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Biogas production from catch crops: Increased yield by combined harvest of catch crops and straw and preservation by ensiling

Beatriz Molinuevo-Salces [a,*], *Søren U. Larsen* [c], *Birgitte K. Ahring* [a,b], *Hinrich Uellendahl* [a]

[a] *Section for Sustainable Biotechnology, Aalborg University Copenhagen, A C Meyers Vænge 15, 2450 Copenhagen, Denmark*

[b] *Center for Bioproducts and Bioenergy, Washington State University, 2710 Crimson Way, Richland, WA 99354, USA*

[c] *Agrotech — Institute for Agri Technology and Food Innovation, Agro Food Park 15, DK-8200 Aarhus N, Denmark*

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ABSTRACT

The combination of catch crop cultivation with its use for biogas production would increase renewable energy production in the form of methane, without interfering with the production of food and fodder crops. The low biomass yield of catch crops has been shown as the main limiting factor for using these crops as co-substrate in biogas plants, since the profit obtained from the sale of methane barely compensates the harvest costs. Therefore, a new agricultural strategy to harvest catch crops together with the residual straw of the main crop was investigated, in order to increase the biomass and the methane yield per hectare. Seven catch crops harvested together with stubble from the previous main crop were evaluated. The effects of stubble height, harvest time and ensiling as a storage method for the different catch crops/straw blends were studied. Biomass yields as TS ranged between 3.2 and 3.6 t ha^{-1} $y^{-1}$of which the catch crop constituted around 10% of the total biomass yield. Leaving the straw on the field until harvest of the catch crop in the autumn could benefit methane production from the straw both due to increased biomass yield and an increased organic matter bioavailability of the straw taking place on the field during the autumn months. Ensiling as a storage method could be feasible in terms of energy storage and guaranteeing the feedstock availability for the whole year. This new agricultural strategy may be a good alternative for economically feasible supply of catch crops and straw for biogas production.

1. Introduction

Catch crops are used in agriculture to reduce nutrient losses in soil and to improve the soil quality. They are grown after the main crop, retaining nutrients from the soil during autumn and winter and releasing them during the following growth season. In this way, they contribute to protect the aquatic environment since they reduce nutrient leaching and,

* *Corresponding author*. Tel.: +45 9940 3594; fax: +45 9940 2594.
E-mail address: bms@bio.aau.dk (B. Molinuevo-Salces).
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additionally, reduce the need for additional fertiliser in the following season. Based on this contribution of catch crops to the sustainability in crop production, the cultivation of catch crops on a proportion of the area on most farms has become mandatory in Denmark [1]. Furthermore, catch crops have recently become of major interest as a potential biomass resource for biogas plants in order to achieve the new target for Denmark of treating 40% of the total manure in biogas plants until 2020.

The feasibility of using different catch crop species as co-substrate for manure-based biogas plants in Denmark has recently been studied [2,3]. The methane yield that can be obtained per hectare of catch crop per year ($m^3\ ha^{-1}\ y^{-1}$), which is the product of the biomass yield as volatile solids (VS) per hectare of catch crop per year ($t\ ha^{-1}\ y^{-1}$) and the specific methane yield on VS of the catch crop ($m^3\ t^{-1}$), is the main parameter determining the economic viability of using catch crops as substrate for anaerobic digestion [4]. In general, catch crops provide most often biomass yields as TS below $1\ t\ ha^{-1}\ y^{-1}$. However, biomass yields as TS of more than $3\ t\ ha^{-1}\ y^{-1}$ were obtained in some cases [3]. The biomass yield of a specific catch crop depends on several parameters. These include time of establishment, time of harvest and fertilization, as well as soil and climate. An earlier establishment generally leads to higher biomass yields. A later harvest may lead to higher biomass yields; however, the biodegradability of more mature biomass can be reduced due to the lignification of the plant [2]. Fertilization may also improve biomass yields up to 77% but the effect of fertilization on biomass yield varies considerably depending on the soil type, the climate conditions and the ability of the crop to uptake nutrients [5]. All these parameters influence the development of the plant and thus the chemical composition of the biomass. These parameters determine the specific methane yield [6–8]. This specific methane yield on VS for catch crops is in the range 213–442 $m^3\ t^{-1}\ y^{-1}$ [3]. The volume of biogas that can be achieved per hectare of catch crop is rather determined by the biomass yield of catch crop per hectare than by the specific methane yield of the catch crop biomass [2]. Therefore, increasing the biomass yield would determine the economic feasibility of using catch crops for biogas production.

Since catch crops are seasonally produced, it is necessary to find a storage method that guarantees the availability of this feedstock for biogas production during the whole year. Silage as a storage method has been studied for different catch crops, indicating that the anaerobic digestion of the ensiled samples showed a more rapid degradation in the beginning of the digestion, which could represent an economical advantage for biogas plants since lower hydraulic retention times would be needed when feeding ensiled samples to the reactors [9].

The objective of the present study was to assess a new agricultural strategy with the aim of increasing the biomass yield of catch crops. In this manner, the catch crops were harvested together with straw left as a high stubble from the main crop, spring wheat. The biomass yield and specific methane yield resulting from the harvest of seven catch crops or catch crop mixtures together with the stubble were evaluated (Trial 1). The effect of the stubble height on biomass yield and specific methane yield were also studied for one catch crop species (Trial 2). Moreover, the effect of harvest time on chemical composition, biomass yield and specific methane yield of the stubble of spring wheat was assessed (Trial 2). Finally, the effect of ensiling as a storage method for different biomasses was studied.

2. Material and methods

2.1. *Agricultural practices and sampling*

2.1.1. *Trial 1 — catch crop species and species mixtures*

Trial 1 was carried out to study biomass yield and specific methane yield from the harvest of different catch crops together with stubble from the previous main crop. Trial 1 was located in a field with spring wheat (*Triticum* sp. cv. Amaretto) (geo-coordinates East, 56° 69′ 71″North, 62° 46′ 41.5″). The following catch crops or catch crop mixtures were cultivated (Table 1): Perennial ryegrass and white clover (*Lolium perenne* and *Trifolium repens*; T1), tall fescue (*Festuca arundinacea*; T2), red clover (*Trifolium pratense*; T3), oil seed radish (*Raphanus sativus* var. *oleiformis*; T4), oil seed radish with nitrogen fertilization (T5), oil seed radish and common vetch (*Vicia sativa*; T6) and oil seed radish and red clover (T7). The trial was designed as a randomized block design with four replicate blocks and a plot size of 13.5 m^2. Spring wheat was sown on April 10th 2013, using a seed rate of 240 $kg\ ha^{-1}$, and the catch crops were sown on April 10th 2013 (T1–T3) and July 5th 2013 (T4–T7).

The spring wheat crop was fertilized with 54 $kg\ ha^{-1}\ y^{-1}$ of nitrogen supplied as fertilizer and 70 $kg\ ha^{-1}\ y^{-1}$ of plant available nitrogen supplied as slurry from anaerobic digestion. In the area with trial 1, weeds were controlled by spraying with the herbicide Fighter® (480 $g\ L^{-1}$ bentazone). Diseases and insects were controlled chemically, using a conventional control strategy with application of fungicides and insecticides when required. The whole field was sprayed with growth regulator (0.2 $L\ ha^{-1}\ y^{-1}$ of Moddus®, 250 $g\ L^{-1}$ of trinexapac-ethyl) to reduce the straw length of the spring wheat in order to avoid lodging. The precipitation in the area was within the normal range, and no irrigation was applied.

The spring wheat was harvested on August 29th 2013 by an experimental cereal harvest machine, adjusted to a stubble height of approx. 45 cm above soil level. The crop height of the spring wheat was approx. 80 cm, and the 'upper fraction' of the straw which was harvested was left on top of the stubble. On September 6th 2013, 50 $kg\ ha^{-1}$ of nitrogen was applied to the catch crop in treatment T5. The catch crops were harvested together with stubble from the previous main crop on October 31st 2013, using an experimental forage harvest machine which harvested the whole area of each plot. The cutting height of the forage harvester was approx. 8 cm. A representative biomass sample was taken from each plot for analysis of specific methane yield. All samples of approx. 1 kg were frozen at −18 °C after harvest until methane yield determination. Biomass yields as TS and VS were calculated as $t\ ha^{-1}\ y^{-1}$.

2.1.2. *Trial 2 — stubble height and harvest time*

Trial 2 comprised the evaluation of stubble height on biomass yield and specific methane yield as well as the effect of harvest