DLG Expert Knowledge Series 386

Biogas from Grass

How grassland growths can contribute to producing energy

Competence Center
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1. Introduction

The demands made of grassland management to produce high grade basic diet in cattle husbandry call for appropriately high management intensity, which in view of the currently high prices for protein feedstuffs is becoming more significant. However, as the demand for basic feed can frequently be satisfied already with the first two cuts as regards quantity and quality, and as cattle stocks in many dairy regions have declined in recent years as performance has been boosted, substantial quantities of green matter that are no longer needed for animal husbandry and for which no expedient use is evident are produced every year. Moreover, for environmental-ecological reasons it is not possible to simply plough up permanent grassland and use it for other purposes. "Two cuts – and what then?" was therefore the question raised already at the DLG Grassland Conference in 1998.

Throughout Germany the development of farm biogas plants operated with renewable raw materials has increased substantially. The shortage of substrate is now becoming perceptible in some regions. Even if silage maize represents the most suitable plant at present, the substrate for biogas plants need not necessarily be specifically cultivated. The biomass generated on grassland sites can serve as a substrate supplement in biogas plants for decentralized energy supply.

2. Grassland growth as substrate for digestion

Today already 30 – 40 % of the biogas plants in Germany are operated with grass or grass silage as co-substrate. On average the share of grass silage in the total substrate is reported as 8 % by weight. In Baden-Württemberg the level is on average 20 %. In regions with a high grassland component the shares are even well over 50 %. Biogas plants that use 100 % grassland growth are, however, only encountered in isolated cases.

2.1 Specific properties, general suitability, yields

Well mechanizable and intensively managed areas are generally needed for low-cost biogas production from grass growth. Accordingly, on the one hand use of the growth

as biogas substrate stands in direct competition with use as feed in dairy cattle farming, while on the other hand using grass growth in a biogas plant is particularly attractive for farms that combine biogas and milk production.
The first growths have a very high feed quality because of their high energy and crude protein content. They are thus important especially for dairy cattle feeding. The following growths that do not display such high quality are converted more poorly by the animals, but can be degraded well by the microorganisms in biogas plants. This combination makes it possible to defuse the competition situation and, depending on the quality of the harvested product, to satisfy both avenues of use by targeted coordination.

The digestibility and hence the speed and extent of methane formation in the biogas plant are influenced by the chemical composition of the plant material. The microorganisms can only convert the organic dry matter (oDS) into biogas, with simple molecules such as saccharose (sugar) being degraded more quickly by comparison with relatively complex compounds such as cellulose and hemicellulose.

Table 1: Grass ingredient contents by comparison with maize

		Grass silage	Maize silage
DS	[%]	22 – 55	24 – 37
oDS	[% of the DS]	85 – 94	95 – 99
ADF	[g/kg DS]	177 – 435	126 – 269
ADL	[g/kg DS]	11 – 78	9 – 24
Nitrogen	[%]	1.1 – 3.4	0.1 – 1.7
C/N ratio		approx. 11	approx. 55

With a relatively long dwelling period in the biogas plant, the slow-degradable substance too can still be digested well. Substrates with a low energy density of below five MJ NEL can thus also achieve a satisfactory gas yield. As regards the specific methane yield, the informative power of the energy density in MJ NEL (net energy lactation) is of low significance and the higher crude fibre contents of grass (Table 1) do not necessarily lead to lower methane yields [4]. The dwelling time of the digestive substrate in the biogas plant and the share of lignin that cannot be converted into biogas are crucial determinants.

Alongside these criteria the substrate quality is also important, as are the plant technology and the process management. Grassland management and the subsequent conservation influence the substrate quality. Important factors that have to be steered and checked include the vegetation composition, the cutting time, the chopping length and the use of ensiling agents.

Figure 1: The turf composition influences the biogas recovery rate [1]

When a high amount of crude fibre-rich substrate is used, specific properties need to be observed that require adaptation of the plant technology. In order to feed the grass silage better into the digester and avoid process upsets resulting from the formation of floating layers, the grass substrate should be reduced in size as far as possible before feeding into the plant. Dosing equipment must loosen the substrate, augers and riser pipes must have sufficient diameters and take routes that as far as possible have no bends or only wide bends in order to prevent clogging. Slow-running agitators are preferable in the actual digester. Altogether it is to be expected that the higher agitator input means higher electricity consumption and stronger wear. Experience has shown that by comparison with maize the earth and stone component in grass cuts is higher. Accordingly it is important to examine the machinery and equipment for suitability before purchasing or before using crude fibre-rich substrates.

The close correlation between the dry matter (DM) yield and the methane yields/ha requires yield-rich grassland for cost-efficient use. Generally, site-appropriate stand management following which the same criteria applying for feed production in needs-driven dairy cattle management is sufficient.

Figure 2: Grassland shortly before mowing [1]

Alongside site-adapted species, varieties and mixtures, all yield-increasing measures such as fertilizing, tending and the design of the cutting regime form part of successful management (see also DLG Expert Knowledge Series 328). At the same time the crude ash content should be minimized. Accordingly, the long-known rules of grassland care (levelling and rolling) should be maintained, injury to the turf should be avoided (e. g. by not driving over at the wrong time, by adjusting the implements correctly), and/or the working height during harvesting work in general should be considered. One of the most important influences on the DM yield, alongside site factors, is the botanic composition of the grassland. In experiments the grasses and mixtures shown in Table 2 proved to be particularly suitable. However, other top grasses (tall fescue, white agrostis, and reed canary grass) have a high yield potential and produce high methane yields.

Table 2: Dry matter yields from grassland/maize (WURTH, 2008)

Substrate	DM yield/a [dt/ha]
Cocksfoot	110 – 168
Perennial ryegrass	80 – 139
Grass-clover mixture	118 – 194
Silage maize	181 – 214

By contrast with performance-oriented dairy cattle feeding, the correlation between ingredients contents and methane yield is lower than between yield and methane yield.

Options for optimizing results lie above all in organizing the cutting regime. By comparison with grass for dairy cattle feeding, it is frequently possible to reduce the frequency of use by one cut. The optimal cutting date can also be deferred depending on the ageing speed of the stand (especially with ryegrass varieties).

Alongside the grass growths from intensively managed fields, on many farms cut material is generated from areas that are used very extensively and for which there is no competition for use, as dairy cattle feeding does not enter into consideration here. These include for example grassland with FFH habitat types (e. g. flatland hay meadows or mountain hay meadows), which may not be intensified any further for reasons of nature conservation and that can only be used very late. Landscape care material can also serve as a substrate for biogas plants. Growths on such areas lose approx. 10 – 20 % of the methane yield by comparison with cuts from intensively used areas. With a late cutting date, the degree of lignification in the substrate rises strongly and with it the lignin component. This process has a negative influence on the methane recovery rate and greatly restricts the use of the substrate for biogas plants.

2.2 Harvesting method, conservation, storage

A number of different work steps are necessary to ensile grassland growth. The complete process chain comprises cutting, collection, transport and conservation.

The optimal cutting date for grassland used for biogas production should be three to four days after that used for dairy cattle fodder [1]. In order to keep the degree of soiling (sand) in the digester as low as possible, a minimum cutting height of 7 cm should be observed during harvesting and the position of the working implements should be adapted appropriately when turning and swathing. Such measures also reduce damage to the sod and promote re-growth of the plant stands. This potential subsequent disturbance factor should be considered already in the tending of grassland (e. g. levelling of mole-hills or vole-hills).

A high sugar content at harvesting time guarantees a high energy content (6.4 MJ NEL/kg DM) in the dry matter.

A short chopping length (5 – 7 mm) renders the grass material optimal for ensiling and improves digestibility in the digester. A number of techniques and process combinations can be used here.

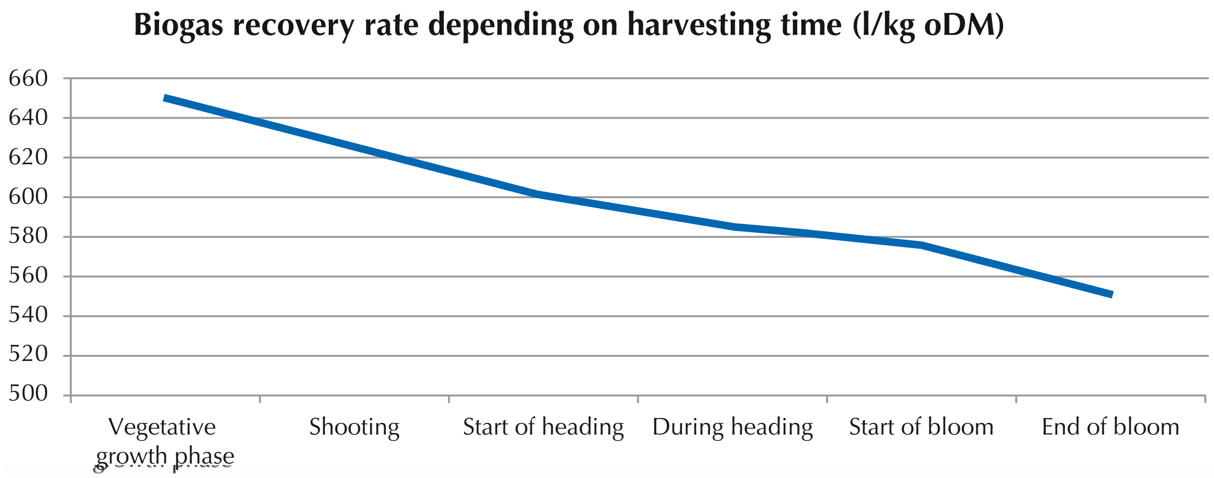

Figure 3: Biogas recovery rate from grassland growth depending on the harvesting time [Lütke-Entrup, Gröblinghoff, 2005]

Generally, grass growths are conserved as silage for biogas plants. As in dairy cattle feeding, good silage quality (Table 3) is extremely relevant, as spoiled fermented silage leads to massive losses in the biogas yield by comparison with high-grade silage. In addition to the sugar content, the crude fibre content of the grassland growth influences the compressibility and is a key factor. Both can be influenced by selecting the optimal cutting time.

Table 3: Contents to be targeted in grass silages (after DLG, 1999; SPIEKERS, 2004)

Parameter		Grass silage
Dry matter	%	30 – 40
Crude ash	% of DM	< 10
Crude fibre	% of DM	22 – 25

On ensiling, sugar is converted into lactic acid by anaerobic microorganisms. Accordingly, careful exclusion of air in the substrate is important for the ensiling process and should be observed already during filling and compacting. Compaction in the silo can be improved, for instance, by a short chopping length of 5 – 7 mm of the material for digesting. This also has a positive influence on the subsequent degradability in the digester, as it offers a relatively large target area for the bacteria.

The most frequently used method for conserving wilted silage is the bunker silo method. Bunker silos can be filled quickly and the silage can be compacted intensively. During storage intake it is important to work quickly in order to ensure sufficient, continuous compaction. Compaction should be carried out with a freshly delivered layer of max. 30 cm, with as a rule of thumb one metre silo length per cubic metre load volume on the trailer. If the compaction time of 2 – 3 min./t silage material is exceeded because of high harvest quantities, then two vehicles should be used for compacting. In order to ensure a good quality fermentation process, the storage density should be 200 to 210 kg DM/m^3 depending on the DM content. The compaction and chopping processes contribute to suppressing undesirable microorganisms (yeasts, fungi and bacteria).

The harvested material should be wilted to a dry substance content of at least 30 %. In high silo stacks, a level above 30 % is more effective. However, if wilting is carried out too strongly, this inhibits the formation of the lactic acid and the pH value does not drop sufficiently. That is why short field periods of at most 35 hours are recommended.

In order to avoid post-warming or mould formation, in addition to complete compaction a good cover and proper unloading are particularly important.

Alongside the disadvantages already stated, high sand contents or a high degree of substrate soiling are detrimental to good fermenting. In order to maintain the quality of the harvested material as far as possible, ensiling agents can be used. These affect the fermentation process, suppress undesired microorganisms and reduce nutrient losses. Biological additives such as lactic acid bacteria accelerate the lactic acid fermentation. Chemical additives such as organic or inorganic salts and acids inhibit faulty fermentation and restrict the fermentation intensity. However, the content of carbohydrates for lactic acid bacteria can be steered by adding enzymes or agents with a sugar content. The use of ensiling agents not only improves their fermenting quality, but also promotes the conversion of the substrate in the biogas plant. The addition of agents with a sugar content provides the microorganisms in the biogas plant with additional nourishment. Enzyme preparations improve the breaking down of the organic substance and acids promote or inhibit microorganisms. Here too, however, it is important to weigh up the effort involved and the benefits.

2.3 Conditioning and dosing

In order to offer the microorganisms in the biogas plant a larger target surface area and thus to improve and accelerate degradation of the substrate, the substrate should be suitably conditioned. Selecting a short chopping length for the green material creates optimal conditions for the microorganisms.

3. Digestion and gas yields

The digestion of grassland growths makes higher demands on the process parameters (e. g. dwelling time, temperature) than other substrates. The total dwelling time lies between 100 and 150 days. A thermophilic (50 – 55 °C) process management increases the microorganism activity and improves the stirring capability thanks to faster substrate degradation. However, as the temperature rises, the ammonium nitrogen components increasingly change into process-inhibiting ammonia. The digestion process also responds more sensitively to upsets (due to the few species of methanogenic microorganisms). Thus an excessively high temperature here has a negative effect on the process stability. A constant temperature level is more important for a stable digestion process.

That is why a process temperature of 40 °C is recommended for the plant concepts [6].

The substrate-specific methane (CH_4) recovery rate is on average 300 norm litres (Nl) per kilogram organic dry matter (oDM) for grassland substrates. Ranges of approx. 200 – 400 CH_4/kg oDM are stated. The methane yields of maize are on average 370 Nl/kg oDM and thus on average around 20 per cent higher than the yields of grassland substrates.

Table 4: Substrate-specific parameters (guiding values)

Substrate	DS [%]	oDS [%]	GAS [Nl/kg oDS]	Methane component [Nl/kg oDS]
Maize silage	32	93	677	392
Grass silage	19 – 32	85 – 88	407 – 607	220 – 328
Various feed grasses				
Perennial ryegrass	25	87	570	302
Annual ryegrass	23	91	624	331
Smooth-stalked meadow grass	27	92	624	331
Meadow fescue	24.8	90	626	332
Red clover	17.6	84	633	342

In addition to the silage quality and plant composition of the grassland, the cutting regime with the parameters of cutting frequency and harvesting time exert a major influence on the yields. The crude fibre component that is more difficult to degrade increases at later harvesting dates. Since biogas plants are also able to convert growth with a somewhat lower energy density well, as already described, where appropriate it is worth considering whether it might be useful to reduce the cutting frequency in order to save time and costs. It is observed in practice that biogas plants already reduce the frequency of use of grassland by one cut. The autumn growth is frequently combined. Studies over many years at the Landwirtschaftliches Zentrum Baden-Württemberg (LAZBW Aulendorf – Baden-Württemberg Agricultural Centre) show that a reduction in the grassland cutting frequency from five to three cuts results in hardly any methane reductions, while a further reduction in frequency of use from three to two cuts has a negative impact.

4. Cost-efficiency

4.1 Substrate costs of grass silage

Alongside the construction costs, the substrate costs are the crucial parameter for cost-efficient success of biogas plants. If grassland could be used, for example, for dairy cattle or for producing hay, under certain circumstances opportunity costs may arise that have to be covered by the biogas plant. Frequently, however, there is no alternative use.

The costs of grassland management are made up of tending and harvesting costs (which include all other costs such as lease, fertilizing, machinery costs). Table 5 summarizes typical guide values for the individual cost items. The tending measures such as levelling and re-seeding cannot be costed generally and depend strongly on the condition of the grassland. For levelling the meadows and possibly rolling, as well as an initial mineral fertilizer application, costs of around 100 €/ha can be appraised, in other words about 4 to 5 €/t grass silage. Even if the digested residues are returned completely to the land, moderate nitrogen application may still be expedient, as unavoidable nitrogen losses have to be compensated and mineralizing of organic fertilizer starts too late for the first growth.

The substrate costs are determined essentially by the harvest. Especially the last cut is incommensurately expensive due to the generally low yield. If the technology of the biogas plant allows alternatives, the offer prices and services of the contractor play an important role here in selecting the individually adapted harvest chain.

If longer haulm material does not have any negative effects on the process stability of a biogas plant, and where short transport distances and a large number of small fields are involved, self-loading trailers are to be preferred. Pure harvesting costs of less than 12 €/t FM for wilted silage can only be achieved under optimal conditions. In general, the harvesting costs lie between 12 and 30 €/t FM. Good organization and coordination of the harvesting chain is crucial for low-cost collection.

For most biogas plants the chopping chain is used. Chopping generally costs at least 4 €/t FM. The diesel consumption is of the order of magnitude of 0.8 to 1.0 l/t FM.

Table 5: Guide values for production costs of grass silage free input including storage and use of digester residues

Cost item		Conditions	
		favourable	unfavourable
Meadow tending	€/t FM	1.5	2.5
Fertilizing	€/t FM	2.5	2.5
Mowing	€/t FM	3.0	4.0
(Turning)	€/t FM	1.0	2.0
Swathing	€/t FM	1.0	2.0
Chopping	€/t FM	3.5	6.0
Transport	€/t FM	3.0	12
Compacting	€/t FM	1.5	2.0
Covering the silo	€/t FM	0.5	1.0
Losses	€/t FM	2.5	4.0
Silo	€/t FM	3.0	4.5
Unloading[1]	€/t FM	2.0	3.5
Spreading digester residues	€/t FM	3.0	4.0
Total costs free infeed[2] €/t FM		27	48
	€/t TM	**77**	**137**

[1] with labour costs
[2] without turning

The mean substrate costs in the year 2007 were 26 €/t FM for grass silage [3]. The range of substrate costs is 15 – 45 €/t FM.

The transport costs naturally depend on the transport distance and are in the order of 2.00 €/t for very short distances (2 km). Roughly 0.40 €/(t*km) can be calculated for each further kilometre of agricultural transport operations.

Costs of around 1 to 2 €/t FM are incurred for compacting silage. The silo should be covered as a matter of principle. Open silo heaps suffer high additional losses. Generally it is sufficient to reduce these by one to two per cent in order to cover the additional costs this incurs.

4.2 Cost-efficiency of grass digestion plants

At grassland sites with declining feed use, biogas production represents an alternative. The following model calculation aims to show whether it can be worthwhile operating a biogas plant with grass silage and slurry under the conditions of the Renewable Energy Act (EEG) in the version of 2012.

In the following model calculation the costs of providing the grass silage free solids infeed amount to 32.50 €/t FM. This sum comprises all costs incurred by mineral fertilizing, harvesting, transport, storage intake, storing (taking weight losses and seepage juice generation into account), unloading and feeding, as well as spreading digester residues. The cattle slurry is available free of charge. The gas recovery rates of the substrates on which the calculations are based are summarized in Table 6. It is assumed that 35 % of the useful thermal energy can be marketed in compliance with the EEG and after deduction of the costs for providing heat a surplus of 2.00 Ct/kWh$_{therm}$ can be achieved.

Table 6: Substrates and their quality parameters according to the KTBL calculation data

Substrate	DM (%)	oDM (%)	Nm³/t oDM	Nm³/t FM	Methane (%)
Grass silage	35	90	600	189	53
Cattle slurry	8	80	380	24.3	55
Cattle manure	25	85	450	95.6	55

Table 7: Model calculations according to the EEG 2012 for the commissioning year 2012

Installed electric output		KW_{el}	75	190	500	1,000
Revenues from electricity sales	Commissioned 2012	Ct/KWh_{el}	20.88	20.39	19.14	17.44
Heat sales		kWh	306,331	718,400	1,743,029	3,220,240
Heat proceeds minus costs	2 Ct/kWh_{el}	€/a	6,127	14,368	34,861	64,405
Total proceeds		€/a	127,900	320,975	801,581	1,480,289
Total annual costs of biogas plant		€/a	97,021	224,577	437,189	782,007
Substrate costs free solids infeed	Grass silage 32.5 €/t FM	€/a	40,625	113,750	310,700	629,850
Profit expectation (without labour costs/rates)		€/a	**-2,305**	**-6,908**	**36,232**	**100,032**
(Entrepreneur) profit expectation		€/a	**-9,745**	**-17,351**	**17,692**	**68,433**

In the model operation a small farm biogas plant (75 kW_{el}) processes around 1,250 t grass silage, for which – depending on the site – 45 to 70 hectares permanent grassland must be available to supply the substrate. In addition, the plant uses slurry from approx. 100 cattle large animal units and 260 t cattle manure. At 6,000 €/kW_{el}, this small plant has relatively high procurement costs. The correspondingly high fixed costs have a negative effect on the farm results. The remuneration under EEG 2012 is by far not sufficient to operate the small biogas plant cost-efficiently.

A 190 kW_{el} biogas plant in the model operation covers its substrate requirement with 3,500 t grass silage, the slurry from around 150 cattle large animal units and a small quantity of manure. The area requirement lies between 125 and around 300 hectares, depending on the yield expectation. This plant would not be built under the conditions specified in the EEG 2012. Under otherwise equal conditions a plant will only just rise above the break-even point when the procurement costs drop well below the one million level.

A 500 kW_{el} biogas plant in the model operation requires between 350 and 550 hectares of grassland for its raw material supplies. Under the conditions of the EEG 2009, however, it was extremely competitive. It uses a little more than 30 per cent by weight slurry and manure and thus secures the slurry bonus. Under the conditions of the EEG 2012 the entrepreneurial profit drops to below € 20,000. The return on capital is now only a good six per cent.

Under the remuneration conditions of EEG 2009, the 1,000 kW_{el} biogas plant with investment costs of 3,500 €/kW and using 19,000 t grass silage could not be operated profitably. The massive increase in remuneration for large plants in EEG 2012 makes the plant more attractive. Under the model assumptions, an entrepreneurial profit of around € 68,000 can be calculated. With a land requirement of 700 to 1,100 hectares, the scope for lease payments or increases in substrate prices is low. In order to move into economically less troubled waters, the plant requires distinctly better heat exploitation than is assumed here.

When is it worthwhile using grass by comparison with maize?

This question is repeatedly posed. Maize and grass silage are compared on the basis of their costs of provision free infeed. The "maize price free infeed" should be between 30 and 50 € per metric ton fresh matter (33 % DM). To compare this with the costs of grass silage the following assumptions are made: the grass silage can also be provided at a cost of 90 to 100 € per metric ton dry matter free infeed, depending on the harvest yield and without taking the land use costs into account. Dry matter storage losses of 12 % and grass-related extra costs in plant operation of 3 € per metric ton fresh matter were also taken into account.

This results in the "affordable" land use costs (= lease payments) for permanent grassland that are competitive for grass silage in competition with the maize price assumed in each case. If the grassland is available free of charge and if the grass silage can achieve a good quality gas recovery rate, then depending on the grass yield (Figure 4) and at maize costs between € 35 and 39 it becomes an interesting alternative.

If, under the same assumptions, despite a high hectare yield of 10 metric tons dry matter it is only possible to achieve an 80 % gas recovery rate, then grass only becomes an alternative without land use costs at a maize price of around € 44. Figure 4 shows the lower gas yield as a dotted line.

If the maize costs "free infeed" rise to € 50 per metric ton fresh matter, a lease payment of between € 150 and 350 per hectare could be "afforded" for grassland areas. However, with such high substrate costs the question arises as to whether plant operation could fundamentally be conducted profitably and continued in the customary form at all.

Conclusion: The use of grass is cost-efficient under the present cost ratios if the following conditions are satisfied:

- The biogas yield of the substrate may not be too low. As in cattle feeding, care must be given to appropriate quality. The use of poor quality grass silage causes higher costs.
- The logistic chain in ensiling must work efficiently. Large fields and large total quantities lead to lower costs than small fields and smaller total yields.
- The plant technology must be coordinated for the use of grass silage. Inadequate technology leads to extra costs in the event of failure. Moreover, the substrate cannot be broken down completely.

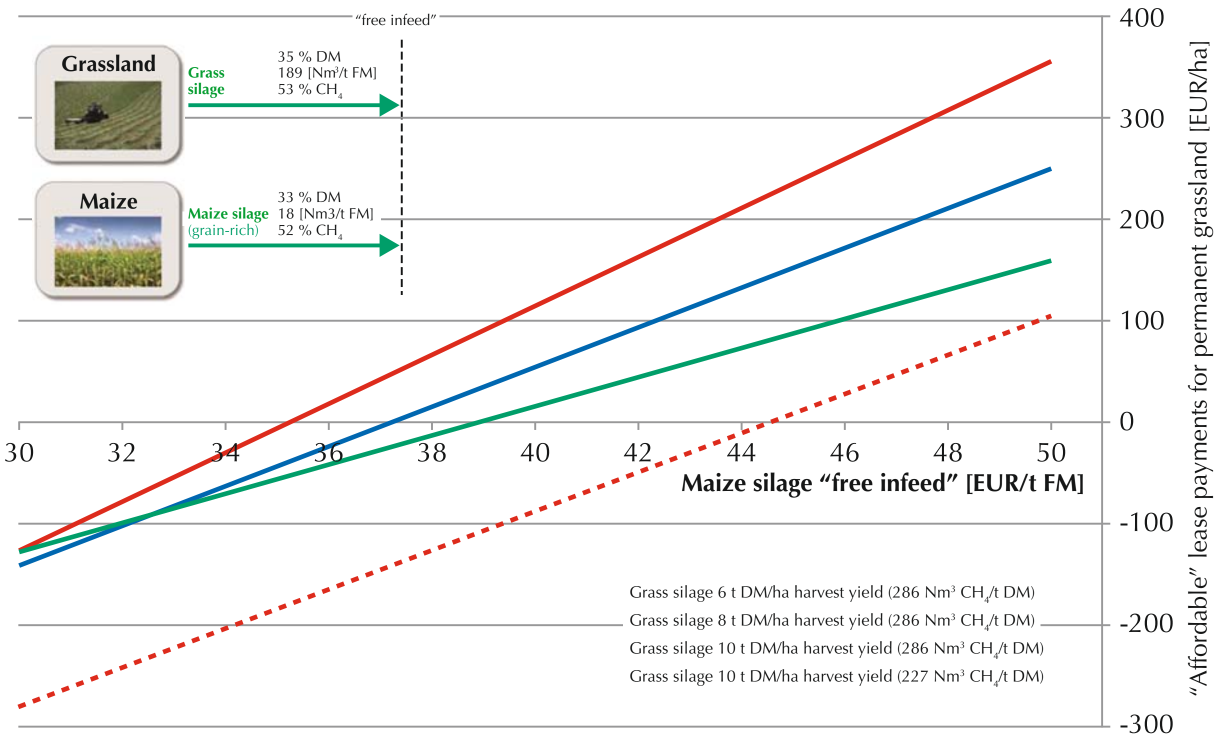

Figure 4: Affordable land use costs for permanent grassland

5. Use of digester residues in grassland

Land used for agricultural purposes requires that the nutrients withdrawn by harvesting be returned in order to enable sustainable management. Nutrients can be provided on the one hand via purchased mineral fertilizers, and on the other hand by organic fertilizer (cattle slurry), or where biogas plants are operated by digester residues. During the entire digestion process the nutrients remain largely contained in the substrates. At most the carbon fraction is changed. Thus at the end of the digestion process a nutrient-rich digester residue remains. In individual fertilizer strategies the digester residues can be integrated optimally. Moreover, by comparison with strategies using mineral fertilizers they display a distinctly better energy balance [5]. In order to bring the nutrients contained in the digester residues to the plant roots with customary precision, techniques such as those used when applying fluid organic fertilizers can be applied. Spreading close to the ground is preferable. The higher ammonium-N share in conjunction with a high pH value of generally > 8 in the digester residue leads to the possibility of nitrogen losses in the form of ammonium gassing being high after spreading. That is why care should be taken that optimal conditions prevail when spreading digester residues. Furthermore, fibre-rich digester residues can cause problems in spreading. However, this can be remedied by separation.

The legal requirements (laws governing fertilizer, hygiene and solid waste) must always be observed in the further use of the digester residues as fertilizer.

6. List of abbreviations

MJ – Mega joule
NEL – Net energy for lactation
DS – Dry substance
oDS – Organic dry substance
ADF org. – (Acid Detergent Fiber): the residue after treatment with defined acid detergents, comprises lignin and cellulose, lies about 30 g/kg DM higher than the crude fibre, contains only the organic part
ADl – (Acid Detergent lignin): by definition comprises above all the lignin and is a component of the ADF: ADF without the cellulose. Batch experiments – laboratory experiments in closed containers

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The German Federal States made many documents that are not listed in detail here available to the members of the DLG "Grassland and Forage Cropping" and "Biogas" Committees for the purpose of preparing this Information Leaflet, for which we are extremely grateful.

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