Andreas Lemmer and Hans Oechsner, Hohenheim

Co-fermentation of grass and forage maize

Greencrop cuts are looked-on as waste product in nature protection or landscaped areas or can be a part of planned production on set-aside land. In Hohenheim the form and conditions under which this material could be viably fermented in an agricultural biogas plant were investigated. In laboratory and practical trials the most important factors in the fermentation of grass and maize from different sources were determined. Hereby experience was collected regarding additional technical equipment possibly required when handling structurally strong substrates in biogas plants and the labour input involved. The calculation of economic viability when using different greencrop substrates in agricultural biogas plants rounded the investigation off.

Dipl.-Ing sc. agr. Andreas Lemmer and Dr. Hans Oechsner are members of the scientific staff at the State Institute for Agricultural Mechanisation and Building, Hohenheim University (director: Dipl.-Ing. K. Maurer), Garbenstr. 9, 70593 Stuttgart, e-mail: *oechsner@uni-hohenheim.de*
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Literature

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In many German communities there are problems regarding the utilisation of cuttings representing waste from non-agricultural green areas. In Baden-Württemberg alone, the area of nature protection reserves has risen from 80000 ha in 1976 to nearly 800000 in 1999 [1, 2]. Cuttings have to be removed to preserve the oligotrophic conditions by avoiding oversupply of available plant nutrients [3]. This problem is especially intensified in poorly structured regions through the decrease in cattle production leading to areas once used for forage now having to be clipped and carted-off too. For this reason a model project was planned investigating the use of cuttings as co-substrate in agricultural biogas production plants. Forage maize and grass silage were included in the investigations because these alternatives can be produced on the farmland and added to the organic material coming from outside the farm.

Construction of the experimental plant

The trials evaluation cutting fermentation were conducted between 1999 and 2001 in the Hohenheim University biogas laboratory and on three commercial biogas plants in Allgäu.

The 16 horizontal throughflow laboratory biogas plants with a working capacity of 18 litres were used along with a horizontal half-technical throughflow biogas plant with a working capacity of 400 l which was run parallel using different green substrates. Plant construction has already been described in [4].

The three commercial biogas plants were upright concrete digesters with working volumes from 280 to 520 m^3. In these plants the structure-rich material was fed directly into the digesters via loading auger (*fig. 1*) or flushing shaft. Submersible propellers with 11 to 15 kW performance were used for mixing the substrates in the digesters. This resulted in a performance density of 28.8 to 39.2 W/m^3 digester volume.

Fermentation trials

In the fermenting trials cuttings from nature protection areas, grass silage from extensive (2-cut) and intensive (4-cut) leys, lawn clippings from golf greens and forage maize were used. Thus the input ranged from extensive grassland with single annual cuttings receiving no fertiliser to lawn clippings with 450 kg N/ha fertilisation per year and mowed daily. The substrates were ensiled so that homogenous material of consistent quality was available throughout the trial period.

To test the working suitability of the material and its ease of handling, the dry matter (dm) contents in the suspensions of slurry and cuttings transported into the digesters were varied from 7 and 12%. The hydraulic working phase lay between 25 and 60 days from which space loadings of between 1.2 and 3.4 kg organic dm per m^3 digester volume and day were produced. The digester running temperature was mesophilic at 37°C.

Results

From the biological processing stability aspect, greencrop cuttings grown under different intensities are very well suited for fermenting along with manure slurry. But care must be taken that the mixture of slurry and

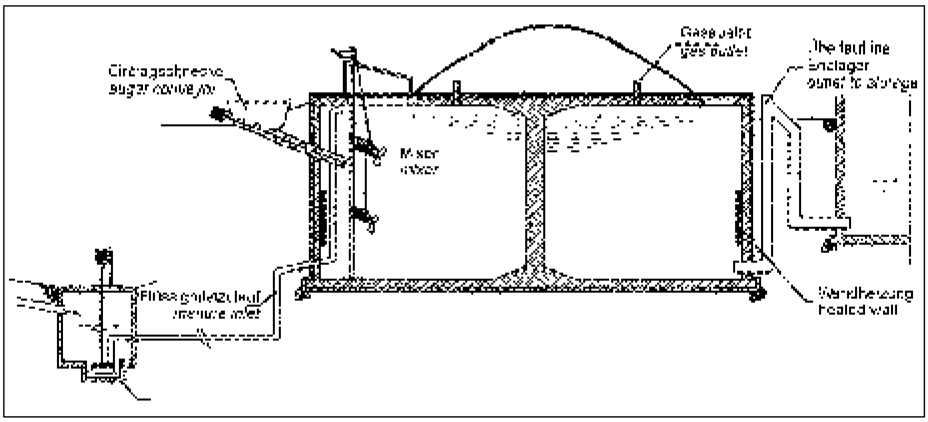

Fig. 1: Biogas plant, built up for co-digestion of biomass

cuttings fed into a biogas the plant has a dry matter content of not more than 10 to 12% so that the substrate remains suitable for passage through pipeline and pumps. In the commercial plants investigated, a mixing time of 3 to 5 min per hour was necessary for the homogenisation of the digester contents. In one of the plants in which a 12% dm mix of slurry-green crop cuttings was used, a second mixing apparatus had to be fitted. If regular mixing is neglected, then biogas cannot escape out of the grass-slurry mix into the gas storage area and the volume of substrate expands. Co-fermentation plants for greencrop should, therefore, be fitted with inspection windows and large-capacity pressure release valves.

Available digester volume is more efficiently used when greencrop is fed compared with pure slurry fermentation. If, during a working phase of 25 days, around 1.1 dt silage from intensive leys or forage maize is added into the digester, the reactor-specific methane yield rises from 0.37 to 0.78 m^3/m^3 FV (grass silage) and to 0.75 m^3/m^3 FV (maize silage). Thus reactor-specific methane yield can be more than doubled over a 25-day phase by adding silage. Methane content, however, sinks and with this the burning value of the biogas. Where, in the laboratory, digestion with pure slurry achieves a methane content of 57 to 60%, co-fermentation of grass and forage maize gives a methane value of between 54 and 57%. At the commercial plants investigated, values between 47 and 51% methane were measured after the biological hydrogen sulphide reduction (blowing air into the digester, 7 to 8 volume % raw gas).

Fig. 2: Methane yield of different substrates. Digestion in laboratory biogas plants, HRT 25 d, mesophilic digestion (37 °C)

Substantial differences existed between the gas yields of the individual substrates. For instance, the substrate-specific methane yield of grass silage from intensive leys and forage maize over a working phase of 25 days was with 0.41 and 0.32 m^3/kg organic dm, clearly above that of silage from extensive grassland (0.24 m^3/kg organic dm). Adding cuttings from nature protection areas meant a lower substrate-specific methane yield was achieved (0.1 m^3/ kg organic dm) compared with that (0.18 m^3/kg organic dm) from cattle slurry. An increase in working phase to 40 days led to an increase in the substrate specific methane yield from nature reserve cuttings of 12.5%, in the case of extensive leys silage of 9.0%, and 6.3% for forage maize. The gas yields determined in the laboratory were able to be confirmed by the commercial plant results.

Table 1: Economic aspects of the digestion of green plants, calculated for a farm with 100 livestock units

	Co-ferment	Forage maize	4-cut leys (intensive)	2-cut leys (extensive)	Care of nature protection area
Stocking	[GV]	100	100	100	100
Co-substrate amount	[dt FM/d]	6	6	6	6
Growing area	[ha]	4.87	7.23	13.90	60.23
Dry matter yield	[dt TM/ha]	175	125	65	15
Substrate-spc. methane prod.	[m^3 CH_4/kg oTS]	0.35	0.41	0.24	0.10
Digester volume	[m^3]	250	250	250	250
Power production capacity	[kW_{el}]	28	29	23	18
Total costs of biogas plant, net of VAT	[DM]	172075	173730	166476	160501
Total costs of biogas plant with subsidy	[DM]	154868	156357	149828	144451
Specific investment/el. output (with subsidy)	[DM/kW_{el}]	5548	5333	6472	7995
Annual biogas plant costs (depreciation, interest, repairs)	[DM/a]	17438	17606	16871	16265
Annual costs silage storage area and additional slurry storage	[DM/a]	1720	1657	1657	399
Forage costs: cultivation, harvesting and yield in digester	[DM/a]	9213	5403	6365	28809
Gross margin II	[DM/a]	6691	11966	4860	-21387
Labour time requirement Cultivation and ensiling	[Akh/a]	367	452	455	844
Wages (electricity price 0.20 DM/kWh)	[DM/Akh]	18.22	26.47	10.68	
Electricity production costs (wages 25 DM/mh)	[DM/kWh]	0.21	0.20	0.24	0.56
Required minimum ground care compensation	[DM/ha]			468	705

Assumptions: Investment support: AFP; low interest loan: reduced by 4.8%; building cost subsidy: 10% max. 60000 DM; working phase 40 days; running time for electricity production 18 h/d; electr. production efficiency: 30%; Electr. price: 0.20 DM/kWh; heated living quarters: 250 m^2.

Economic viability

Building onto an investigation by [5] the economics of fermenting greencrop was investigated based on the example of a biogas plant on a 100 large animal unit dairy farm (*table 1*). With the addition of 6 dt silage per day, a dm content of 10% was achieved with the suspension fed into the digester. With this addition the total output from 5 ha forage maize, annual growth of 7 to 14 ha pasture or the mown yield from 60 ha nature reserve can be co-fermented. The model plant digesters were conceived for a working phase of 40 days and the appropriate power output for a running time of 18 h/d. For calculating system costs an investment grant was assumed according to the combined support of the agricultural investment support programme. The specific total investment costs at 5300 to 8000 DM/kW installed electricity capacity reflected that of the investigated commercial biogas plants. The costs for the co-substrates were according to the variable costs for production and harvesting and the specific fixed costs for the used silage area and the additional slurry storage required.

According to the calculations, working time for cultivation and harvest as well as for ensiling the plant material was taken as from 367 man hours (mh)/y for the forage maize (5 ha) up to 844 mh/y for the care of 60 ha nature reserve area with the subsequent ensiling of the greencrop is in the main dependent of the type of green crop being prepared for the biogas fermenting. Taking account of all costs, and wages at DM 25/mh, the production costs for electrical current representing something like the producer price of 0.20 DM/kWh as guaranteed by the „Renewable Energy Law“ is only possible through the digestion of forage maize and grass silage from intensive leys. Output from extensively-managed leys or nature reserves can only be cost-effective as biogas plant substrate where farmers are also paid for taking care of the those areas supplying the greencrop.