Catalogue of biomass quality discription for different categories of grass residues V1.0
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1. Introduction

The potential to use grass as a fuel is considerable but in order to assess the economic profitability of the valorization of this material with anaerobic digestion, its biogas potential (BGP) has to be known. There are a lot of parameters determining this. During the growth and harvest of the plant the BGP (expressed in Nm³ biogas/ ton DM) is strongly influenced and after storage and pretreatment it could have increased but also decreased. Pretreatment can have a positive impact on the BGP. Because it can make the degradable compounds more accessible for the microorganisms. Reactor design is another important parameter. Full scale digesters have more trouble reaching the high BGP's reported in literature during laboratory scale experiments. The addition of micronutrients or enzymes during digestion can also improve the biogas yield.

The BGP can be estimated using the concentrations of different components in the biomass but in this paper it is estimated using characteristics of the biomass during the different stages: such as growth, mowing, storage and pretreatment before it ends up in the digester. In order to have a high quality feedstock for the anaerobic digester it is necessary all steps of this processing chain are done properly. In this model the grass will be given a score during each of these steps and this will result in an estimated BGP.

During all of these stages the BGP depends on more factors. First of all the influence of different factors during the growth of the grass, will be investigated more thoroughly and every parameter will be given a mathematical effect that will be put together into a model.

1.1 Growth factors

The biogas potential per ton of DM of grass from intensively cultivated grassland and public green areas is 650Nm³ biogas/kg DS but for nature management grassland this is only 250Nm³ (18, 19, 51). The yield (dry mass) per hectare per year is also 8 times higher for the first one compared to the latter. It is approximately between 1.5 t/ha·y from single-cut conservation grassland and up to 12.6 t/ha·y intensively managed grasslands or fertilized public green areas. This difference results in biogas production per hectare which is about 25 times lower for one hectare of conservation grasslands compared to intensively managed grasslands or fertilized public lawns. Compared, this is 300 m3/ha from conservation grasslands with 7.560 m3/ha from intensively managed grasslands, including fertilized public lawns. Public lawns (such as sports fields) are fertilized and they are also cut much more than the other fields, about 20 times compared to 1-4 times. These characteristics explain the higher biogas yield. The grass remains short and young and contains therefore less components which are non-biodegradable.(1)

The intensity of management is defined by the frequency and dating of harvesting, fertilization, water table control, re-seeding and mechanical treatment. (18) Grasslands in dry regions in Portugal or the south of Italy that are not managed will have a very low BGP because of the continuous water deficiency, especially per hectare. The same could be said for grass from the Pyrenees of Alps. In the latter the BGP is three to four times higher in the intensively farmed valley than the extensively used mountainous site at the same cutting frequencies. (16) The values in table 1 are less pronounced

(18). The BMP (biomethane potential (Nl/kg ODM)) and ABMP (area specific biomethane potential (Nl/ha)) are reported in this table.

Table 1: Intensity of grassland management (18)

	BMP (Nl/kg ODM)	ABMP (Nl/ha)	Conditions
8 Grass from a hill site, extensively used, and a valley site, intensively used, one to four cuts per year at varying stages of vegetation, samples fresh and ensiled, Austrian Alps, 2004			First/last cut Laboratory/batch/40 C/40 d/ mono-digestion
Valley site, 4 cuts per year, first cut stem elongation	257/351	3459	
Valley site, 3 cuts per year, first cut inflorescence emerged	362/243	3187	
Valley site, 3 cuts per year, first cut inflorescence emerged-anthesis	315/190	2746	
Hill site, 3 cuts per year, first cut inflorescence emerged	221/152	1108	
Hill site, 2 cuts per year, first cut anthesis	171/128	977	
Hill site, 1 cut per year in August	153	649	
Different cutting frequencies, south Germany			Laboratory and farm/semicontinuous/ 37 C/25 d/codigestion
Four cuts per year, ensiled	390	n.r.	
Two cuts per year, ensiled	220	n.r.	
Landscape management	80	n.r.	

Table 2 summarizes the effect of fertilization and a different number of cuts in southern Germany. It can be concluded that the beneficiary effect of mowing 4 times compared to 2 times is insignificant for the DM. If you take into account the energy necessary to mow, the additional methane produced is not enough to make it worthwhile. Doubling the nitrogen fertilization from 30 to 60 kg nitrogen per hectare per cut was also insignificant. Therefore it is concluded that the most sustainable system is a two-cut regime with a fertilization level of 30kg nitrogen per cut. This system maximizes the net energy yield for permanent grasslands in southern Germany (46).

Table 2: Management of grassland (46)

	kg nitrogen per hectare per cut	**Dry matter yield (t ha^{-1})**	**Methane yield (L kg−1)**
2 cuts per year	30	10.25 ± 3.24	232.66 ± 3.86
	60	10.84 ± 2.69	231.92 ± 3.38
4 cuts per year	30	9.05 ± 3.00	287.43 ± 3.56
	60	10.70 ± 3.09	288.40 ± 2.98

The difference in BGP between different species was not significant in a study done by Tilvikiené et al. Tall fescue, cocksfoot, and reed canary grass yielded a BGP between 9.5 and 16.1 MJ kg^{-1}DM(32). Other similar experiments are summarized in table 3. The differences in BGP between different species were in these tests also minor. (18)

Table 3: Grass species (18)

	BGP (Nl/kg ODM)	**BMP (Nl/kg ODM)**	**ABMP (Nl/kg ODM)**	**Conditions**
Four grass species from Switzerland				Laboratory/batch/35 C/35 d
Timothy	490	n.r.	n.r.	
Cocksfoot	540	n.r.	n.r.	
Reed canary grass	535	n.r.	n.r.	
Meadow foxtail	420	n.r.	n.r.	
Eight grass species, first cut in mid-May, fresh and ensiled, northeast Germany, 2001				Fresh/ensiled Fresh/ensiled Fresh Laboratory/batch/35 C/28 d/ mono-digestion
Perennial ryegrass	904/929	629/650	2041	
Cocksfoot	800/718	554/503	1480	
Tall fescue	836/818	566/n.r.	1462	
Red fescue	845/767	624/506	1723	
Meadow fescue	909/846	641/584	2621	
Meadow foxtail	804/n.r.	554/n.r.	1463	
Timothy	828/591	556/401	1362	
Meadow fescue x ryegrass	n.r./921	n.r./599	n.r.	

From table 4 it can be concluded that different species do not influence the specific methane yield. Per hectare the methane production mostly depends on the DM production. The results are very similar to the conclusion of Khalasa who found that the correlation between the methane specific yield per hectare and the biomass yield per hectare was very high (R^2 = 0.97). He advices to maintain a legume abundance since that causes high biomass yields (34). For this dataset the R^2=0.93. The potential methane yield is calculated based on the methane yield from the first cut.

Table 4: Grass species (47)

Grass species	DM productionfrom 1st cut (t ha^{-1})	Specific methane yield (Nm^{3}t^{-1} DM)	Methane yield from 1st cut (Nm^3 ha^{-1})	Total annual DM production (t ha^{-1})	Potential methane yield (Nm^3 ha^{-1})
Italian ryegrass	2.96	237	702	8.82	2090
Perennial ryegrass	2.61	233	608	8.47	1974
Meadow fescue	3.74	214	800	9.59	2052
Timothy	5.47	227	1242	12.11	2749
Cocksfoot	4.76	230	1095	11.11	2555
Tall fescue	4.01	239	958	11.08	2648
Festucololium (festucoid)	3.62	228	825	10.75	2451
Festucololium (loloid)	4.61	222	1023	10.62	2358
Tall oat grass	5.78	247	1428	11.66	2880
Yellow oat grass	6.38	200	1276	10.7	2140

Figure 1: Mowing-sucking combination (8)

The biogas potential per ton VS of grass can be maximized when the grass is harvested when it is not yet lignified and is still leafy. Changes in chemical and structural composition of cell walls in grasses can be caused by management decisions, such as fertilization, harvesting date and frequency and ensiling. (2) As compared to a one cut management system a two cut management increases the biogas yield from 160-240m^3/ton VS to 480-520m^3/ton VS (1). The importance of choosing the right harvesting time has also been investigated in Germany by A. Prochnow et al. They reported a yield of 547 Nl biogas/kg VS when the grass is harvested in June compared to 299 Nl biogas/kg VS in February.(4) Similar results are found in table 5 but unpublished data from our Italian partners indicated that the BGP could be similar all year long. This could be explained by the fact that in Italy grass could have good growing conditions all year long. Another interesting thing to notice is the speed of degradation during the test. After 17 and 10 days the maximal methane yield was achieved for respectively the grass harvested in summer and winter. This has important repercussions on the residence time in the reactor but this experiment was done under controlled small scale batch conditions. In table 6 the influence of fertilization was also shown, but the effect on the BGP seemed insignificant (52).

Table 5: Influence of the harvesting date on the BGP (18)

	BGP (Nl/kg ODM)	**BMP (Nl/kg ODM)**	**ABMP (Nl/kg ODM)**	**Conditions**
5 Fresh samples from a meadow foxtail grassland taken monthly from June to March, always first cut, northeast Germany, 2001–2004				Laboratory/batch/35 C/28 d/ mono-digestion
June	547	298	1164	
September	438	229	1604	
February	299	155	155	
6 Extensive grassland, National Park Neusiedler See, Austria, 2005/06				Laboratory/batch/38 C/47 d/ mono-digestion
Silage, first cut 08.09.	559	315	910	
Silage, first cut 25.11.	297	137	481	

Table 6: The influence of the harvest date and fertilization on BGP (52)

	Harvest date					
	Mid-May		Late May		Early June	
	Fertilization (kg N ha^{-1})					
	none	80	none	80	none	80
	BGP(Nm^3*kg^{-1}ODM)					
Sward type						
Arrhenatherum-dominated	0.305	0.301	0.299	0.273	0.293	0.301
Lolium-dominated	0.327	0.321	0.328	0.319	0.313	0.307
Species						
A. elatius	0.328	0.347	0.329	0.325	0.317	0.311
D. glomerata	NA	0.334	0.322	0.321	0.317	0.313
F. rubra	0.331	NA	0.331	0.312	0.325	0.317
H. lanatus	0.335	0.326	0.303	0.308	0.309	0.300
T. flavescens	NA	0.314	0.332	0.328	0.315	0.309
L. perenne	0.334	0.335	0.325	0.324	0.325	0.320

1.2 Storage

Grass degrades very quickly, losses of 30-50% DM can also occur during storage. This happens when lactic acid, sugars and proteins are degraded by bacteria. Measures can be taken to prevent this rotting such as: pre drying of the grass, anaerobic storage, reduce the impurities in the silage and the use of additives. As shown in figure 2, grass should be ensiled without any air, and therefore oxygen, trapped between the biomass. A plastic cover also creates a barrier against leaching or oxygen.

Mulching also improves the compatibility of the grass. If it is mulched the DM per m³ rises from 150kg to 250kg (8). But it is also very important to put the grass as soon as possible into the digester after the round bale is opened. Experiments indicated that BGP decreases from 500l/kg ODM to 370l per Kg ODM. After 30 days only 250 L remained per kg ODM. In the southeast of Germany the BGP for a good, well preserved sample was 216l per Kg ODM but if the batch is spoiled it decreases to 155l per kg ODM (18). When using a silo to store the grass it is important to cover it every time properly.

Storage can increase the biogas yield in nm³/ton VS because of the loss of VS of 20-35%. But compared to the original mass the methane yield of ryegrass dropped in the experiment of O. Pakarinen et al. with 98% and 91% after two and six months respectively. Suboptimal storage conditions can cause losses of up to 52% of methane after 6 months. (39)

Figure 2: freshly cut grass stored in a big silo (22)

During storage a DM loss of 3-6% caused by respiration by plant enzymes or aerobic microorganisms and lactic acid fermentation is unavoidable. However, if the biomass is not treated properly, DM losses can be up to 25% because of secondary fermentation by clostridia bacteria and other aerobic deterioration. The DM lost during the period it is left on the field and in the rain approximately 7%.(49)

Biomass can be pretreated mechanically or biochemically. This can be done before ensiling or after. The effects of this step are further explained in the next chapter.

1.3 Pretreatment

When lignin is wrapped around the other components they are not accessible for the bacteria to digest them. Therefore there are some pretreatment techniques. Compared to grass from a lawn which is mowed quite often, roadside verges contain much more fibers. This is mostly because the number of cuts is also much lower and therefore the grass is older. As stated earlier this decreases the BGP but pretreatment can reduce this problem. In order to use additives or use some kind of pretreatment it is necessary that it yields an economic benefit but if it reduces problems further down the process chain it can still be worthwhile. As indicated in table one the use of these additives can have a positive effect on the BGP.

1.3.1 Mechanical pretreatment

During mowing the size of the grass is reduced. The use of a flail mower or a mulcher is advised to reduce problems more downstream. It can reduce the oxygen level during ensiling and prevents clogging in pumps. Financially a flail mower is better than a circle mower and afterwards a mulcher but the first one usually also takes more soil. Biomass can also be further cut or pulped. These techniques also reduce the formation of floating layers and the biogas potential rises. Another advantage of the circle mower compared to the flail mower is that is brings less sand into the reactor. The grass is picked up instead of sucked up. (7).

In table 7 it is stated that the chopping length of grass does not influence the biogas potential but for wet digesters the length of the fibers can be a crucial parameter, if the grass is too long there can arise problems with floating layers. Another advantage of mechanical pretreatment is the decrease in HRT of 23-59% depending on the difficulty of degradation of the feedstock. (42)

Table 7: The effect of chopping length on methane yield of nature grass silage (42)

Type	**Grass length (mm)**	**Nm³ methane/ton VS**	**VS losses in silage (%)**
Normally chopped	5-15	250	13
Extra chopped	2-7	245	7
Not chopped	600	240	14

An extruder (figure 3) processes the biomass in a thermomechanical way, two rotating screws push the material through the pipe and it is pressed into a compact mass with high density. In the graskracht report it was stated that almost double the biogas potential could be achieved. The BGP rose from 180 nm^3/ton DS to 300 nm^3/ton DS(8).

In table 8 it is also visible that an extruder can increase the BGP of grass but this is marginal compared to the difference in BGP lost during ensiling. The benefit of using the extruder on average is 16.5% whereas the loss during ensiling was on average 35.7%.

Figure 3: The Lehmann extruder (21)

Table 8: Results from an extruder experiment (21)

	Dry matter %	**organic %DS**	**C/N**	**pH**	**m³ biogas /t FM**	**m³ biogas /t oDM**	**CH4 %**
silage cut	53,7	54,2	19,1	7,4	81	267	54
silage extruded	51,3	53,7	17,9	6,8	93	337	55
uncut fresh, not extruded	25,7	88,1	17,4	7,1	135	596	55
uncut fresh extruded	28,6	86,0	17,8	7,2	148	602	55
cut fresh, not extruded	22,7	85,6	25,7	7,2	115	593	55
cut fresh, extruded	27,1	85,9	26,0	6,9	143	614	55

1.3.2 Biochemical pretreatment

When adding additives the biogas potential can be preserved and the degradability of the biomass might even improve. Biochemical pretreatment uses additives such as bacteria, yeasts or enzymes but it is important that they help the hydrolysis process that has to occur later on in the digester. Vervaeren et al. reported even higher methane yields per ton VS (11-14%) for maize. The DM losses are minor, only 1-3%. (29) In table 9 the results from another experiment are shown (43). Because additives increase the accessibility of the microorganisms to reach the degradable compounds through the maze of lignin they increase in BGP is bigger in the semi-continuous reactor where the residence time is shorter than in the batch reactor. In general it can be concluded that the BGP increases approximately 16% when adding additives. This improvement is very similar to the extra methane yield obtained using an extruder before digestion.

Table 9: additives for ensiled biomass (43)

Additive	Composition of the additive	Biogas Test	Extra methane yield per ton VS in comparison with untreated biomass (%)
Silasil Energy	lactic acid producing bacteria	Batch	10.25
		Semi-continuous	23.80
Sil All 4x4	lactic acid producing bacteria cellulase, hemicellulase, pentosanase, amylase	Batch	7.82
		Semi-continuous	18.02
Microferm	lactic acid producing bacteria enzymes micronutrients clostridiaphages	Batch	10.88
		Semi-continuous	22.05
Lalsil dry	lactic acid producing bacteria cellulase, hemicellulase	Batch	16.90

1.4 Problems with digestibility

Grasses are rich in fiber and therefore it is not often used in biogas fermenters. At high concentrations it causes floating layers and can bring too much sand into the reactor which causes abrasion. Most digesters have problems treating high amounts of this material. In this regard it is either advised to use a dry digester or a batch leach-bed system coupled with a UASB (2). However De Moor et al. concluded that co-digestion of up-to 20% grass with manure and maize in a wet digester was feasible and no major problems were observed however they advised to use an enzyme mixture to reduce the viscosity and DM content (3). Another technique to valorize grass and other roadside cuttings is the IFFB technology where the cuttings are washed and then dehydrated with a screw press. The liquid phase is digested and the solid material is compressed into briquettes. (13)

It is also important to state that extrusion also negates floating layer problems that can occur later in the processing chain in the reactor (8).

1.5 Types of digesters

The dry matter content (DM) is an important parameter during digestion. Water is essential for microorganisms to degrade the biomass. Certain digester types work at a higher DM and are called dry digester. The DM content will be between 20 and 40%. For wet digesters the DM content should be lower than 15%. (44)

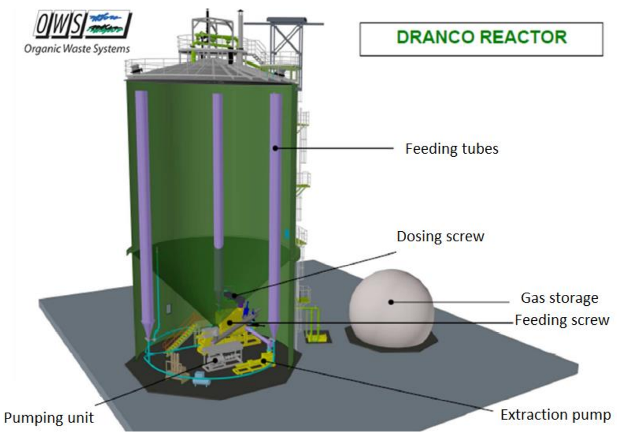

Figure 4: A dry digester: the Dranco reactor (45)

There is, according to Nizamia and Murphy, a significant potential for UASB reactors with a leach bed reactor to digest grass. Both reactors are then adapted to the optimal operation conditions for either the hydrolysis or the methanogensis. However it is important to state that the investment costs are higher for this type of reactor. Nizamia and Murphy also believe that many systems are not adapted to process grass. A CSTR reactor for example should have a good mixing system because otherwise floating layers could be formed. (40) Enzymes, as stated above, could also help.

1.5.1 Digestion parameters (48)

Generally, the solubility increases with rising temperatures. But heating the reactor increases its parasitic energy demand. Therefore is suggested that a two-phase digester should operate in the first reactor at thermophilic temperatures and the second stage at mesophilic temperatures to accelerate the grass hydrolysis and therefore the methane yield. In such a reactor 85% of the total methane yield reached after 30 days will be reached after 18 days. The pH is most suitable between 6.8 and 7.2 for anaerobic digestion. At lower pH the methanogenic population decreases and at higher temperatures the microbial granules disintegrate. Gentle mixing increases the methane yield because it improves the contact between the bacteria and the substrate. Mixing can be done with a paddle mixer in a continuously stirred tank reactor or with the gas entering the reactor again. Another option to create mixing is to use support media on which the microorganisms grow and to create a flow of wastewater/leachate over these filters.

Codigestion

Methane production increases when grass silage is codigested with manure. The microbiological stability, the buffering capacity and the improved nutrient concentration cause this increase. Slurries or activated sludge also fulfill these characteristics. When grass is digested in a mono digester the addition of Ni, Co, Mo, Se, and N can increase the methane production up to 96%.

1.6 Biogas potential: component analysis

1.6.1 Theoretical biogas potential

The biogas potential is influenced by a lot of factors. As mentioned above the number of cuttings and in what month the grass is mowed influence the biogas potential. But also the concentrations of protein, fat, cellulose, hemi-cellulose, starch, and sugars have an impact. (15)

The maximal methane yield was calculated using the concentrations of crude fiber (CF), nitrogen-free extract (NFE), ether extract (EE) and crude protein (CP). (24)

$$\text{Methane yield}_{max}(Nl/kg\ VS) = (373*(CF*NFE)+8000*EE+560*CP)/(1000*VS/DS)$$

Equation 1: theoretical methane yield calculated by Richter et al. (24)

The formula Triolo et al. suggested to calculate the theoretical biochemical methane potential based on the stoichiometric equations of the digestion reactions, is stated in equation 2. Here the TBMP is expressed in CH4 NL kg VS−1 and $C_{57}H_{104}O_6$, $C_5H_7O_2N$, $C_6H_{10}O_5$ and $C_{10}H_{13}O_3$ is the empirical formula for lipid, protein, carbohydrate and lignin, respectively, expressed as g kg VS^{-1} (28).

$$TBMP = (C_{57}H_{104}O_6 \cdot 1014 + C_5H_7O_2N \cdot 496 + C_6H_{10}O_5 \cdot 415 + C_{10}H_{13}O_3 \cdot 727) \cdot 0.001$$

Equation 2: theoretical biogas potential calculated by Triolo et al. (28)

As shown in table 2, Weiland et al. considered carbohydrates, protein and fat as the most important parameters to determine the theoretical maximum biogas yield. The formula he obtained from this data was stated in equation 3. But this is similar but clearly different from the one Triolo published. (23)

$$TBMP = (C_{57}H_{104}O_6 \cdot 1225 + C_5H_7O_2N \cdot 700 + C_6H_{10}O_5 \cdot 795 + C_{10}H_{13}O_3 \cdot 0) \cdot 0.001.$$

Equation 3: theoretical biogas potential calculated by Weiland et al. (23)

1.6.1 Practical biogas potential

Since formulas in the previous part estimate the theoretical maximum BGP, these estimations are too high. Therefore the formula could be modified by multipling all concentrations individually with the corresponding percentage of digestibility.

Cellulose and lignin are the most interesting parameters to determine the biogas potential of the leaves of reed canary grass according to Kandel et al.:

$$\text{Biogas NL (kg VS)-1} = -18.3 * \text{Lignin (\%DM)} - 5.4 * \text{Cellulose(\%DM)} + 765.8.$$

Equation 4: biogas potential estimated by Kandel et al. (27)

Compared to the previous formulas Kandel tries to estimate the real biogas potential. The R^2 is equal to 0.73. The estimation of the biogas potential of the stem was similar but the variance seemed higher since the R^2 is only equal to 0.46 for this formula. (27)

$$BGP = (-15.4 * \text{Lignin} - 1.5 * \text{Cellulose} + 728.3)$$

Equation 5: biogas potential of stems estimated by Kandel et al. (27)

According to Undersander et al. the formula to calculate the percentage of biomass which is degradable is stated in equation 6.

$$BGP = 88.9 - (0.779 \times ADF)(26)$$

Equation 6: biogas potential calculated by Undersander et al. (26)

Experiments done by Plöchl et al. indicated that the methane yield of grass silage is correlated with the acetic acid concentration formed during ensiling. The total organic acid concentration also seems to be correlated.

$$\text{Methane yield}(mN^3\ tODM\text{-}1)\sim= \text{total organic acid concentration}(g\ kgFM\text{-}1)*12.7+140$$

$$\text{Methane yield}(mN^3\ tODM\text{-}1)\sim= \text{acetic acid concentration}(g\ kgFM\text{-}1)*11+230$$

Equation 7: biogas potential of silage estimated by Plöchl et al. (35)

Richter et al stated that the biogas potential of the press liquid is equal to (41)

$$BGP = 491.91 + 1.5452*NDF - 1.9367*ADF - 1.0757*ADL.$$

Equation 8: biogas potential of press liquid estimated by Richter et al. (41)

The biomass composition can be linked to the climate parameters. How they are linked can be found in the article written by Gützloe(46).

2. Proposed model

2.1 Introduction

The parameters that determine the BGP of the grass before entering the biogas reactor mentioned above are now used to make a model. The first parameter: the growth factor (<u>intensely</u> or extensively grassland) is binary and the assumed BGP are 600 and 250 Nl biogas /kg DM for the intensely and extensively managed grassland respectively (18, 51). Values higher than 600 Nl biogas /ton DM are often reported in literature but they are unlikely to occur in full scale digesters. Therefore it was decided to negate these values and to take values more realistic.

The grass species are not taken into account in this model since there influence on the BGP is less significant.

The <u>cutting period</u> and the time since the last mowing are taken into account. It is know that in May or June the BGP is higher than in February for example. Knowledge from several articles (18, 19, 50, 51, and 52) has been put into figure 4. This graph looks different for each country, every year and for every grass species but in general something like this can be suggested for European countries. It is important to notice is the correlation between the first factor and this one because when a grass field is well maintained and thus has good climatologic conditions all year long: the graph will look much flatter. Notice also that figure 4 is similar to a graph where the growing speed of grass has been plotted in function of the months.

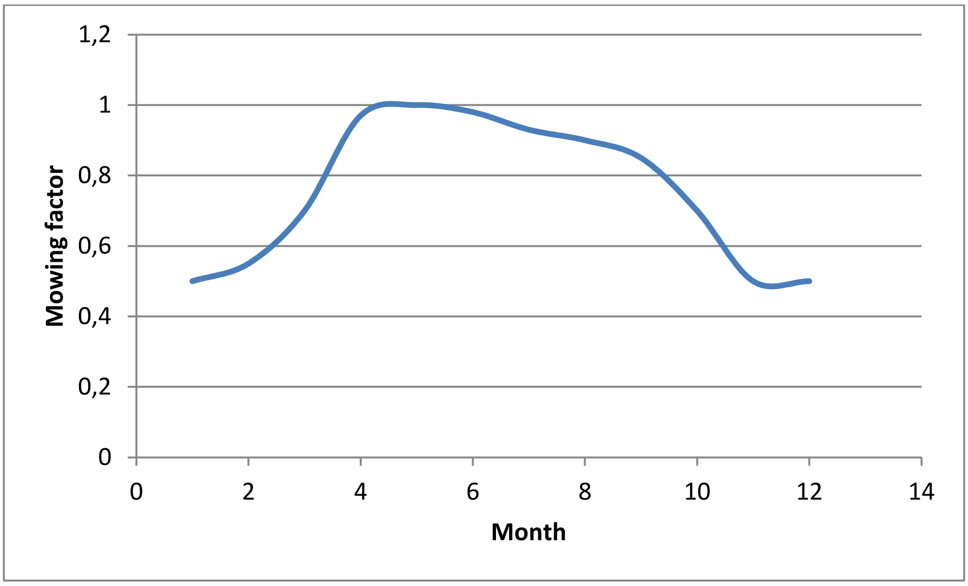

Figure 4: factor used to estimate the effect of mowing month

For storage it is known that the BGP can decrease with 50% in case of aerobic, humid storage. Good storage in this model is assumed to have no impact on the BGP, expressed in Nl biogas/ kg DM.

More scientific parameters to determine whether silage is considered good are bad, are ammonia and butyric acid. When the ammonia content in silage is lower than 8% the quality is considered good, between 9 and 15 moderate and higher than 16 the quality is bad(29). When the butyric acid concentration is measured and this content exceeds 0.3% the silage is also considered bad (17).

All numbers are based on laboratory tests. Full scale anaerobic digesters will have a lower mixing speed, the temperature control could be worse, the residence time is lower etc. Therefore the BGP for grasses digested in full scale reactors can be lower than the expected values reported in this paper. Analysis of the full scale reactors will be conducted by partners in the GR3 project and the results will be used to improve the model. Most likely another factor will be added to the equation.

2.2 Model

Any grass sample will get a code. The first letter in the code will depend on the level of intensity by which the grassland has been maintained. This letter will be A or B and the corresponding BGP is 600 and 250. Secondly the way the material has been stored will be taken into account. Fresh material or very well ensiled biomass gets the letter A, worse storage techniques will get a B or C. The corresponding factors are respectively: “1, 0.75 and 0.5”. The last symbol in the code is the number, in which the grass has been mowed, so 1 for January, 2 for February and so on…

The code given to a grass sample could be for example AB5. This corresponds to a BGP of 600*0.75*1 = 450 Nm^3 biogas/ ton DM. The way this model works is also summarized in figure 5.

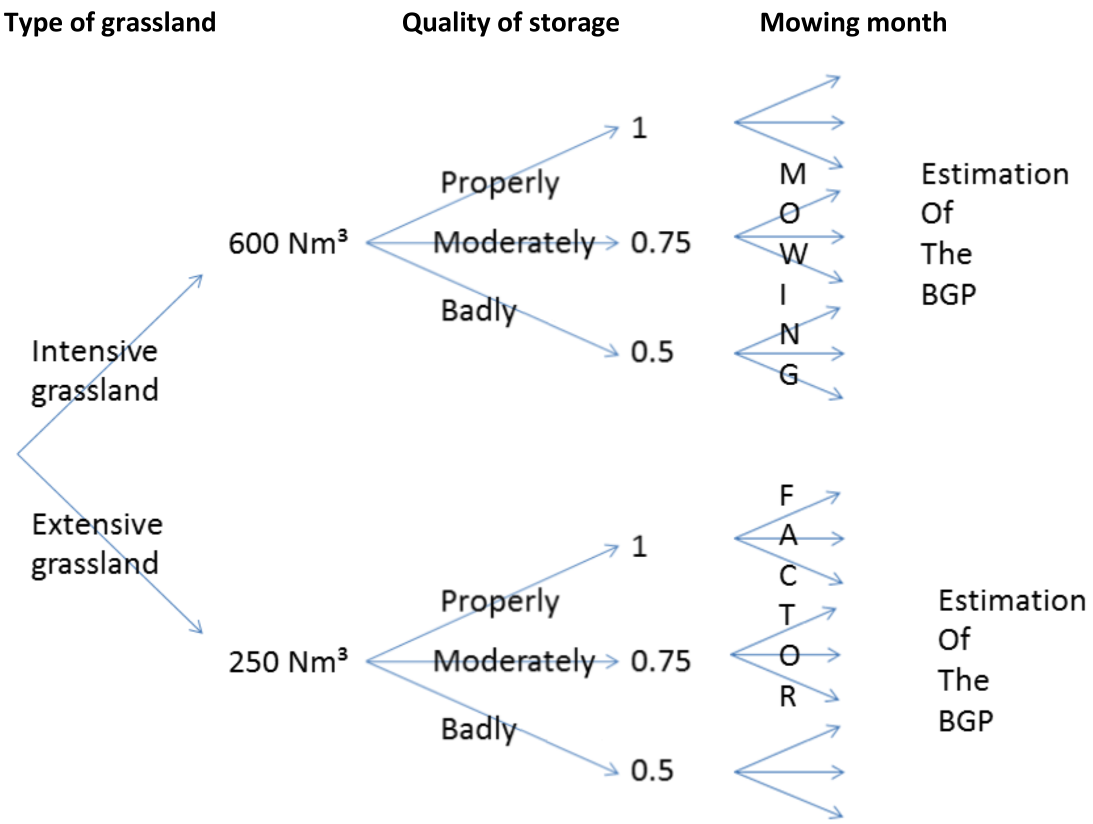

Figure 5: Simple proposed model based on the type of grassland, quality of the storage and the month in which the grass is mowed (use factor from fig. 4)

2.3 Possible addition to the model

Both pretreatment and digestion parameters could also be taken into account. Pretreatment with an extruder or shredder could be indicated with a "+" in the code and cause that a factor of 1.16 (table 8) would be added to the equation. When additives are added, another "+" will be added to the code and also a factor of 1.16 will be used. So a grass sample could get a double plus. Thus far no research has been done to investigate this processing chain and it is very doubtful that this will be economically feasible but the factor used in case of a double plus is estimated to be approximately 1.20. We expect the added value of another pretreatment to be limited.

The biogas produced for this particular reactor design could be compared with laboratory scale experiments. This way the optimal, maximal biogas production under controlled parameters could be compared to the yield in the full scale reactor and result in an extra parameter that could be added to the equation.

This way the code becomes for example: $AB8^{+}0.7$. This means that the grass is from a well maintained field, stored moderately well, and is harvested in august. Additives were added or the biomass was pretreated in an extruder and the yield of the full scale digester is 70%. The latter can also be higher than one if the residence time, mixing and nutrient concentration is better than when the grass is mono-digested. The estimated BGP is than equal to 600*0.75*0.9*1.16*0.7= 328.86 Nl biogas /ton DM.

3. Conclusion and future work:

The biogas potential can be estimated from the origin of the grass, and if the biomass is stored properly the yields can be very high for intensive grassland and well maintained fields: 400-600nm³ biogas/ton VS. Grass from landscape management or extensive grassland in general has a much lower BGP. For these the potential is 100-250 Nm³ biogas/ton VS. (4) But as soon as oxygen is entering the ensiled grass the yield can drop by50%. (18) When harvested in winter or after the flowering state the biogas potential also decreases with approximately 50% (18).

This model is simple to use and does not require tough analysis. However a more thorough analysis of the characteristics which determine the biogas yield will be done in the future, including experiments to further determine the parameters that have an impact on the BGP. The theoretical models will be tested and a new model will be developed.

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