Biorefining of proteins from grass clover as an innovative solution to a truly sustainable organic production

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Key words: Leaf protein concentrate, biorefinery, yield, carbon sequestration, economy.

Abstract

To shape a common solution to challenges with low crop yields, proper protein supply and insufficient climate mitigation capacity, biorefining of protein feed from grassland crops for monogastric animals (including human) is introduced to the organic production system. Bio-refining using mechanical and natural fermentation techniques are compatible with the organic principles and standards. Crop yields from Danish field trials with alfalfa, clover and grass-clover mixtures demonstrate average yields around 12 tons dry matter per hectare yielding on average 700 kg extracted protein per hectare and 3000 to 6000 m^3 methane per hectare. With these yields the profitability of biorefining of organic protein feed is calculated and shows a positive economic result, especially when used as wet-feed saving the cost for drying. But it should be noticed that economy is sensitive to changes in yields and prices.

Acknowledgments

The results in this article are made possible by the project "OrganoFinery – Organic growth with biorefined organic protein feed, fertilizer and energy" funded by the Green Development and Demonstration Programme, GUDP under the Ministry of Environment and Food of Denmark and coordinated by the International Centre for Research in Organic Food Systems (J.no. 34009-13-0691).

Introduction

Organic farming is challenged by low yields and difficulties to produce enough protein for monogastric animals. This causes limitations in growth of the organic production.

In organic systems, grassland legumes can produce high yields in dry matter and protein and deliver nitrogen to the succeeding crops. But only ruminants can utilize these crops sufficiently and to fulfil the goal of less greenhouse gas emissions, the population of ruminants should not increase.

Modern biorefining techniques compatible with organic production standards can extract protein from grassland crops with feeding value similar to soy protein and the production residues can be utilized to roughage, biogas production and extraction of high value substances for the growing bio-economy sector (Kiel et.al. 2015)(Santamaría-Fernández 2017a).

By integrating biorefining into organic production systems, it will be possible to increase crop yields, the production of non-ruminant animal products and increase the climate mitigating capacity and thereby form basis for a considerable growth in truly sustainable organic production.

Research in Denmark is demonstrating the potentials of biorefined proteins in organic farming.

Material and methods

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The crop trials shown in table 1 are made in Denmark with field-plots of 5.5 x 1.5 m in 4 replicates. Two cutting strategies are implemented: three and four cuts per season. Fresh biomass, dry matter and crude protein content are measured for the second year of production.

The field trials presented in table 2 have been conducted on two Danish organic farms. On one farm (loamy sand) there were 4 cuts in the season, on the other (sandy loam) there were 3 cuts in the season. On both farms three crops: alfalfa, red clover and a clover / grass mixture, were grown in 15 m^2 field plots with 4 replicates. Fresh biomass yield, dry matter and crude protein content in the harvested crop are measured for the first year of production.

Protein yield in concentrate is estimated based on lab-scale extraction from the crop trials and technical tests in the OrganoFinery project (SantaMaria-Fernandez, unpublished) (Santamaria-Fernandez et al. 2017a). Methane yields from process residues (press cake and brown juice) are estimated based on methane potential analyses on similar crops (Santamaria-Fernandez et. al. 2017b).

Economic calculations on the bio-refining system are done in a spreadsheet divided in three sections for the actors: The green crop field on the farm, the biorefinery and a biogas plant receiving the residue products for gas production. The economic transactions between the three actors are visualized and the profitability of the biorefinery is calculated using average protein yields and estimated methane yields from the field trials and under the precondition that the field has the same margin coverage as cereals and the biogas plant has the same margin on treating the residues as other products. Outputs from the system are: Protein concentrate for feed, biogas and increased yields on the farm caused by the nitrogen in the returned digestate. Investment in the biorefinery plant is estimated to be 12.5 mill. Euro with a capacity to treat grass from 3000 ha. Transport costs (average distance 25 km) are paid by the receiving part throughout the system. The field is paying for the nutrient value of the recycled fertilizer from the biogas plant.

Results

Protein yield from the biorefinery process was dependent both on dry matter and protein yield in the harvested material and the efficiency of the screw press. Lab-scale experiments showed that it is possible to get a protein recovery in the green juice of 40 and 70 % of the protein in the biomass (SantaMaria-Fernandez, unpublished). Practice scale biorefining techniques showed a protein recovery of 40 to 60 % (Hermansen et.al. 2017). In practice 50 % is realistic. Of the protein in the juice, approximately 70 % can be recovered in the final concentrate (SantaMaria-Fernandez, unpublished).

Yields

Yields from trials in small plots with cut-strategies in three grassland crops (white clover / ryegrass; red clover; red clover / cock's foot) are presented in Table 1.

Table 1 Total dry matter yield of biomass and crop protein in grassland crops, estimated yield of extracted crude protein in concentrate and estimated methane yield from press cake and brown juice residues. Crop yields are mean of two trials with 3 and 4 cuts per year in 2016.

Yield (ton ha^{-1})	Crop dry matter yield	Crop protein yield	Estimated protein yield in concentrate*	Estimated methane yield** (m^3 ha^{-1})
White clover / ryegrass	6.26	0.88	0.31	3,056
Red clover	8.82	1.47	0.51	2,392
Red clover / cock's foot	9.50	1.36	0.48	3,090

LSD	*1.51 ****	*0.23 ****		

*) Estimated protein yield in concentrate in table 1 and 2 is based on the assumption that 50 % of the harvested protein is recovered in the green juice and 70 % of the protein in the green juice is recovered in the protein paste (SantaMaria-Fernandez, unpublished).

**) Estimated methane yield is calculated multiplying the dry matter yield with the methane yield per tons dry matter from the residues press cake and brown juice of similar crops found in Santamaria-Fernandez, 2017b.

Yield in grassland crops (alfalfa; red clover; grass clover mixture) under farm conditions are presented in table 2. (Bertelsen, 2016)

Table 2 Total dry matter yield of biomass and crop protein in grassland crops, estimated yield of extracted crude protein in concentrate and estimated methane yield from press cake and brown juice residues. Crop yields are mean of two trials (3 and 4 cuts per year) in 2016.

Yield (ton ha^{-1})	Crop dry matter yield	Crop protein yield	Estimated protein yield in concentrate*	Estimated methane yield** (m^3 ha^{-1})
Alfalfa	13.31	2.53	0.89	3,492
Red clover	16.45	2.86	1.00	4,460
Grass clover mixture[1)]	19.23	2.95	1.03	6,254
LSD	*ns*	*ns*		

1) 8 kg red clover, 1,5 kg white clover, 9 kg festulolium, 9 kg ryegrass seed per ha.

In both trials red clover and red clover / grass mixture gave the highest protein yield and the highest dry matter yield. In the farm trial no significant difference between crops were found.

Economy of the bio-refining system

Table 3 shows model calculations of the biorefinery's economic result under different economic conditions.

Table 3 Economic results of bio-refining organic green crops (model calculation)

	Economic result (€ / ha)[1)]
Standard conditions[2)]	201
Without drying[3)]	540
20 % lower / higher protein price[4)]	-94 / 496
10 % lower / higher biogas price[4)]	24 / 378
10 % lower / higher protein yield[4)]	58 / 343

1) Calculated per ha harvested green crop for processing.
2) 0.7 ton protein per ha, 2,900 m^3 methane per ha, 0.8 € per kg dry protein concentrate, 0.6 € per m^3 bio-methane
3) The protein concentrate is sold as wet-feed.
4) Dried protein

The model calculations shown in table 3 demonstrate a positive economy in biorefining of protein feed under the selected conditions, especially when the protein concentrate can be used for wet feeding. It should be noticed that the crop yields and yields of extracted protein are high in the trials compared to expected yields in practice and that the economic results are sensitive to changes in yields and prices.

Discussion

Introduction of biorefining techniques in organic production to produce organic high value protein feed from grass clover can solve more important challenges in organic farming: Grass clover can get a prominent place in rotations on farms without ruminants and raise and consolidate the crop yields. The crop yield and yield stability are higher in grass clover mixtures than in grain legumes under Danish conditions. The protein supply for organic pig and poultry can be secured and locally produced – with the future perspective to produce high value plant proteins for human consumption. By using the residues for biogas production, the production system also contributes to repress the use of fossil fuels and the extended use of grassland crops will increase the carbon sequestration.

The feed value of leaf proteins from clover and grass is promising as the amino acid profile with high content of methionine indicates that it can be a valuable supplement to other grain legumes like peas, faba beans and lupins (Santamaria-Fernandez et al. 2017a).

The demonstrated economic model calculations show that biorefining techniques are within the range of a commercial production. Especially if biorefined proteins can be used as wet-feed, and if the price of organic protein feed increases as a result of the enforcement of 100 % organic feed. Demonstration of biorefining on practical conditions is needed to confirm the yields and profitability found in the trials. Further development of the biorefining technique to produce protein and other high value products for human consumption could make biorefining of organic green crops very profitable.

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