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Research paper

Optimizing storage of a catch crop before biogas production: Impact of ensiling and wilting under unsuitable weather conditions

Rúben Teixeira Franco, Pierre Buffière, Rémy Bayard*

Université de Lyon, INSA Lyon, DEEP Laboratory, EA7429, F-69621 Villeurbanne Cedex, France

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ABSTRACT

Ensiling and open-air storage of up to 98 days were assessed for a catch crop in order to identify the best management practices before its use as feedstock for anaerobic digestion. For ensiling, this included the study of the effect of wilting limited by unsuitable weather conditions. Results showed that after 98 days, methane potential of biomass open-air stored corresponded to 18% of the one for the ensiling of the same feedstock. Wilting was inefficient while witnessing unfavorable weather conditions at harvesting. Even if prolonged wilting periods under severe conditions led to decrease of moisture content, it did not provide improvements on long-term conservation of methane potential. For high moisture silage, instability of fermentation was offset by gains in biochemical accessibility. In such conditions, biomass should be promptly ensiled without wilting. Leachate produced during ensiling of high moisture crops should be collected and used for biogas production.

1. Introduction

Seasonality of crops and other agricultural wastes used for biogas production is at the origin of storage requirements before anaerobic digestion (AD). Since biogas production through AD should operate continuously throughout the year, seasonal biomass feedstock need to be preserved for prolonged periods, which may reach up to 6 months in some cases.

Among the current preservation methods, ensiling emerges as a logical choice to store wet biomass for energy production purposes. Based on biochemical processes, ensiling provides an anaerobic environment suitable for bacterial fermentation, which leads to biomass acidification, limiting further degradation and energy losses.

Together with the nature of the feedstock, air presence, storage duration or the use of additives, the control of the moisture content is one of the key parameters for the success of feedstock ensiling before AD [1]. Indeed, it is commonly shared that low moisture contents slow down bacterial growth, leading to a more restricted fermentation and better silage preservation [2–5]. Furthermore, silages with at least 25% of total solids content (TS) may prevent leachate formation during ensiling [6–8], avoiding potential energy losses due to seepage.

Field wilting (*i.e.* natural air-drying of crops after harvesting) prior to ensiling is the most common method to achieve higher TS contents for biomass crops when moisture content is excessively high. Besides being inexpensive, it may enable water evaporation with little effect on the remaining chemical characteristics if short wilting duration (around 6 h) is used [3,9,10]. However, wilting effectiveness is strongly dependent on weather conditions of the harvest site. In fact, natural environmental conditions such as solar radiation, vapor pressure, rainfall and eventually wind speed are correlated with the drying rate of biomass [2]. Consequently, when unfavorable weather conditions are present at harvesting, prolonged wilting durations must be used to obtain the desired TS content. In such cases, it is suggested that other chemical changes beyond water evaporation occur, which might influence ensiling conservation as well. For instance, Carpintero et al. [10] observed an impact of 48 h wilting on the water-soluble carbohydrates (WSC) and ammonia nitrogen (NH_3-N) content of ryegrass-clover. Likewise, Dawson et al. [11] studied field wilting durations of 28 and 52 h for perennial ryegrass and reported an impact of wilting on

Abbreviations: AA, acetic acid; AD, anaerobic digestion; ADF, acid detergent fiber; ADL, acid detergent lignin; BA, butyric acid; BMP, biochemical methane potential; CEL, cellulose; HEM, hemicellulose; LA, lactic acid; LAB, lactic acid bacteria; LIG, lignin; NDF, neutral detergent fiber; NH_3-N, ammonia nitrogen; TKN, total Kjeldahl nitrogen; TS, total solids; VS, volatile solids; WSC, water soluble carbohydrates; VFA, volatile fatty acids.

* Corresponding author.
E-mail addresses: ruben.teixeirafranco@insa-lyon.fr (R. Teixeira Franco), pierre.buffiere@insa-lyon.fr (P. Buffière), remy.bayard@insa-lyon.fr (R. Bayard).

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silage chemical characteristics, particularly on the pH and the buffering capacity. However, results on the impact of prolonged wilting durations on the conservation of the biochemical methane potential (BMP) during ensiling are still scarce and inconclusive. To our best knowledge, only Pakarinen et al. [12] have tested this parameter and observed better BMP conservation during ryegrass ensiling after 48 h drying, while an opposite effect was obtained for grass silage.

The objective of this study was thus to compare ensiling and open-air storage as methods for preservation of a catch crop before biogas production. For ensiling, the aim was to optimize the management practices of the feedstock when unfavorable weather conditions are present at harvesting. Both fermentative profiles and BMP were monitored at different stages of preservation, which enabled a detailed analysis of the phenomena involved during storage.

2. Material and methods

2.1. Feedstock

Raw material used was a sample of a catch crop harvested on 9 November 2015 from an agricultural site in the Rhône-Alpes region of France (Gaec Béreyziat, Les Teppes, 01340 Béréziat, France). Biomass was composed by a mixture of sunflower, sorghum, peas, *Vicia sp.* and *Trifolium alexandrinum*.

2.2. Wilting process

Storage preparation procedure is summarized in Fig. 1. After harvesting, part of the fresh biomass (10.1%TS) was ensiled and the remaining fraction was wilted. Non-suitable weather conditions were recorded during wilting: daily average temperatures ranged between 7.7 and 14.9 °C; extremely cloudy sky along with fog patches. After 72 h of wilting, the dried sample had 14.1% of TS content. At this point, part of the 72 h-wilted biomass was ensiled and the remaining amount was moved to an air-ventilated stove at 35 °C, in order to be able to test a larger range of moisture content in the ensiling assays. After a total of 96 h of wilting, the last fraction of biomass (38.7%TS) was removed from the stove, equilibrated to room temperature and then ensiled. Fresh and wilted biomass were chopped to theoretical particle size of 8 mm with a rotary shear shredder immediately before storage. This particle size was chosen taking into account the recommendations of Herrmann et al. [13,14] for a compromise between high methane conservation rates and low chopping costs. Biomass was manually mixed between each step of storage preparation and samples used for storage assays were taken in representative quantity of raw material, *i.e.* 10%.

2.3. Storage approach

Storage assays were conducted at laboratory scale to monitor the impact of ensiling and prolonged wilting on biomass conservation. To evaluate ensiling impact, an aerobic control storage test was also performed for the 96 h-wilted sample. All storage tests were performed in 3.5 L airtight round plastic storage drums modified to allow the gas to escape. In order to enable the output of gas produced and at the same time minimizing headspace, silos were filled up to 2.55 L with raw material at packing density of 0.7 kg/L, the remaining volume being filled with gravel, using a geotextile membrane to separate it from biomass. Silo sealing was different depending on the storage method tested. For ensiling assays, proper plastic lid and rubber ring were used and its airtightness was reinforced with silicone sealant. For aerobic storage purposes no cover was used and the silo was left air-open. Once sealed, the silos were weighed and placed in a temperate room at 25 ± 2 °C for a defined period. Storage duration varied between 7, 14, 28 and 98 days. A total of 16 (4 operating conditions x 4 storage durations) laboratory silos were used.

2.4. Chemical analysis

Chemical analysis procedure after sampling is illustrated in Fig. 2. For each tested duration, one silo (per tested condition) was opened and weighed, biomass was homogenized and two samples were taken. One was used for direct analyses on the crude material and the other one was mixed with water in order to get two fractions: a water-soluble phase and a particulate phase. This leaching test was performed with a 10:1 water/dry mater ratio during 2 h under constant bottle rotation. Phase separation was achieved by centrifugation followed by 0.7 μm particle size filtration. Finally, the particulate phase was dried at 70 °C until constant weight and ground at 2 mm theoretical length. Crude material/water-soluble and particulate samples were stored at 4 °C and −20 °C, respectively, until use.

Crude material was analyzed for its TS content, volatile solids

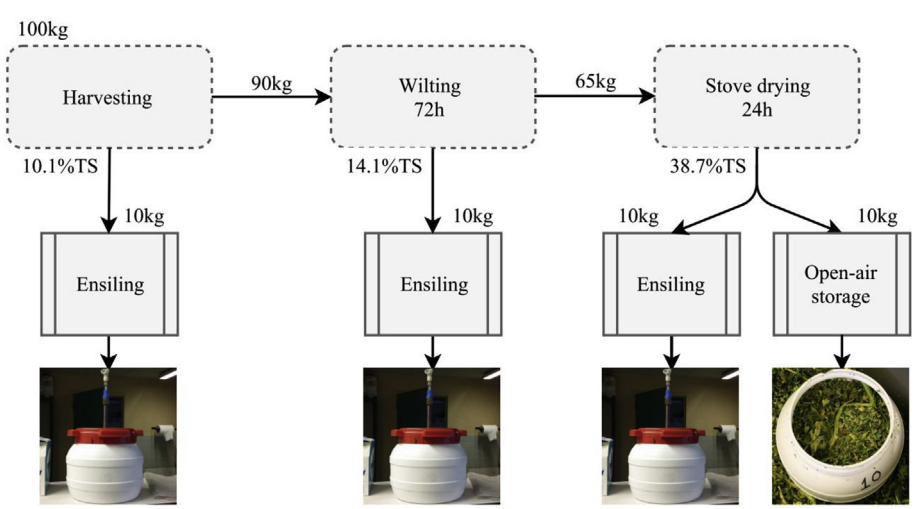

Fig. 1. Storage preparation procedure.