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Crops as a Digestion Substrate in Biogas Plants

In biogas plants, renewable resources are often used as digestion substrates. When designing the systems, it is important to know the yield potential of the plants used. Therefore, trials with different maize varieties, feeding beet, beet leaves, millet varieties, and sunflowers were carried out in a common project of the Agricultural Counselling Service Luxembourg and Hohenheim University. In addition, the interdependence of the degree of maturity, the nutrient- and energy content, and the methane yield was examined in these trials. Up to 10,000 m³ of methane per hectare were produced.

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Since not all agricultural areas are needed for food production, set-aside areas can be used to produce renewable resources, which can be employed as a co-substrate in biogas plants. Currently, numerous farms are already taking this route.

When a biogas plant is designed, a decision about the plant species and -varieties to be used must be made in addition to the choice of a suitable process technique. For an optimal choice, the Ecological Agricultural Counselling Service of the Foundation Eco-Fund and the Young Farmers and Winegrowers in Ettelbruck, Luxembourg, carried out cultivation trials in order to evaluate the suitability of different crops [1]. The biogas- and methane yield of the plants was measured in digestion trials at the State Institute of Agricultural Engineering and Building Research of Hohenheim University [2].

Material and Methods

The cultivation trial comprised eight different silo maize varieties with different maturity numbers and one feeding beet variety. These plants were cultivated extensively (52 kg N/ha) and harvested between 25 September and 7 November so that the degrees of senescence were also different. In addition, beet leaves, sunflowers, and two millet varieties without mineral fertilizing were included in the cultivation trial. The maize variety DOGE was cultivated conventionally with common mineral fertilizing (180 kg N/ha).

During the harvest, the plants were chopped, ensiled in glasses, and subsequently prepared for the digestion trials. With all kinds of silage, extensive nutrient analyses according to Weender and van Soest were carried out.

Digestion took place in three discontinuous fermenters according to the „Hohenheim biogas yield test" over a period of 36 days at a mesophilic temperature (37°C). Per substrate, three repetitions with cattle slurry as inoculum were planned. All substrates were able to be digested without any trouble.

Results

For the silo maize varieties, the dry mass yields achieved per hectare ranged between 139 and 257 dt/ha and, hence, corresponded to the yields reached in agricultural practice. At 257 dt/ha, the intensively fertilized variant of the DOGE variety significantly exceeded the average commonly achieved in practice. For feeding beet, a below-average dry matter yield of 134.4 dt/ha was reached. Sunflowers provided 55.5 dt/ha, and the yields of the millet varieties ranged between 30 and 33 dt/ha.

The maize varieties showed a clear dependence of the dry matter yield per area unit on the time of the harvest and the maturity group. At 19.8% dry substance, the DOGE variety, which had been harvested very early, had by far not achieved its possible yield potential. At 31.45% (dry-substance-related), it had a signficantly higher percentage of raw fibres than the matured variant with a dry substance content of 35.44% and a raw fibre content of 18.28% (*table 1*). In addition, the non-matured variant did not show optimal ensiling properties.

Figure 1 shows the biogas formation of selected substrates in the experimental period as a function of the digestion time in cumulative frequency curves as mean values of the three repetitions. This leads to the different gas formation rates and the achievable maximum biogas yield of the substrates.

In those maize varieties which were able to be harvested mainly at a mature stage with a dry substance content of 30 to 42%, the average, substrate-specific standard methane yield was 0.40 m³ methane/kg oDS with a standard deviation of 0.01. In the trial, those varieties which were harvested before yellow ripeness (DK 604 and a variant of DOGE) at a dry substance content of 22.2 and 19.8% provided a 6.5 and 16% lower substrate-specific methane yield of 0.37 and 0.33 m³ methane/kg oDS. At 0.40 m³ methane/kg oDS, beet also had a very high methane yield. At approximately 0.3 m³ methane/kg oDS, the yield of the other plants (among them the by-product beet leaves)

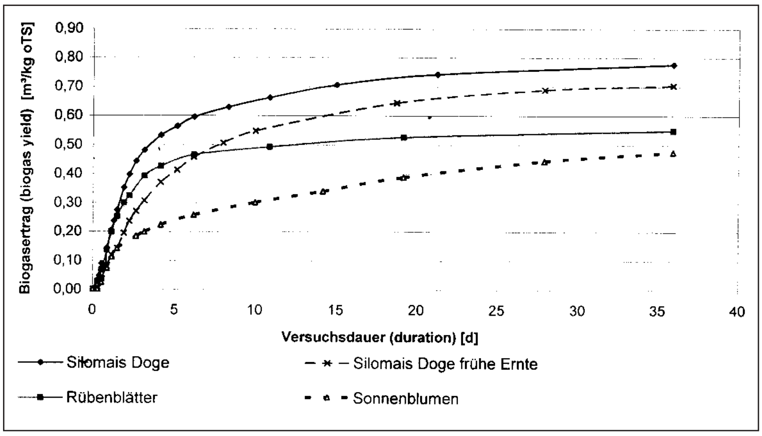

Fig. 1: Biogas yield of selected substrates as a function of digestion time (cumulative frequency curves)

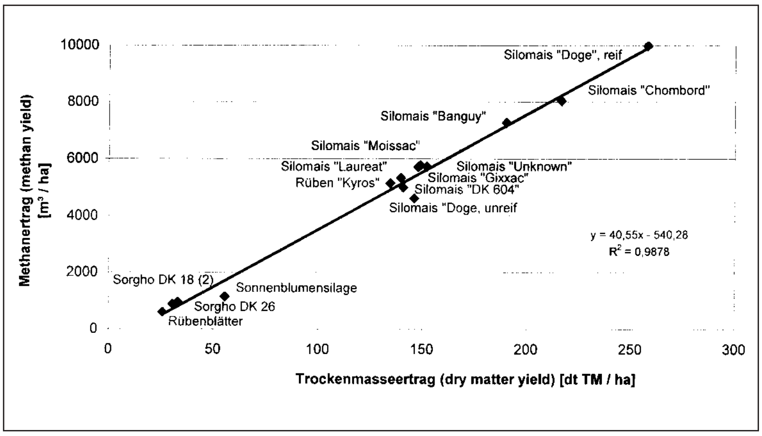

Fig. 2: Dry-matter yield versus methane-yield per hectare

was considerably lower (*table 1*). At 0.23 m^3 methane/kg oDS, the lowest yield was achieved with ensiled sunflowers having a high percentage of raw fibre. This, however, must likely be attributed to the very low degradation speed and the anaerobic degradation, which was not entirely completed after 36 days.

In all examined plants, the substrate-specific methane yield exhibits a clear dependence upon the nutrient content of the trial substrates. Especially the raw fibre content has a decisive influence on the degradability of the organic dry substance and thus negatively affects the methane yield. The C:N ratio of the substrates also exerts a significant influence on the convertibility of the organically bound energy into biogas. If this ratio is only approximately (15:1) like in beet leaves, for example, the organic mass cannot be completely converted even at low raw fibre contents. Substrates having a C:N ratio of (37 to 45:1), like beet and silo maize, for example, allow a significantly higher percentage of the organically bound energy to be converted.

The average methane content during the digestion of mature maize varieties was 52.5%. In millets and immature maize, methane concentrations of less than 50% were measured. The best values were achieved with beet, which reached a methane content of 57.5%. The low methane concentrations in the biogas are typical of the digestion of plants rich in carbohydrates. According to stoichiometric calculations, the digestion of carbohydrates only results in a methane content of 50% in the biogas [3].

For the practical farmer who plans a biogas plant, the ultimately decisive question is which plant or which variety provides the highest methane yield per hectare because this has a decisive influence on the profitability of his biogas plant. *Figure 2* lists the dry matter yield per hectare and the methane yield in m^3 methane per hectare. This also shows the clear interdependence of these two parameters. At a methane production of approximately 10,000 m^3 per hectare, high-yielding silo maize varieties characterized by late senescence and, hence, long exploitation of the vegetation period, provide the best results. Extensively fertilized varieties of maize and beet only yielded 50% of this methane production. Under economic aspects, millet and sunflower are inappropriate for cultivation with the goal of digestion. Even though beet leaves as a by-product only allow low hectare yields to be achieved, they may be appropriate for digestion if harvested at low expense.

Summary

This study has confirmed that the cultivation of selected crops, such as maize silage or beet and their digestion in agricultural biogas plants may enable a considerable methane yield to be reached. For the most efficient possible conversion of the energy organically bound in the plant mass into biogas, the crops must be chosen and combined depending on their raw fibre content and the C:N ratio. Due to the strong dependence of the methane yield per area unit on the plants' dry matter yield potential, it is well possible that maize used as a digestion substrate in biogas plants requires other breeding objectives than silo maize cultivated for cattle feeding. In the years to come, crop breeding and biogas process engineering must try to answer this question.

Literature

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Plant species/ -variety	Maturity index Maize	DM-yield [dt/ha]	DS [%]	oDS [% of DS]	Nutrients XP [% of DS]	XF [% of DS]	NfE [% of DS]	ME [MJ/kg oTS]	Methane yield [m^3/kg oDS]
Maize Banguy	240	190,1	37,78	97,1	6,73	14,15	73,08	12,4	0,39
Maize GIXXAC	270	139,6	33,83	96,6	7,44	17,63	68,40	11,8	0,40
Maize Chamboro	290	216,3	36,47	96,4	6,76	17,16	69,36	11,9	0,39
Maize Laureat	300	147,8	41,64	96,8	6,52	16,79	70,36	12,0	0,40
Maize Moissac	420	148,8	29,56	96,7	6,24	18,80	68,57	11,7	0,40
Maize DK 604	580	140,7	23,12	95,9	6,25	20,83	65,73	11,4	0,37
Maize Doge	700	257,8	35,44	96,2	6,18	18,28	68,63	11,8	0,40
Doge early harvest	700	145,9	19,79	95,2	7,26	31,45	56,53	9,8	0,33
Maize unknown		152,0	39,42	96,7	6,80	13,68	73,16	12,4	0,39
Sunflower		55,5	34,83	88,1	7,11	58,89	15,29	8,5	0,23
Millet DK 18 (2)		33,1	25,76	93,1	8,72	29,10	54,31	8,1	0,31
Millet DK 26		30,6	24,11	92,7	10,77	26,34	54,40	8,6	0,31
Feeding beet Kyros		134,4	23,00	95,3	6,20	5,40	83,40	12,7	0,40
Beet leaf		25,8	11,18	79,9	15,84	13,42	47,26	9,5	0,29

Table 1: Yield data and nutrient contents of different cultivated crops and their methane yield