OPTIMISATION OF BIOGAS PRODUCTION FROM ENERGY CROPS

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ABSTRACT: Biogas production is of major importance for a sustainable use of agrarian biomass as renewable energy source. Economic biogas production depends on high biogas yields. Key factors for a maximum biogas yield are species and variety of energy crops, time of harvesting and mode of conservation. The project aimed at optimising anaerobic digestion from energy crops. The following aspects were investigated: suitability of different varieties, optimum time of harvesting, specific methane yield and methane yield per hectare. Energy crops were grown on 60 ha in several Austrian regions. The experiments covered 18 maize varieties (FAO 280 – 650), 4 winter wheat varieties, 2 triticale varieties, 2 winter rye varieties and 16 treatments with permanent grassland. Biomass yield in course of the vegetation period and biomass composition were measured. Anaerobic digestion was carried out in eudiometer batch digesters. The highest methane yields of 7,500 to 10,200 $Nm^3CH_4 \cdot ha^{-1}$ were achieved from maize varieties with FAO 300 – 400 harvested was at wax ripeness. Methane yields of cereals ranged from 3,200 to 4,500 $m^3 * ha^{-1}$. Cereals should be harvested at grain-milk to dough stage. Alpine grassland can yield 2,700 to 3,5000 $m^3 * ha^{-1}$. From the digestion experiments, the Methane Energy Value Model was developed. It estimates the methane yield from the composition of energy crops.

Keywords: Anaerobic digestion, methane, sustainable use of biomass

1 INTRODUCTION

Biogas production is of major importance for a sustainable use of agrarian biomass as renewable energy source. Mitigation of green house gas emissions (GHG) through renewable energy production from biomass is of rising importance. Economic biogas production requires high biogas yields. Key factors for a maximum biogas yield are species and variety of energy crops, time of harvesting, mode of conservation and pre-treatment of biomass prior to the digestion process. There is currently a lack of data on biogas production from energy crops. Guidelines on optimum energy crop production, optimum harvesting time and technology and pre-treatment must be worked out.

All activities must aim at the sustainment and productive use of a multifaceted cultivated landscape [1]. A lasting success is only achieved, if arable land and grassland are managed after sustainable principles [2]. A wide range of energy crops must be grown in versatile crop rotations. The research project measured methane yields from a range of energy crops and developed the "Methane Energy Value Model" for the estimation of methane yields from energy crops.

2 MATERIALS AND METHODS

A range of energy crops was grown on 60 ha in several Austrian regions (Fig. 1). The following energy crops were included in the research programme: 18 maize varieties (FAO 280 – 650), 4 winter wheat varieties, 2 triticale varieties, 2 winter rye varieties and 16 treatments with permanent grassland. Biomass yield in course of the vegetation period and biomass composition were measured. Anaerobic digestion was carried out in eudiometer batch digesters according to DIN 38414 [3]. The investigations covered a wide range of parameters: specific biogas and methane yield, biogas quality (CH_4, H_2S, NH_3), transformation of biomass carbon and energy into biogas carbon and energy. More details on the measurement technology can be found in [4,5,6].

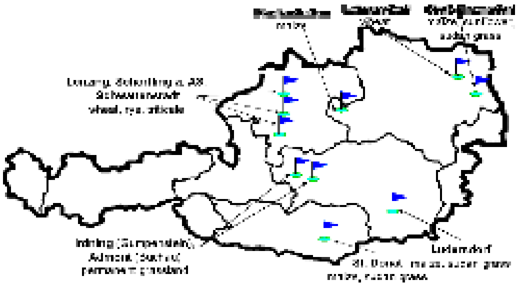

Figure 1: Locations of the field trials

3 RESULTS

3.1 Maize

The specific methane yield of 18 maize varieties was measured. The average specific methane yield was 399 $Nl\ CH_4 \cdot VS^{-1}$ with a standard deviation of 21 $Nl\ CH_4 \cdot VS^{-1}$. There were no significant differences between the maize varieties.

Biomass yield was dependent on the maize variety. The biomass yield of medium ripening maize varieties like Baxter and Wexxil was higher than the biomass yield of the late ripening varieties. Because of their higher biomass yield, medium ripening varieties gave higher methane yields per hectare than late ripening varieties. The highest methane yields per hectare of

7,500 to 10,200 Nm^3 CH_4 ha^{-1} were produced by maize varieties with FAO 380 – 400 (Fig.2).

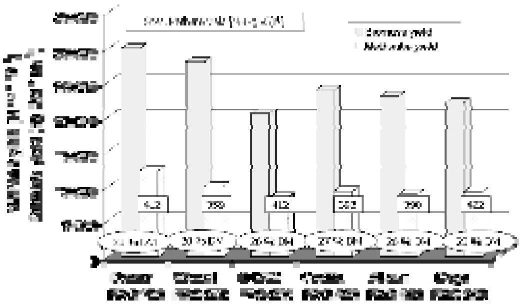

Figure 2: Biomass and methane yield from maize varieties

The time of harvest is a key influence on the methane yield that can be produced per hectare of maize. The variety “KWS 1393” (FAO 400) was harvested at five consecutive times in course of the vegetation period. The highest biomass and methane yield per hectare were measured 171 days after seeding, at the vegetation stage “wax ripeness” (Fig. 3).

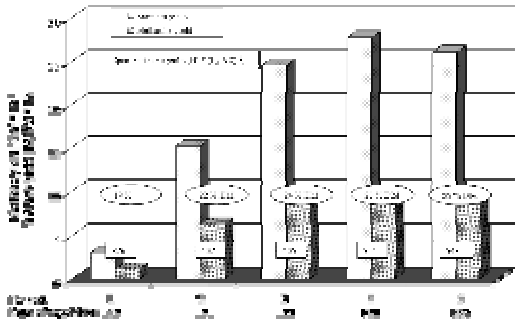

Figure 3: Biomass and methane yield from maize in course of the vegetation period

3.2 Cereals (Wheat, Triticale, Rye)

4 varieties of winter wheat, 2 varieties of triticale and 2 winter rye varieties were grown in two locations that differed in their climate. “Lenzing” (Upper Austria) received an average of 1200 mm rainfall per year. The precipitation at “Loimersdorf” (Lower Austria) was 450 mm. The biomass yield of each crop was measured at five occasions in course of the vegetation period. The highest biomass yield from winter wheat (19 t DM*ha^{-1}) was achieved at the vegetation stage “grain in the dough stage” or “maturity complete”. Triticale showed the highest biomass yield (15 t DM*ha^{-1}) at the vegetation stage “anthesis flowering” or “grain in the milk stage”. Rye reached the highest biomass yield (15 t DM *ha^{-1}) at the vegetation stage “corn in the dough stage”.

The specific methane yield from wheat ranged between 230 and 340 Nl $CH_4 \cdot VS^{-1}$. Triticale and rye showed a lower specific methane yield than winter wheat. The highest specific methane yield was achieved at the vegetation stage “anthesis flowering”. In course of the vegetation period, the specific methane yield of cereals declined, whereas the total biomass yield increased. When cereals are harvested at the optimum vegetation stage, a methane yield per hectare of 3,200 to 4,500 Nm^3 CH_4 ha^{-1} can be achieved (Fig. 4).

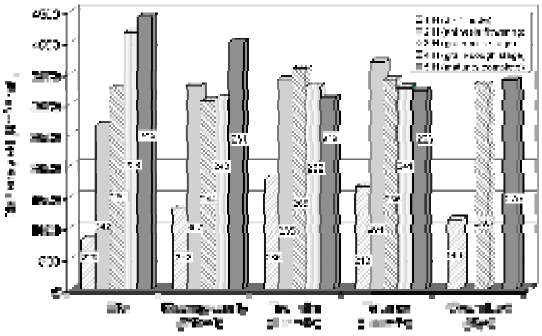

Figure 4: Methane yield from cereals in course of the vegetation period

3.3 Grass

16 grassland treatments were grown in two Alpine regions: “Buchau/Admont”, a low input mountainous region and “Irdning/Gumpenstein”, an intensive valley area. Experimental set up and sampling allowed a differentiation of management intensity and vegetation stage at harvesting. More details on the two locations, on the climatic conditions and on the grassland composition can be taken from [2].

Figure 5 gives the biomass yield per year of all grassland treatments. The low input location yielded 4.2 t dry matter per year when cut once and 6.4 t dry matter per year when cut twice. The treatment with three cuts resulted in a decline in total biomass yield (5.9 t DM yr^{-1}). The treatments grown in the intensive valley area were cut three to four times and yielded more biomass. The “three cut treatment” was further differentiated into “early first cut” (1st June, Int. 4) and “late first cut” (15th June, Int. 5). The treatment “early first cut” yielded much less biomass than the treatment “late first cut”. The loss in biomass yield was not compensated through slightly higher biomass yields in the second and in the third cut. This means, that the timing of the first cut is of key importance for the total biomass yield from a full vegetation period.

The specific methane yields of grassland from the mountainous and from the valley region showed significant differences (Fig. 5). Independent of the number of cuts and time of harvest only a low specific methane yield (128 – 221 Nl $CH_4 \cdot VS^{-1}$) was measured from the low input grass. The grass grown in the intensive valley region produced 190 to 392 Nl $CH_4 \cdot VS^{-1}$. The highest specific methane yield was measured in the 4-cut system from the second cut in the vegetation stage “anthesis flowering”.

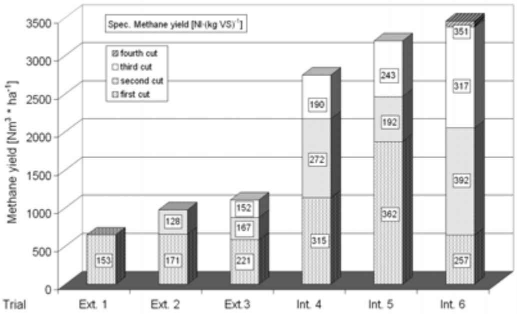

Figure 5: Methane yield from permanent grassland

4 METHANE ENERGY VALUE MODEL (MEWM)

4.1 Development of the Methane Energy Value Model

A new model – the Methane Energy Value Model – was developed, which estimates methane yield from the nutrient composition of energy crops via regression models. Existing models concentrated on picturing the kinetics of anaerobic digestion and showing influences such as e.g. pH value, NH_4-N content, or content of volatile fatty acids ([7], [8], [9], [10], [11]). They are only valid for specific areas of digestion of organic wastes. [12] and [13] developed a model that estimates biogas composition (CH_4, CO_2, H_2S und NH_3) from the chemical composition of organic substrates: C, H, N, S.

Methane production from organic substrates mainly depends on their content of substances that can be degraded to CH_4 and CO_2. Structural substances, especially lignin, are key influences for the digestibility of organic substrates in biogas plants ([14], [15]). They determine the degradability and thus the methane yield that can be produced through anaerobic digestion. Crude protein, crude fat, crude fibre, cellulose, hemi-cellulose, starch and sugar markedly influence methane formation.

From the digestion experiments, the new Methane Energy Value System was developed. It estimates the methane production potential of nutrients if these are fed as natural organic substrates.

MEV [l CH_4 (kg VS)$^{-1}$] =
x1 * crude protein (XP) (content in % DM)
\+ x2 * crude fat (XL) (content in % DM)
\+ x3 * crude fibre (XF) (content in % DM)
\+ x4 * nitrogen free extracts (XX) (cont. in % DM)

The new Methane Energy Value System helps to optimise biogas production by the following capabilities:

- estimation of the methane production of organic substrates from their nutrient composition;
- estimation of the nutrient requirement of micro-organisms that are responsible for anaerobic digestion;
- estimation of the power of agricultural biogas plants in dependency of amount and composition of organic substrates that are digested;
- recommendations on varieties and optimum harvesting time of energy crops;
- estimation of methane yield per hectare of energy crops, varieties and crop rotations.

4.2 MEVW for maize

Table I shows coefficients of regression, standard error and level of significance of the regression model for the estimation of methane yield from anaerobic digestion of maize silage. The nutrients crude protein (XP), crude fat (XL), crude fibre (XF) and nitrogen free extracts (XX) proved to have a significant influence on the level of methane production. From their content – expressed as % in maize silage dry matter – the specific potential of maize to produce methane – its methane energy value – is estimated. The regression equation is based on 95 experiments. Crude fat and crude protein contribute most to the net total Methane Energy Value of maize silage.

Table I: Coefficients of regression, standard error and level of significance for the estimation of the methane yield from maize silage

parameter	coefficient of regression	level of significance
crude protein (XP)	15.27	0.000
crude fat (XL)	28.38	0.001
crude fibre (XF)	4.54	0.000
N free extracts (XX)	1.12	0.008

Quality parameters of the whole equation:
R^2 = 0.968; F value = 1583.027; Durbin-Watson value =1.176; level of significance level= 0.000; n = 95

Specific methane yields measured in the eudiometer batch digesters were compared to the values estimated with the Methane Energy Value Model (Table II). Estimated values differed between 0.1 and 52 Nl CH_4 (kg VS)$^{-1}$ from the measured values. This corresponds to a difference of 0.0 to 16.1 %. Mean difference was 1.0 %.

The Methane Energy Value for maize is currently validated on commercial biogas plants. First results show a good agreement between estimated and measured values with a difference of 2 – 5 %.

Table II: Specific methane yield from anaerobic digestion of maize: measured values and values estimated with the Methane Energy Value Model

maize variety	spec. CH_4 yield measured	spec. CH_4 yield estimated	difference	
	[Nl CH_4 (kg VS)$^{-1}$]		Nl	[%]
Tonale 1.harv.	333.7	339.4	- 5.7	1.7
Tonale 2.harv.	283.2	324.8	- 41.6	14.7
Tonale 3.harv.	280.4	266.0	-14.4	5.1
PR34G13 1.harv.	365.9	313.6	52.3	14.3
PR34G13 2.harv.	302.1	320.7	-18.6	6.2
PR34G13 3.harv.	268.2	311.4	-43.2	16.1
LZM 1.harv.	312.6	296.4	16.2	5.2
LZM 2.harv.	325.6	300.6	25.0	7.7
LZM 3.harv.	286.8	286.9	-0.1	0.0
mean error				*1.0*

4.3 MEVW for cereals

The methane yields from 20 digestion experiments with cereals were correlated with their nutrient composition. Table III gives the coefficients of regression, standard error and level of significance of the regression model for the estimation of the methane yield from cereals.

Crude protein (XP) and Crude fibre (XF) contributed most to the methane yield from cereals. The statistical analysis did so far not show a significant influence of the cereals fat content on the methane yield. It may be assumed that the reason for this lies in the contrasting quality of the different fats present in the cereals. In a further analysis, fats will be disaggregated according to their chain length and degree of saturation.

Table III: Coefficients of regression, standard error and level of significance for the estimation of the methane yield from cereals

parameter	coefficient of regression	level of significance
crude protein (XP)	5.904	0.004
crude fibre (XF)	3.791	0.001
N free extracts (XX)	1.352	0.015

Quality parameters of the whole equation:
R^2 = 0.985; F value = 371.739; Durbin-Watson value =2.442; level of significance = 0.000; n = 20

Table IV compares the specific methane yields measured in the eudiometer batch digesters and the values estimated with the Methane Energy Value Model. Even without inclusion of crude fat, the model gives very good results. The mean difference between estimated and measured value is 0.5 %.

Table IV: Specific methane yield from anaerobic digestion of cereals: measured values and values estimated with the Methane Energy Value Model

Triticale	spec. CH_4-yield *measured*	spec. CH_4-yield *estimated*	difference	
	[Nl CH_4 (kg VS)$^{-1}$]		Nl	[%]
1st harvest	286	259	-27	9.5
2nd harvest	255	265	10	3.9
3rd harvest	265	272	7	2.7
4th harvest	232	235	3	1.4
5th harvest	212	221	9	4.3
mean error				0.5

4.4 MEVW for grass

The Methane Energy Value Model for methane production from anaerobic digestion of grass is currently under development. Table V gives preliminary results on coefficient of regression, standard error and level of significance of the regression model. The complete regression model is highly significant, however the single parameters are currently not significant. The methane energy model for grass needs further refinement.

Table V: Coefficient of regression, standard error and level of significance for the estimation of the methane yield from grass

parameter	coefficient of regression	level of significance
crude protein (XP)	2.19	0.602
crude fat (XL)	31.38	0.017
crude fibre (XF)	1.48	0.457
N free extracts (XX)	1.85	0.217

Quality parameters of the whole equation:
R^2 = 0,935; F value = 126,976; Durbin-Watson value =0.804; level of significance = 0.000; n = 40

5 CONCLUSIONS AND OUTLOOK

In the cultivation of energy crops the following should be considered:

Maize:

Prefer locally suitable varieties with a high biomass yield. Harvest in the vegetation stage milk to wax ripeness. Under suitable climatic conditions the methane yields of 7,500 – 10,200 $m^3 * ha^{-1}$ can be achieved.

Cereals:

Prefer fast growing varieties with a high biomass yield. Rye and triticale are very suitable as forecrop. Harvest in the vegetation stage grain-milk to dough stage. Methane yield of 3,200 – 4,500 $m^3 * ha^{-1}$ can be achieved.

Grass:

The first cut should not be made before ear emergence as an early first cut reduces the methane yield per hectare for the whole vegetation period. In Alpine valley regions the “three cut system” with a “late first cut” (15th June, treatment 5) give the highest methane yields per hectare (2,700 – 3,5000 $m^3 * ha^{-1}$).

Methane Energy Value Model:

The statistical analyses have given very good results for the estimation of methane yields from maize and cereals. The MEVW for grass needs further refinement. In a next step, MEVW has to be developed for a wide range of energy crops.

Sustainable biogas production:

Currently, biogas production from energy crops is mainly based on the anaerobic digestion of maize. In the near future, biogas production from energy crops will increase. An environmentally friendly biogas production then requires to be based on a wide range of energy crops that are grown in versatile, sustainable crop rotations.

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