

Biogas from Cover Crops and Field Residues: Effects on Soil, Water, Climate and Ecological Footprint

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Abstract—Cover or catch crops have beneficial effects for soil, water, erosion, etc. If harvested, they also provide feedstock for biogas without competition for arable land in regions, where only one main crop can be produced per year. On average gross energy yields of approx. 1300 m³ methane (CH₄) ha⁻¹ can be expected from 4.5 tonnes (t) of cover crop dry matter (DM) in Austria. Considering the total energy invested from cultivation to compression for biofuel use a net energy yield of about 1000 m³ CH₄ ha⁻¹ is remaining. With the straw of grain maize or Corn Cob Mix (CCM) similar energy yields can be achieved. In comparison to catch crops remaining on the field as green manure or to complete fallow between main crops the effects on soil, water and climate can be improved if cover crops are harvested without soil compaction and digestate is returned to the field in an amount equivalent to cover crop removal. In this way, the risk of nitrate leaching can be reduced approx. by 25% in comparison to full fallow. The risk of nitrous oxide emissions may be reduced up to 50% by contrast with cover crops serving as green manure. The effects on humus content and erosion are similar or better than those of cover crops used as green manure when the same amount of biomass was produced. With higher biomass production the positive effects increase even if cover crops are harvested and the only digestate is brought back to the fields. The ecological footprint of arable farming can be reduced by approx. 50% considering the substitution of natural gas with CH₄ produced from cover crops.

Keywords—Biogas, cover crops, catch crops, land use competition, sustainable agriculture.

I. INTRODUCTION

THE growing of cover or catch crops, cultivated in succession with main crops, is promoted by agro-environmental programs because of beneficial effects on soil, water, erosion, and weed management. If harvested, cover crops may also provide biomass for biogas production without competition for arable land. They enable a more efficient and sustainable use of the growing season and growing space in regions, where only one main crop can be produced per year. Additionally, degradation effects of fallow on the scarcely covered ground are avoided.

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Several projects on the use of cover crops for biogas production have already been carried out in Germany [1]-[9], Denmark [10], France [11], [12] and Czech Republic [13]. Most of the projects were oriented towards practical use and focused on the improvement of yields and profitability. Dry matter (DM) yields determined varied considerably between 1 and 7 t ha⁻¹. Comprehensive investigations of the effects on environment and climate have scarcely been conducted. Reference [1] shows best that effects on environment and climate depend mainly on the approaches and methods applied for biomass and biogas production: Intensive production may increase profitability but increases risks of unintended effects on water, soil, and climate as well. Therefore, a great variety can also be detected regarding recommendations and conclusions drawn from the project results. In summary, it is not possible to identify a common practice or even best practice from project results. And as far as it can be stated from reports in professional journals, on the World Wide Web or conferences, the use of cover crops for biogas production did not enter current widespread practice yet.

II. OBJECTIVES

The investigation of energy yields achievable without competition for arable land or negative impact on food security as well as the enhancement of the sustainability of agriculture concurrently is the overall objectives of the project Syn-Energy. Therefore cover crops are grown with a minimum of digestate, no mineral fertilizer, mulch-till or direct sowing, no application of herbicides and pesticides but with different cover crop mix including a share of legumes up to 50%. With this approach of growing, considerate harvest and the application of an equivalent amount of digestate it is intended to increase the positive effects of cover crops in comparison to cover crops remaining on the field as green manure.

The use of flowering plants such as sunflowers, pea, bean, phacelia, clover, etc. shall additionally contribute to higher public acceptance and provide nutrition for bees and other insects. The aim is not the maximization of cover crop yields but sustainable and climate-friendly optimization of net energy return while preserving positive effects of cover crops for soil and water. Thus we also measure and calculate the impact of biogas production from cover crops on their environmental performance in comparison to green manure and complete fallow regarding water consumption, nitrate leaching, gaseous emissions, nitrogen fertilizer demand, erosion, soil fertility, organic dry matter content, etc. In summary, an environmental life cycle assessment is conducted.

Furthermore, the project aims at the practical testing and the

development of several catch crop seed mix for summer and winter cover crops. With this comprehensive approach including the comparison of yields (main crop for food, cover crop for energy) and environmental performance of crop rotations in cooperation with practitioners we aim at identifying the constraints for practical use and assuring practical usability of our findings.

III. APPROACH

There are no well-established procedures for harvest, storage, and fermentation of cover crops. The same applies for field residues such as the straw of maize or rape. Therefore our project focused on the identification of the range of achievable yields under different conditions and practices for sustainable as well as cost-efficient biomass supply.

Five field experiments with three replicates were conducted, three of them over five years. Five different types of cover crops (most of them a mix of at least 3 plant species with 50% legumes) were cultivated and monitored to state on dry matter (DM) yields of cover crops, yields of main crops and effects on ground water, soil and plant nutrition aspects. The effects were compared with cover crops remaining on the field as green manure and complete fallow between main crops. Energy yields were calculated on the basis of biogas digester lab scale experiments, conducted with frozen cover crop biomass from the field experiments. The results of soil and water monitoring (e.g. soil moisture sensors, pore water samplers, mineral nitrogen content measurement up to 4 times per year) were used to calibrate a numerical soil-plant model (*Simwaser/Stotrasim*). Effects on the risk of erosion were calculated with the model *Bodenerosion, Beratung und Berechnung (BoBB)*. The degree of soil coverage was documented weekly during the growing

phase of the cover crops and analyzed with an image recognition software. Effects on soil fertility and the humus content were analyzed with potassium and organic matter balances (*STAND*), comparison of root development and analysis of applied digestion effluents. The effects on nitrous gas emissions were calculated on the basis of data from literature in combination with data on biomass development, soil water content, and temperature collected in this project with a statistical model. The *Sustainable Process Index (SPI)* was used to evaluate the ecological footprint of different land use and energy supply scenarios. Additionally widespread practical testing (more than 700 ha) was conducted in cooperation with biogas plant managers and farmers throughout Austria. The cooperation with biogas plant managers and farmers provided data on achievable yields on farm-scale level and the basis for the economic assessment of biogas production from cover crops.

The project ends in May 2015. Last data of field experiments was collected in October 2014. Analysis of effects on soil, water, and climate is still ongoing. Therefore, only preliminary results can be provided in this paper.

IV. PRELIMINARY RESULTS

A. Energy Yields and EROI

Biogas digester lab scale experiments resulted in an average energy content of 280 NI CH₄ kg⁻¹ DM or 307 NI CH₄ kg⁻¹ organic DM of cover crops. Dry matter yields in field experiments and practical testing, as well as energy content in lab scale experiments, varied considerably. Therefore we provide results for a range of yields instead of focusing on average yields with statistical evidence.

TABLE I
COMPARISON OF NET ENERGY RETURN FROM COVER CROPS (BIOMETHANE): RAPE (BIODIESEL) AND WHEAT (BIOETHANOL)
THE DISTANCE ATTAINABLE BY CAR AND THE PROVISION OF FOOD AND FEED PER HECTARE

cover crop (CC) / rapeseed / wheat yield per ha	gross energy yield per ha	EROEI average	net energy return per ha	diesel / petrol* equivalent net	distance attained by car on fuel per ha		wheat** for food / byproducts for feed
	m ³ /ha o. l/ha	output / input	m ³ /ha o. l/ha		l/100km	km/ha	t/ha
biomethane (2.5 t CC DM/ha)	700	5.14	562	607*	7,4	8,200	7.2
biomethane (4.5 t CC DM/ha)	1260	5.91	1,045	1,129*	7,4	15,300	7.2
biomethane (6 t CC DM/ha)	1680	6.16	1,404	1,516*	7,4	20,500	7.2
biodiesel (Rapeseed 3.5 t/ha) [14]	1,590	2.17	859	782	5.1	15,300	2.1***
bioethanol (Wheat 7.2 t/ha) [15]	2,760	1.32	662	430*	7.4	5,800	2.7****

* energy content of 1 m³ biomethane = 1.08 l petrol = 1 l diesel; ** instead of wheat any other main crop can be grown for food purposes; *** coarse colza meal; **** DDGS; Source for conversion factors: FNR [16]

In Table I, we calculated the gross and net energy yields per ha for DM yields of 2.5, 4.5 and 6 t ha⁻¹. Gross energy yields ha⁻¹ vary between 700 m³ CH₄ ha⁻¹ for 2.5 and 1.680 m³ CH₄ ha⁻¹ for 6 t DM ha⁻¹. The harvesting of cover crops with dry matter yields below 2.5 t ha⁻¹ may also be possible with adequate methods, as applied in grassland farming, and results in net energy yields below 600 m³ CH₄ ha⁻¹. Under favourable conditions, 7 t DM ha⁻¹ and 2000 m³ CH₄ ha⁻¹ were exceeded. The energy return on energy invested (EROI / EROEI) amounts to 5.14 for lower yields and exceeds 6.16 with yields over 6 t

DM ha⁻¹. Therefore energy efficiency is much higher than with Biodiesel from rape (EROI 2.22) or bioethanol from wheat (EROI 1.32). The result is that the distance attainable by a car on fuel per hectare from cover crops exceeds the distance of bioethanol already with 2 t DM ha⁻¹. In comparison to biodiesel, less than 5 t DM ha⁻¹ are sufficient. However, the crucial difference between biomethane from cover crops and other biofuels is that wheat or any other main crop in succession of the cover crop may completely be used for food purposes, whereas dried distillers grains with solubles (DDGS) from

bioethanol production and coarse colza meal from bioethanol production may only be used as fodder.

With the straw of grain maize or CCM DM yields between 2 and 8 t ha⁻¹ can be achieved with current machinery available and avoidance of a considerable uptake of stones and soil. With solely mechanical pre-treatment the energy content varied between 240 and 320 Nl CH₄ t⁻¹ DM. Energy content depended mainly on the state of maturity of the vegetative parts of the plant. The yields of rape straw amounted to 2 and 5 t DM ha⁻¹ with an energy content of 180 – 250 Nl CH₄ t⁻¹ DM.

B. Effects on Soil, Water, Climate and Ecological Footprint

Summer cover crops were composed of plants with different demands on weather conditions and sunshine duration. With mixtures adapted to soil conditions and seed time, the application of herbicides and pesticides was not necessary. Mulch-till or direct sowing allowed earlier sowing and reduced the risk of erosion. Legumes in summer cover crop mixtures facilitated a minimization of the fertilization with digestate because nitrogen was supplied by nitrogen fixation from the air. Winter cover crops, on the contrary, required fertilization according to nitrogen export with harvested cover crop biomass. Mineral fertilizer was not applied either for summer or for winter cover crops. In total fertilization was adapted to the demands of the crop rotation and the amount of digestate returned to the field derived approximately from the biomass harvested with the preceding cover crop. Besides choppers, self-loading trailers were utilized for harvest in several cases. They reduced the risk of soil compaction, particularly if trailers with 8 wheels were used. Tire pressure control systems enabled a further reduction of soil compaction risks.

Compared to catch crops remaining on the field as green manure or to complete fallow between main crops the specific degree of improvement regarding soil, water and climate vary considerably depending particularly on soil characteristics, weather conditions, and field management.

First calculations show that the risk of **nitrate leaching** can be reduced approx. by 25 % in comparison with full fallow. In comparison to green manure, the risk of leaching may also be improved if a summer cover crop included a high percentage of legumes or the biomass production of a harvested cover crop was considerably higher with equal nitrogen supply. Furthermore, the degree of reduction depends on the nitrogen balance of the crop rotation, the nitrogen content in the soil before winter, as well as the amount of precipitation, leachate generation, and seepage velocity.

The risk of **nitrous oxide emissions** may be reduced up to 50% in comparison to green manure cover crops. In comparison to complete fallow gaseous emissions are reduced only slightly. A reduction of soil water content and the amount of incorporated plant biomass as well as the nitrogen content in the soil result in a reduction of nitrous gas emissions.

Calculations with the humus balance model *STAND* result in the supply of 112 kg ha⁻¹ of humus carbon if a cover crop with 2.5 t DM ha⁻¹ is harvested and an equivalent amount of digestate is returned to the soil. When the same cover crop is incorporated in the soil as green manure, it provides only

80 kg ha⁻¹ of humus carbon. The positive effect on **humus content** increases with higher biomass production. Generally, biomass production was considerably higher if cover crops were used for biogas production because of earlier cultivation and later harvest/mulching. If summer cover crops remain on the field without incorporation in the soil during winter, considerable amounts of the biomass can also get lost into the atmosphere. Furthermore, roots and root exudates provide fresh organic matter for soil life. In comparison to complete fallow considerable improvements regarding humus content and soil fertility were achieved.

The risk of **erosion** was reduced up to 50 % in comparison to complete fallow if cover crops were used for biogas production. Earlier cultivation and later harvest/mulching also reduced the risk of erosion by contrast with cover crops serving as green manure.

The **ecological footprint** of arable farming was reduced by approximately 50 % if the substitution of natural gas with CH₄ produced from cover crops was taken into consideration. Positive effects may be further improved if biomethane is used as biofuel in agricultural machinery.

V. CONCLUSION

Energy yields of cover crops may seem low if compared with maize. In comparison with the yields of ethanol from wheat or biodiesel from rape, the potential becomes obvious. Since main crops can still be used for food or fodder purposes, biogas from cover crops may even contribute to the mitigation of land use conflicts particularly in areas with high land use competition. In manure biogas plants they may replace co-substrates cultivated in main crop position. Therefore, they can also facilitate the use of manure or field residues for biogas production and contribute to a considerable increase of the sustainability of agriculture with less climate relevant gaseous emissions.

Most of current criticism on biogas production is obsolete if maize is substituted with cover crops. The use of flowering plants provides nutrition for bees and other insects and accounts for higher public acceptance additionally. Therefore cover crops may also contribute to a significant improvement of the social acceptance and expansion of biogas production.

Efficient coordination and communication with cooperating farmers are important keys for successful implementation particularly in areas with small average farm scales.

An important step towards the practical use of cover crops for biogas production would be the promotion of the use of CH₄ as biofuel and/or economic incentives to use cover crops and field residues for biogas production instead of maize or other main crops.

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