduced and it is scheduled to end in 2013, resulting in a drop in the prices paid by tobacco companies. Thus, only crops that improve quality and greatly reduce production costs will be viable, but profits will be notably less than farmers currently receive. Therefore, the area dedicate to the tobacco production will be reduced if other alternatives for tobacco cultivation are not found.

This work is focused on the analysis of the feasibility of a new application, the use of tobacco as a substrate to generate renewable energy through anaerobic digestion (AD).

One of the major obstacles to the use of tobacco as biofuel is that its cultivation is expensive and demanding when the leaves are produced for the tobacco industry. However, tobacco plants can be grown by a high-density planting method similar to fodder production. This method can reach outputs of 150 t fresh tobacco/ha with a moisture content of 80%. Its high productivity is due to that four or five cuts can be made during one growing season, which may extend to the end of October. Consequently, the

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potential of growing tobacco for biomass production and its used as fuel is based on its high productivity and on the fact that it is not a food crop.

Although tobacco plant and its wastes have been used as substrate for power generation by pyrolysis [2], gasification [3], combustion [4], and the tobacco seeds can produce biodiesel [5,6], their treatment by AD has hardly been studied. However the high moisture content of the freshly cut tobacco plants makes possible their energy transformation by this technology, in fact it has been applied to the treatment of several forage crops that can be compared with the tobacco plant [7]. Biogas production for some fodder is shown in Table 1.

With respect to the biomethanation of tobacco, we have not found any literature related to the AD of fresh tobacco, hence the importance of the results shown in this paper. Only one article referring to waste from the tobacco industry has been found [8], which showed methane production between 169 and 282 L/kg total solids fed, day, depending on the ambient temperature, with a hydraulic retention time (HRT) of 15 days. Furthermore, we are aware of two tests that a private company performed on the biomethanation of the tobacco plant; in both cases a TS content of 8% was tested. The results that were obtained for tobacco diluted 80% in water (the wet method) were 770 L biogas/kg organic matter, i.e., 50 Nm^3 biogas/t fresh tobacco (Kompogas, personal communication). For a 50% dilution (the dry method) the amount of biogas produced was lower because the TS content (8%) was far below the optimum content required in a biodigester that operates in the dry mode, which should be approximately 30%. In agreement with these previous experiments, the best option is to operate in wet mode, which allows to work with TS contents from 5 to 15%.

The main objective of this work is to analyse the environmental and energetic feasibility of an AD system at a laboratory scale that utilises the freshly cut tobacco plant as a substrate, which has been cultivated specifically for this purpose. Is the use of tobacco as a biofuel environmentally acceptable? Is the use of tobacco as a biofuel energetically feasible?

As mentioned, the idea is to take advantage of the excellent outputs per hectare of tobacco that are achieved in the north of Extremadura (Spain) and biodegradability of tobacco. Definitively, this study may offer an alternative to tobacco cultivation for human consumption while preventing the elimination of jobs in the region, improving living conditions in the area, attempting to allow the rural settler to remain in their environment.

2. Materials and methods

2.1. Anaerobic inoculum, substrate and experimental design

The substrate that is analysed in this work, tobacco plant, lacks suitable microorganisms to activate a biodigestion process, thus an acclimated inoculum is necessary. It was taken from an anaerobic reactor located at the Wastewater Treatment Plant (WTP) in Badajoz which treat the sludge from the primary and secondary treatments. 2 L of this sludge (usable volume of the reactor), without mixing with any other, were used to start up each experimental digester.

Table 1
Biogas production and percentage of methane obtained via the AD of various fodder substrates.

Substrate	Biogas production (L/kg)	Percentage of methane (%)
Corn silage	202	52
Grass silage	172	54
Rye silage	163	52
Sudan grass	128	55
Fodder beet	111	51
Millet	108	54
Turnip leaves	70	54

Initially, the freshly cut tobacco plant were forced to undergo a mechanical treatment to obtain a sufficiently small particle size [9], because the lower the particle size, the higher the efficiency of the process, given the fact that a decrease in particle size implies an increase of the surface on which bacteria might act. After this pre-treatment, crushed tobacco was mixed with tap water in order to increase the moisture content of the mixture. Four mixtures of fresh tobacco and water were tested: 5% fresh tobacco/95% water, 10% fresh tobacco/90% water, 15% fresh tobacco/85% water, and 20% fresh tobacco/80% water. The characterisation of these substrates is summarised in Table 2.

Despite the low pH of the substrates, the AD experiments were firstly performed without regulating the acidity of the mixtures. After that, the four mixtures were treated with pH 7 in order to determine the influence of pH in the AD process. To obtain pH values of approximately 7, a small quantity of $Ca(OH)_2$ was added to the substrate mixtures. This compound is very inexpensive, has a strong alkalinity, and is chemically inert, non-toxic, and easy to handle. The operational conditions for each experiment are shown in Table 3.

2.2. Experimental setup, start up and development of the anaerobic digestion process

Fig. 1 shows a schematic of the experimental setup used to perform the AD experiments in semicontinuous mode. This operation mode involves a daily extraction of a given volume of digested sludge from the reactor, immediately followed by the introduction of the same volume of new substrate, so that a constant volume of the reactor is guaranteed.

The setup basically consists of a 2 L glass flask with a rim attached to a central tube immersed in the reaction medium and with an input opening for the insertion of the substrate and the extraction of the digested sludge, and an output one for the collection of the biogas generated in the process.

The digestion unit was submerged in a water tank maintained at 38 °C by a thermostat. The substrate inside the reactor was homogenised using a magnetic stirrer. Experimental design guaranteed that the temperature was uniform throughout the reactor volume. The operating conditions should therefore be regarded as optimal. A 5 L tank attached to the biodigester was used to determine the volume of methane generated during the AD process. A squeeze bottle containing a sodium hydroxide solution (20% by weight) was placed between the digester and the gas tank, with the aim of retaining the carbon dioxide generated during the digestion process. The methane generated during the experiment displaced the water in the tank, which was collected in a measuring cylinder. Thus, the volume of the displaced water could be used to calculate the volume of methane generated daily in each experiment at ambient temperature (23 ± 1 °C) and atmospheric pressure (1017 ± 5 hPa).

The start up of the AD process begins with the introduction of 2 L of inoculum into the digesters after that, they are sealed so that the biodigestion process take place in the absence of oxygen and inoculum is subjected to gentle agitation to promote the contact with the microorganisms. The day after the load starts the feeding process, increasing volumes of substrate are daily added to the inoculum until reach the flow of substrate to be treated so that the bacteria could acclimate to the substrate.

Each flow was treated for a period of time that can ensure that reliable results were obtained, in terms of the level of degradation and the methane production. The optimum time for each assay was calculated based on the HRT which is the period of time that the