GO-GRASS

Grass-based circular business models for rural agri-food value chains

Review paper on traditional and alternative grassland management technologies

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GO-GRASS in a nutshell

The GO-GRASS project (www.go-grass.eu) aims to create new business opportunities in rural areas based on grassland and green fodder and to support their replication throughout rural communities in the EU. The project will develop, deploy and validate a set of small-scale demonstration sites (DEMOs) showing a circular integrated agro-food system in four EU regions (Denmark, Germany, Sweden and the Netherlands). The project aims to move technologies from the current technology readiness level (TRL between 5 and 6) to more advanced level (TRL 8), and see them successfully implemented under real conditions by the end of the project.

The DEMO in Denmark aims to develop small-scale biorefining technology to extract protein concentrates for monogastric animals from grass biomass grown on land in nitrate-sensitive areas. The DEMO in Germany aims to produce biochar, for use as a supplementary soil improver, by hydrothermal carbonisation or pyrolysis of grassland cuttings from wetlands. In the Netherlands DEMO, the aim is to develop digester and fermentation technology to produce paper and carton products from road-side grass and nature or fauna grass. In Sweden, the aim of the DEMO is to establish briquetting technology at local and small scale to produce climate-friendly heat-treated biofuel briquettes using reed canary grass. Beyond development of the individual DEMOs, the project aims to integrate the technologies and business models across the DEMOs, to create additional values and value chain nodes.

In order to realise and support its objectives, the project will employ the principles of cumulativeness, innovation, replicability, inclusiveness and circularity. These principles will serve as guidelines and requirements for adapting and developing various tools, integrating a circular economy in rural areas, ensuring successful DEMO implementation, creating favourable business environments and maximising the replication potential in other rural areas in the EU.

The tools to be developed by the GO-GRASS project include: online tools for business case assessment and funding; a manual on how to get started and succeed; a tool kit for cluster and network development; training courses for existing and future entrepreneurs; and guidelines on creating favourable business environments.

GO-GRASS will contribute to a range of circular and sustainable business models with high replication potential that can be used by entrepreneurs, local authorities and other stakeholders. It will demonstrate innovative cost-effective technologies, processes and tools applicable within the diverse DEMO scenarios. This will enable effective use of grassland and shrub biomass that is currently left to decay after mowing, creating costs and loss of benefits for individuals and society.

To stay up to date with GO-GRASS project events and reports, follow us on Twitter (@GoGrassEU) or LinkedIn (GO-GRASS) or visit www.go-grass.eu.

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Summary

This report provides an overview of the grassland management strategies at the different DEMO locations and describes the different harvesting, storage and preservation techniques available. Some specific technical and socioeconomic issues related to the respective areas and the desired quality of the grass are also mentioned. An overview of all grassland types within the EU can be found in Deliverable 1.1 and an overview of the social aspects of grassland management in Deliverable 1.2. The specific process ideas within the DEMOs can be found in Deliverables 2.3 and 2.4. The experiments and expected outcomes within the DEMOs are described in Deliverables 3.1, 3.2, 3.3 and 3.4.

Within the GO-GRASS project, grass is used in different value chains. The grass comes from different areas with varying types of grassland and varying availability of grass that is used for different purposes. This requires specific quality aspects of the grass to be considered. Important quality aspects to be taken into consideration are maturity and lignification level, moisture content and content of specific constituents such as fibres, proteins, polyphenols, and other high-value components. These constituents are dependent on grassland management operations such as levelling, rolling, re-seeding, fertilisation, mulching or removal of senesced grass at specific points before, during or after the growing season. The seasonal work with grass is dependent on the work period, weather conditions, floods, droughts and other weather-related aspects. The combination of these different grass qualities and regional differences creates a need for DEMO site-specific grassland management, harvesting, storage and preservation techniques.

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1. Grassland management

The traditional use of grass in Europe is for grazing or harvesting for silage. The intensity of use depends on the growth rate of grass during the year, which usually shows distinct differences associated with the different biogeographical regions in Europe (Figure 1). In northern and central Europe, the best period for grass growth is the summer, when enough water is available and temperatures are sufficiently high to permit fast growth rates. This results in an excess of grass that is usually harvested to produce hay or silage, in order to feed housed animals during the winter. Southern European countries have a different growth rate curve where the maximum grass growth rate occurs in spring, when the water supply is not restricted, while the high temperatures in summer severely limit the growth rate. Therefore grass is harvested during the spring to produce silage, which is used to feed animals during the summer and also the winter. In some regions, cereals (often maize) are grown to produce whole-crop silage, due to the high yield per ha compared with grass. However, replacement of grass with cereals to make silage usually results in less flexibility and resilience in animal feed supply on the farm, in spite of the high stocking rate allowed (Mosquera-Losada & González Rodríguez 2003). Pasture production is not stable when different years at the same location are compared, as the yield depends on the specific weather conditions within years. As on-farm livestock numbers are usually stable, the changing yearly weather means that there is a lack of grazing in some years, and therefore external inputs are needed, while in other years there is an excess of grass production and the animals are not able to consume all the biomass available. This surplus biomass could be profitably used by transforming it into products with high added value, such as biogas, biofertilisers or dry protein, through the implementation of bioeconomy concepts. The inter-annual variability in grass production and occasional surpluses are mostly associated with permanent grasslands, which comprise 34.6% of the Utilised Agricultural Area in the EU (Peeters & Osoro, 2016).

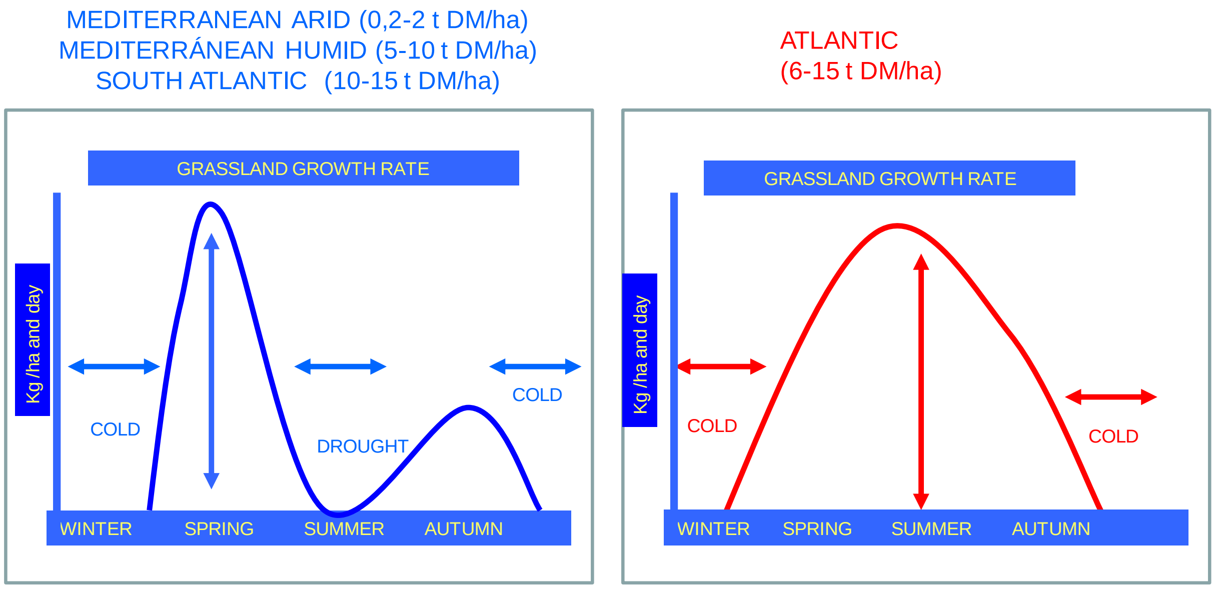

Figure 1. Grassland growth rate curves in the Mediterranean and Atlantic biogeographic regions of Europe

Grassland management is generally carried out by farmers, agricultural contractors and municipal departments or contractors, depending on the type of grassland. For every type of

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grassland, the reason for maintenance is different. For example, the management of road verges mainly consists of mowing to improve the line of sight, increasing road safety (Noordijk et al., 2009). The management of grassland for animal feed production is different. In feed production, optimal grass feeding qualities are the target, and therefore farmers usually fertilise the grass and introduce grazing animals when the relationship between productivity and the quality of the feed is optimal. The grassland management is optimized on this and a lot of literature is written about it, for example "het handboek melkveehouderij" (Remmelink et al., 2019) which has a very extensive chapter on grassland management for cattle farming and almost yearly updated. Also on grazing a lot can be found (Gibb 2007). However, this management aims to have an optimal quantity vs quality ratio for the harvested grass related to feed. This can be quite different from the optimum quality for biorefining, where extractability of components such as protein, cellulose, sugars and/or bioactive components are the most important parameter (e.g. Solati et al., 2018). Moreover, on natural grasslands, management and quality aspects may differ from the biodiversity desires or the environmental aspects.

There are currently EU regulations governing grassland maintenance in terms of the seasons/months in which maintenance is allowed. In the first instance, these permitted mowing times lie outside the hatching times of meadow birds. After meadow birds, other biodiversity aspects like insects and butterflies are taken into account (Marriott et al., 2004; Blokhina et al., 2011; Kemp et al., 2013; Tälle et al., 2016). For natural meadows within nature conservation areas, there is an intermediate form of harvesting called "sinus mowing", where strips of a field are mown in a sine wave pattern and other unmown strips are left to meander through the field. The mown strips can always be located elsewhere in the field, depending on the management objectives. This results in a larger variety of grass types and an optimal environment for insects and butterflies (De Vlinderstichting, 2018). While mowing twice a year is good for maintaining the current biodiversity (Moog et al., 2002), in some locations this might not be possible, for example due to ground-nesting birds which allow only a single late harvest (Blokhina et al., 2011).

Within the GO-GRASS project the grass is not used for direct feed application. Therefore, most of the optimization performed over the years by farmers are not optimal for the grass qualities desired for the demo's. The specific usage of the grass within the demos can be found in the next chapter. Cropping grass for optimal biomass creation for usage within the bio-based economy requires different aspects to be optimized. Currently the grass within the demo's is more like a waste stream. Optimization of the harvested grass quality is of importance, for example for the Danish demo for which the protein quantity and quality is important. However, most DEMO's are not yet working on optimal cultivation. Therefore, cultivation techniques are not taken into account within this report.

1.1. Grassland management per DEMO

Within GO-GRASS, four demonstration (DEMO) locations throughout northern Europe have been selected. These locations host different grassland types, which are managed for different goals, and therefore no DEMO is the same. Different techniques are used at the four locations, due to the different purposes and parameters. More detailed information on the grassland type and grassland management at the four demonstration sites is provided below.

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1.1.1. Denmark

The Danish DEMO is built on the concept of green biorefining. Here cultivated, fresh green crops such as grasses, but also legumes, are used. The varieties of grasses, clovers and lucerne that are usually used for forage production in Denmark can be used for the biorefinery. However, it is expected that a biorefinery may have a wider range of “digestibility” acceptance than a cow. It is therefore expected possible to use grasses that are more productive and hardy than the usually produced perennial ryegrass. Tall fescue, and Festulolium varieties can produce 1-5 tonnes more DM/ha than can perennial ryegrass, and total crude protein yield can be proportionally higher as well. The first experiences with Festulolium on the biorefinery have shown high extractability of protein, which is very promising.

The grass is expected grown on intensive farmland, and can substitute some of the annual crops, which today makes out some 80% of total farmland in Denmark. Such a substitution can improve agricultural sustainability by reducing soil erosion, nitrate leaching, GHG emission and pesticide use (see e.g. Manevski et al., 2018). Another aim is to substitute some of the large import of 1.6-1.7 mio. tonnes of soy cake for feed purposes to Denmark annually. A recent policy note sets up scenarios for the area requirement to substitute the whole import for Denmark, which will vary between approx. 0.5 and 1 mio. ha, dependent on the maturity of the grass production and biorefinery technology (Jørgensen et al., 2020).

The green grass and/or legumes are processed by wet fractionation, producing a green juice and a fibrous press cake. This is followed by protein precipitation and separation from the green juice to give protein concentrate and brown juice. The protein concentrate is used for monogastric animal feed, as a replacement for soy meal, while the two side-streams (press cake and residual (brown) juice) are used for ruminant animal feed and biogas production, respectively. In order to maintain high yield and quality of the protein concentrate, the process requires the grass to be harvested and processed within the same day and preferably with as little storage and biomass damage as possible, thereby avoiding protein degradation and enzymatic alterations to protein. This places great demands on grassland management and forage handling logistics in the Danish DEMO. Full utilisation of process capacity at the biorefinery requires harvest to be continuous from May to October, delivering fresh green biomass on a daily basis. In addition, the forage harvesting method needs to prevent or reduce contamination with sand and soil particles and to handle the biomass in a gentle manner to avoid unnecessary damage. In the Danish DEMO, Aarhus University is testing a harvesting method using a Grass Tech Grazor developed for direct feeding of grass to dairy cows, which cuts and collect whole-length grass into a forage wagon. This method has been shown to decrease sand and soil contamination and to increase the quality of input material to the biorefinery.

For cultivation on wetlands, tall fescue is also one option. If very wet, reed Canary grass and cattail are other options for cultivation, which are currently being investigated. Machinery for harvesting grass on wet lowlands (paludiculture) has to some extent been developed already, with the best examples in the Netherlands by Hanzewetlands and De Vries Cornjum. In such cases, tractor wheels are replaced by wide tracks to reduce pressure per area unit on the soft and vulnerable soil types. Until now, paludiculture grass quality for green biorefining has only been tested at laboratory scale.

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1.1.2. Netherlands

In the Netherlands DEMO, the farmers' association Noardlike Fryske Wâlden is responsible for supplying the grass. The grass comes from the fields of livestock farmers and from nature conservation organisations that manage natural meadows. In total there is 100.000 ha of nature meadows in agricultural use, of which 15.000 ha are mainly for non-feed purposes. From the full area 90.000 tonnes of dry grass is harvested each year.
The association also does some work for municipalities and mows road verges. The amount of road verges is very high, resulting in 500.000 to 600.000 tonnes of dry grass per year. Natural meadows are not fertilised and there is little or no grazing. Instead, the management objective is to preserve the most diverse vegetation and, wherever possible, to increase biodiversity. The natural vegetation on these meadows is mown once a year after the plants have dropped seed, usually in July-August. There are different types of natural meadows, ranging from very dry to extremely wet, and all have their own community of species. Over the years, biodiversity of the biomass increases and the feed value for highly-demanding production animals such as dairy cows decreases. The quality of the grass can become so low that it has hardly any nutritional value for productive cows and biomass productivity also decreases. For livestock farmers, the quality and quantity of the grass can become so low that alternative applications to feed uses must be sought. In the Netherlands DEMO, digester and fermentation technology is used to produce paper and carton products from grass biomass.

Figure 2 Harvesting of nature grass (left), a stork in the mowed fields (right) (source: noardlike fryske wâlden)

1.1.3. Germany

The DEMO in Germany is located in the Lower Oder Valley National Park on the German-Polish border, in the northeast of the state of Brandenburg. The park covers an area of 10,500 ha, of which approximately 4,200 ha consists of cultivated grassland on the polders of the Lower Oder valley (Blokhina et al., 2011). The grassland areas are managed very extensively, as they are subject to strict nature conservation regulations (Bellebaum et al., 2010; Hamin et al., 2002). They are mown once a year in Germany and are often not harvested or used on the Polish side. In winter, the areas are regularly inundated by flood water from the river Oder. After drainage in April, the area offers an ideal habitat for many birds. Charting of ground-nesting birds, particularly the corncrake, occurs annually in May. Areas found to be free of nesting birds may be released for farming starting from early July, and are either mown or

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grazed. Areas where nesting birds are found may not be utilised before mid-August and yield approximately 8 tonnes/ha, with 85% dry matter content (Blokhina et al., 2011). This late-harvested grass is heavily lignified and not suitable as feed for dairy cows (Farruggia et al., 2014). An alternative use as feedstock for biogas plants is inefficient because of the increasing crude fibre content and declining crude protein and crude fat content, which are associated with low biomethane yield (Amon et al., 2007 a,b; Prochnow et al., 2009). The grass can also be used as bedding material in animal houses, but only a few remaining farmers follow this practice. Due to the low grass quality in areas where only late harvest is permitted, utilisation is often only minimal. Through minimal utilisation, the farmer receives the bonus from the national park, but much of the grass is currently abandoned on the polder. The DEMO in Germany is producing biochar, for use as a supplementary soil improver, by hydrothermal carbonisation or pyrolysis of polder grass.

1.1.4. Sweden

The Sweden DEMO has two facilities in different locations, one located in Glommersträsk, a small town in Norrbotten county and the other located outside Umeå in Västerbotten county, both in northern Sweden. There are numerous abandoned grasslands in northern Sweden that could contribute to rural development. A suitable crop that can be grown on this type of land is reed canary grass (*Phalaris arundinacea* L), a perennial rhizomatous grass which is native to Sweden and many other European countries. In Västerbotten and Norrbotten counties, some 30,000 ha have been identified as suitable for production of this grass species. Reed canary grass (RCG) is suitable for cultivation in most agricultural regions and a suitable crop for cold climates. It can be grown on most soils, but grows best on moist, humus-rich and light soils. RCG can provide a good return on most soil types throughout Sweden, and grows better than many other crops on peat and mire soils. In the year before sowing RCG, perennial weeds must be controlled. If the land is overgrown, more extensive restoration is needed. RCG is sown early in the spring, to allow it to develop before autumn. The grass reaches a height of about 2 m in autumn and is harvested in early spring of the following year, using similar techniques to those in conventional forage harvesting. The delayed harvest gives a dry matter content of 85% and a storable material that can be directly briquetted without any artificial drying (Figure 3).

Figure 3. (Left) Growing stand of reed canary grass and (right) the cut biomass in the following spring

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Reed canary grass has been studied previously as a fodder crop, but the delayed harvest makes it interesting as an energy crop. However, the raw material cannot compete economically with wood-based biomass fuels, so today it is primarily used as animal bedding. The DEMOS in Sweden are developing low-cost, low-impact technology to make biofuel briquettes using reed canary grass. The area of spring-harvested RCG is still very limited in northern Sweden, where currently about 500 ha of RCG are cultivated.

Table 1. Overview of the four DEMOs in the GO-GRASS project

	Type of grass	Type of land (marginal / cultivated)	Area (ha)
Denmark	Forage grasses and Legumes	Cultivated	Potentially 500,000
Netherlands	Natural meadow & road verges	Marginal	15,000 nature meadow
Germany	Polder meadow	Marginal	4,200
Sweden	Reed canary grass	Cultivated	500

The grassland management per demo has some overlap for Germany, the Netherlands and Sweden like no fertilization and no high frequency harvesting. While the type of land and the purpose of the grass is different. The Danish Demo is completely different in using fresh green grass, that should be high in protein, and is thus either leguminous or highly fertilised and with frequent cuts.

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2. Harvesting & collection of grass

In the Netherlands, verge (roadside) grass and natural meadows in nature reserves are mown twice a year. However, at some locations they are only mown once, while at other locations they are mown up to eight times per year. The frequency of mowing depends on the specific demand, e.g. road verges are mown more often due to road safety concerns. For the same reasons, the grass is removed after mowing. The grass can be used as natural fertiliser, feed, digester feedstock etc. A reason for not collecting grass is to prevent soil degradation (Zwart & de Boer, 2015). Apart from mowing, natural meadows can also be grazed, although the vegetation may still be topped and removed later in the season, to maintain the meadow as it is.

There are different methods available for mowing and removing grass. The most common mowing methods are flail mowing (Figure 4 and Figure 5), rotary mowing (Figure 6) and sickle mowing (Figure 7). For grass removal there are also multiple options (Figure 8-Figure 13): direct suction, with a combined machine or separate machine with the mowing devices (Figure 8), or later on grass recovery by a rotary rake (Figure 9) and a forage harvester on a trailer wagon (Figure 11). If the material is collected later, it is often spread out and mixed/shaken by a tedder (a device quite similar to a rotary rake) to improve the drying of the material (Holshof et al., 2014b). Dried material may be collected and baled using a baling press (Figure 9).

A flail mower is a device on which loosely attached flails spin around an axis and hit and cut the grass (Figure 4 and Figure 5). Therefore, fail mowing is a robust technique providing a rough cut. It is often used in combination with a suction device to remove the grass. Due to the robustness of the flail mower, soil and other debris is also collected. A rotary mower uses multiple rotating blades within a chamber to cut the grass (Figure 6). This type of mower is often used in areas where fewer obstacles are present. Since the technique is not as robust as the flail mower, use in these specific areas improves the lifetime of the mower. After rotary mowing the grass is often collected, but this is not a necessity. In contrast to flail mowing, following rotary mowing it is possible to harvest and collect the grass without soil contamination (Holshof et al., 2014a). However, when there are piles of soil, for example, mole hills or tractor ruts, much soil may be collected. Therefore, to avoid collecting soil the mowing should be optimised by increasing the mowing height, levelling the surface (e.g. using a grass roller) and preventing soil heaping by repelling moles and other rodents. The sickle mower, also known as (knife)-bar mower or finger-bar mower, is a double bar with triangular blades on both bars (Figure 7). These blades can move from left to right, cutting the grass passing between the bars. The sickle mower is not used with a direct suction device on the same machine, and is usually used without direct grass removal. Instead, the grass is often first dried on the field before being removed. Regarding soil contamination, the sickle mower can be compared with rotary mowing. A short overview of these mower types is presented in Table 2.

All of the mower types can be upscaled easily and are therefore available in different sizes, ranging from hand-pushed devices to heavy tractor-mounted machines. The size of the mower determines the weight of the equipment, fuel consumption and pressure on the soil. Apart from the differences in mowers, the tractor-mounted devices can be fitted in front, behind or

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directly alongside the tractor and/or on a variable arm. Therefore, there are many different options available, but all based on the principles described above. Depending on the area and target of the DEMOs, different systems are used.

Table 2. Summary of different grass mowing techniques

	Type of mowing	Robustness	Soil collection
Flail mower	Loosely attached flails hit the grass	Very robust	Soil and debris collection inevitable
Rotary mower	Spinning blade cuts the grass	Needs low amounts of obstacles	Possible to avoid soil collection
Sickle mower	Knife-bar blades cut the grass	Needs low amount of obstacles	Possible to avoid soil collection

The grass from road verges is usually contaminated with different kinds of waste, often food packaging waste such as metal cans, plastics, paper etc. Some of these types of waste can be separated from the solid fraction containing the grass fibres after the digestion process in pulp and paper production, but this is difficult for other types, especially plastic waste. When these remain in the solid fraction with the grass fibres, they cause disturbances in the paper production process. In order to prevent difficulties further in the value chain for using grass fibres for paper production the plastics need to be removed, but this is not done during the regular collection process of the grass.

Figure 4. Perfect van Wamel Serie KW flail mower (source: Perfect van Wamel BV).

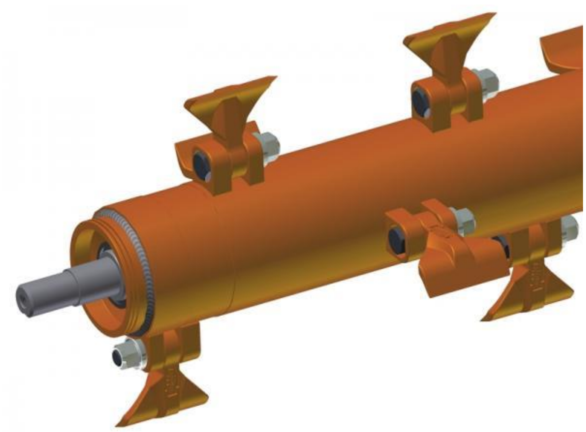

Figure 5. Flail mower details, the triangles are the flails (source: Perfect van Wamel BV).

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Figure 6. Vari DS-521Z Agatha single-rotor hand-pushed rotary mower (source: Helthuis.nl)

Figure 7. Feider FT200 scythe-bar (sickle) mower (source: Chipperfield.co.uk)

Figure 8. Trilo S10 suction wagon with a separate flail mower in front of the tractor. The grey bar underneath the suction wagon can be replaced by a flail mower, creating a single device for cutting and collecting (source: Trilo).

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Figure 9. Niemeyer Twin 470 DR rotary rake (source: https://www.tractors-and-machinery.nl/)

Figure 10. Krone BiG Pack HDP II high-pressure baling press (source: Profi – Special Edition 03 / 2013)

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Figure 11. Harvested reed canary grass on a trailer wagon.

Figure 12. Combined mowing and harvesting equipment used in the Danish DEMO (grasstech gt-140) (source: Grasstech.ie).

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Figure 13. Large-scale Kverneland 3232 MN disc mower (source: Kvernland).

3. Storage of grass

After harvesting and collecting the grass, it is often stored. Storage is needed since processing cannot be performed immediately due to the scale of the operation. Only within the Danish demo direct processing is possible. The grass should be stored in a correct way to optimise the biomass quality, and thus the performance further on in the value chain, depending on the precise end-use of the grass (Mitchell & Schmer, 2012). Grass storage is common practice when the grass is used as animal feed, while at biogas refineries storage is less common. However, the storage techniques used are very similar. Collected grass can be stored in different ways, as hay or grass silage (McDonald, 1981), on in a large pile or in smaller batches. In storage of grass, multiple quality-related parameters must be taken into account. For example, the grass should not have a high moisture content, since if it contains a lot of water the material will not be preserved and spoilage will occur. This decreases the quality of the grass and also leads to health threats to workers handling the grass. On the other hand, if the grass is too dry digestion is difficult. Therefore, within animal production systems a combination of hay and grass silage is often used. Apart from low moisture content, the stored grass should not be allowed to become too warm, since if it does the material loses energy and, in the worst case, can undergo spontaneous combustion (Durksz, 2015). The risk of spontaneous combustion increases with the size of the piles. Stored grass is called hay if it is dried on the field and reaches a dry matter content of 84% or above, which is needed to prevent heating. It also has to be stored in a dry place. When using grass silage, the dry matter content is lower than with hay and the material has to be preserved to prevent microbial spoilage (Muck, 2010). Preservation is done by airtight and watertight storage (McDonald, 1982).

Storage is generally performed to use the grass later on, currently mainly as animal feed. However, when there is still grass left or the quality of the grass is not sufficient for feed, the

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grass can be used for different applications, which are assessed in the DEMOs of the GO-GRASS project.

3.1. Bulk storage of grass

The most basic type of bulk storage of grass is in a haystack, which is simply a pile of hay compressed lightly in place. For more advanced bulk storage of silage, there are multiple options, like storage on a pit plate or within a trench box (or bunker silo) (Figure 14 and Figure 15). In both systems, there can be variations in the type of flooring, coverage or not, the cover material, the height and depth of the pile, the weight on top of the pile (e.g. sand or old tyres) and the type of side-walls. In the Netherlands, both types of bulk storage are used. All common silage storage practices involve compression of the material (often by driving over the grass pile with a tractor) and complete watertight and airtight storage, with the pile size dependent on farm practices and facilities. The size and construction of the pile is optimised to maintain good quality of the material for the intended use (Holshof et al., 2014c).

A different version of bulk silage storage is a tower silo (Figure 14), which can be up to 30 m high. Due to the height and filling from above, the grass is pressed together under gravity. The principles of watertight and airtight storage and compaction apply for all types of bulk storage of grass silage.

Figure 14. Tower silo for forage storage (source: Forages.oregonstate.edu).

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Figure 15. Open-pit plate silo with a plastic cover and car tyres (source: WageningenUR).

3.2. Batch-wise storage of grass

Batch-wise (bale) storage of grass is an alternative to bulk storage where the grass is first wilted or dried partly or fully in the field. The material is picked up by a tractor-mounted device and placed in a baler (Figure 16). The baler tightly compresses the grass and places a net or cords around it. The bales can be cylindrical (round) or bar (square) shaped (Figure 17). In countries where more manual labour is performed on the farm, bales are mostly bar-shaped and much smaller. In the Netherlands, it is nowadays common practice to produce bale silage by using specialist tractor-driven equipment to wrap 4-6 layers of plastic around the bale. This is done to create a watertight and airtight unit, as in bulk silage storage. Additives can be used to better preserve the silage (Muck & Kung, 1997), as discussed further in section 3.4.1 of this report. In Germany, it is more common to stack multiple round or square bales on a compact area and cover the entire pile with a tarpaulin.

After the bales are created, they can be stacked and stored until use. However, in some cases the bales may be stored outside unwrapped, although open outdoor storage is not recommended. In Iowa, USA, corn stover bales (similar to reed canary grass bales) are often stored with a roof type of cover, e.g. plastic tarpaulin, covering only the top part of the pile of bales or a more tunnel-like structure with wrap directly on the bales or a more hangar-like structure (Figure 18) (Darr & Shah, 2012). The hanger-like structure can be compared to the old way of storing hay in a hayloft or hay barn. This type of “wrapping” does not create an airtight construction.

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Figure 16. McHale 998 square bale maker (source: Knollbv.nl).

Figure 17. Square and round bales (source: www.verantoordeveehouderij.nl).

Figure 18. (Left) Hangar-like bale store and (right) tunnel-like bale store (source: Darr & Shah, 2012).

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Figure 19 Bales in the field covered with a net (source: noardlike fryske wâlden)

3.3. Bulk vs batch storage of grass

As described above, there are some similarities between bulk and batch storage, but there are also major differences (Table 3). For example, with batch-wise storage it is possible to take small amounts of grass from storage without a lot of labour and reclose the pile. This makes use of the stored grass more flexible (Braker et al., 2005), and also limits the risk of air and water entering the stored material. However, the plastic wrap used for covering the grass is much weaker that the coverings used for bulk storage. In addition, creating bales is more labour intensive than bulk storage, the costs for materials are higher and more space and plastic are needed for grass storage in batches. A short overview can be found in Table 3.

Table 3. Summary of differences between batch and bulk grass storage

	Flexibility	Labour	Plastic use
Batch	Flexible due to portion packs	Relatively intense	Relatively high
Bulk	Less flexible to high volume and opening/reclosing	Relatively non-intense	Relatively low

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3.4. Quality of stored grass

In the literature, the quality of stored grass is mainly described for feed purposes and storage in bales, which is therefore the main source of available information. Processes during storage can be favourable for feed purposes, but unfavourable for biorefinery processes. For example, higher digestibility of the grass is often caused by degradation of the cellulose in cell walls, but the cellulose in cell walls is the major component within the Dutch DEMO, where the focus is on making paper from grass cellulose. Therefore, a high level of cell wall degradation is not beneficial for the process within the Dutch DEMO.

During storage, the crude protein content of various types of grass declines, irrespective of whether the grass is pressed in bales and wrapped one, two or three days after cutting (Koech et al., 2016). The dry weight of bales also declines linearly during storage, at a rate of 5-6% DM loss per month (Sanderson et al., 1997). Apart from dry weight, the crude protein, acid detergent fibre (ADF) and total digestible nutrient content in baled material also becomes significantly lower over time (Huhnke et al., 1997). However, the highest contents of these nutrients can be found when using covered bales, whether covered inside stores or individually wrapped/bagged (LaFlamme, 1989).

Late-cut (long) grass has a much lower crude protein, ash and water-soluble carbohydrate content (% of DM) and higher lignin content than early-cut grass per kg of harvested grass. Early-cut grass has a higher leaf:stem ratio (Waite & Gorrod, 1959) and better nutritive value, as does wilted grass. After wilting, grass has a higher DM content and lower water-soluble carbohydrate and protein content. Moist wilting increases the DM content and decreases the carbohydrate and protein content further, although this takes time (Carpintero et al., 1979).

3.4.1. Preservation as silage

The preservation of grass as silage is based on acidification of the material (McDonald, 1981) under certain storage conditions (Bolsen et al., 1996). The main component of acidification is lactic acid, either naturally produced by bacteria or supplied in an additive to the grass. Other additives can also be used, e.g. salt, which is one of the oldest known preservation agents. These additives are used to increase the speed of the preservation process or to increase the nutritional value of the grass. To prevent spoilage or self-ignition or to increase digestibility, different mixtures of bacteria and enzymes can be added (Kung et al., 2003). These types of mixtures are mainly added when the silage is used for cattle feed (Henderson, 1993). If the silage is made from grass from nature reserves or roadside verges, additives are not often used, since the quality of the grass is too low to cover the cost of the additive.

Besides adding bacteria and/or other additives, lactic acid is produced by bacteria already present on the grass, but this natural preservation effect can be optimised. For example, the temperature of the silage has an effect on the lifetime of bacteria living in the silage. However, Lactobacilli, which are gram-negative anaerobes, and other bacteria are almost all gone after 180 days of storage. When silage is baled at 30°C, it contains the most bacteria at the start (Gibson et al., 1961). Production of lactic acid starts faster when the bales have a slightly higher moisture content, meaning lower DM%. However, after 60 days of storage no significant difference between the lactic acid concentrations can be observed, even though the water-soluble carbohydrate content is lower and the ammonia level is higher when

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starting with wetter bales. When the grass was stored within plastic bags, there is faster and greater acid production. The water-soluble carbohydrate content is lower when using bag storage, while the ammonia levels are similar to those in bale storage (Nicholson et al., 1991; Shin, 1990). Due to the acidification process, the pH value goes down during storage (Henderson et al., 1972). The cellulose content rises during storage of grass as silage, since other components are degraded. The increase in cellulose content is highest when unwilted grass is used. The density of the bales does not affect the quality of the baled material (Huhnke et al., 1997). The density is dependent on the type of baler used and the travelling speed (the higher the traveling speed, the lower the density and the lower the weight of the bale). The weight of the bales also does not affect the quality of the baled material (Shin, 1990).

3.5. Storage parameters per demo

3.5.1. Denmark

The protein separation process tested in the Danish DEMO requires fresh quality green biomass. Storage is therefore not an option between harvest and processing. However, the Danish DEMO is looking at opportunities for expanding the seasonal production by making a supplementary business case for biorefining silage grass. This approach would not include production of protein concentrate for monogastric animals, but instead possible separation and production of amino acids, as has been investigated in previous green biorefinery projects in the EU (Kamm et al., 2010; Ecker et al., 2012). After protein extraction, the fibre fraction has been proven to still be a good or even better source of roughage for cattle (Damborg et al., 2019). The fibre fraction is well suited for ensiling, and can be packed to a significantly higher density than can grass.

3.5.2. Netherlands

Within the Dutch DEMO, cellulose is the main product. Sugars and proteins should thus be minimised, and biogas production is one way of doing this. Another way is by lactic acid bacteria removing the sugars and creating lactic acid for the preservation process. The cellulose content is highest when unwilted grass is stored in wrapped bales, so this is the preferred storage process in the Dutch DEMO.

3.5.3. Germany

In the German DEMO, bales are produced from cut and wilted grass and stored before pyrolysis. Silage could be an option, but high dry matter and insufficient sugar content of the late-harvested grass at the DEMO site are not suitable for this process. With an approximate yield of 8 tonnes/ha with 85% DM, about 22 square bales or 42 round bales can be produced. The bales are stored either outside or in large storage barns. If stored outside, multiple bales are stacked. Large stacks are often covered to minimise weathering. If possible, the bales are stored in completely enclosed barns (similar to Figure 18) with concrete flooring. In this case, the bales are protected from weathering and may be stored for long periods.

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3.5.4. Sweden

Reed canary grass is harvested for the first time in spring of the year after planting. Spring harvest results in higher energy content and a dry material with about 12-15% water content. Harvesting takes place as soon as the frost has gone out of the ground and the field has dried up. Reed canary grass is harvested with a conventional harvester. Cutting is usually done with a disc mower conditioner, which puts the RCG into rows for baling. Baling is done in round bales, but square bales have been tested with good results. For smaller fields and bad weather conditions, a disc mower and a rotor rake are used. The large square bales result in lower handling costs, due to higher energy density and better shape. Bales are stored either outside or in storage barns. If stored outside, multiple bales are stacked (Figure 20). Large stacks are often covered by a tarpaulin to minimise weathering.

Figure 20. Large bales of reed canary grass stored outside in the Swedish DEMO.

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4. Overview of the techniques used in different countries

Table 4. Summary of techniques used within the countries within the project

		NL	DE	SW	DK	HU	ES	RO
Mowing	Flail mowing	X				X	X	X
	Rotary mowing	X	X	X	X	X	X	X
	Sickle/bar mowing	X			X	X	X	X
Collection	Immediate collection	X	X	X	X	X	X	X
	Tedding	X	X	X		X	X	X
	Rotary raking	X	X	X		X	X	X
	Collecting loose grass	X			X			X
	Collecting in bales (using machines)	X	X	X		X	X	X
	Collecting in bales (manual labour)							X
Bulk storage	Pit plate	X				X	X	X
	Tower silo					X		X
	Hay stack						X	X
	Trench box (bunker silo)	X				X	X	X
Batch storage	Unwrapped bales		X	X		X	X	X
	Wrapped bales	X				X	X	X
	Wrapped tunnel storage							X
	Outdoor storage (unwrapped bales)		X	X		X	X	X
	"Roofed" storage (hangar/hay barn)	X	X	X		X	X	X
Extra's	Additives with silage	X				X	X	X

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5. Conclusions

Within the GO-GRASS project there are four different DEMO locations, one in Denmark, one in Germany, one in the Netherlands and one in Sweden. All DEMOs have the aim of biorefining grass. However, there are differences in grassland type between the locations. There are also multiple differences in techniques used, e.g. multiple ways of mowing, collecting and storing grass, which makes each DEMO unique. The type of grass and the handling chain until biorefining are of major importance, as they influence the quality of the substrate material for biorefining. Despite the many differences, there are also many similarities between the techniques used within the different countries (see Table 4).

Within the GO-GRASS project, grass from less common areas is used for very specific purposes. This results in extra challenges, such as prevention of pollution of the harvested material and a need for different management strategies. Due to all the differences, but particularly all the similarities, the partners involved in the project can help and learn from each other in order to overcome the challenges arising in the DEMOs. The technical solutions emerging from this work will be described in deliverables 3.2 & 3.3.

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