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GreenGrass – developing grass for sustainable renewable energy generation and value-added products

Key external stakeholders:

Policy makers, biorefining and anaerobic digestion industries; grass technology companies; farmers, researchers and advisors involved in grass production and utilisation.

Practical implications for stakeholders:

Although grass is normally used as an animal feedstuff it also has potential for industrial use.

- Major grassland management and grass processing technologies to support biogas production or fibre utilisation have been identified.
- Grass press-cake has limited value as a ruminant feed, moderate value for combustion (if dry) and real potential to reduce shrinkage cracking of cement mortars.
- Ireland can produce sufficient grass to meet the needs of both livestock and biogas/biorefining industries.

Main results:

- Ryegrasses were preferable for producing biogas by anaerobic digestion, but higher yielding timothy showed more potential for fibre production.
- Repeated washing (up to 2 washing steps) and mechanical pressing (3.0MPa) proved the most effective treatments for the isolation of a fibre-rich press-cake fraction.
- Press-cake derived from ensiled grass when included at 2.2kg/m^3 eliminated crack formation during restrained shrinkage in cement mortars, comparable with the performance of polypropylene fibres.
- Grass growth stage rather than herbage species had the largest influence on biogas produced during anaerobic digestion. The anaerobic digestion technologies and operational practices for biogas production from grass were improved.
- Recycling silage effluent to the anaerobic digester and employing digestate as a biofertiliser reduced the production cost of grass silage feedstocks.
- Anaerobic digestion and biorefining need not compete for grass with cattle and sheep production systems.

Opportunity / Benefit:

- Circumstances were identified where grass species, growth stage at harvest and conservation or fractionation methodologies could be exploited for biomass production, anaerobic digestion or the utilisation of a fibre-rich press-cake.
- The inclusion of fibre-rich press-cake can reduce surface cracking of cement mortars.
- Improved designs and operation of anaerobic digesters utilising grass as a feedstock, and the potential of hydrolytic pre-treatment, have been demonstrated. (UCC; Questor)
- Practical opportunities were identified to reduce the cost of grass as a feedstock for anaerobic digestion.
- Anaerobic digestion and biorefining would not necessarily have to compete for grass with traditional agricultural production systems. This could allow for additional farm enterprises and thus improve income.

Collaborating Institutions:

Environmental Research Institute, University College Cork (UCC)
Questor Centre, Queens University Belfast (QUB)
University College Dublin (UCD)

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1. Project background:

The need to develop alternatives to non-renewable fossil fuel-derived products has stimulated an interest in plant biomass as a 'natural chemical factory' to provide renewable energy, materials and chemicals. In Ireland, grassland represents the most significant biomass resource, accounting for approximately 90% of the 4.3 million hectares of agricultural land. Although grass is normally used as an animal feedstuff, it also has considerable potential for industrial use. Fresh grass can be used for such purposes, but in most cases it may be necessary to preserve it as silage to ensure year round availability and a predictable quality. This silage can be used directly (e.g. anaerobic digestion) or separated into solid and liquid fractions that can be refined into a range of marketable products. The separated solid fraction (i.e. press-cake) is rich in cellulose, hemicellulose and lignin, while the liquid fraction (i.e. press-juice) contains a mixture of protein components, organic acids, water soluble carbohydrates, minerals and other substances. These can be subjected to a series of downstream processes to recover valuable products.

Biogas (about 55% methane) produced by anaerobic digestion is generally used on-site to generate electricity that is exported directly to the national electricity grid, while the co-produced heat is ideally used on the farm or locally. Alternatively, the biogas can be upgraded to natural gas quality (>97% methane) and injected into the natural gas grid.

2. Questions addressed by the project:

What is the potential of different grass species and red clover for use as a biomass feedstock?
What is the potential of these species to provide fibre for industrial applications?
What are suitable anaerobic digestion technologies for grass silage feedstocks?

3. The experimental studies:

Replicated field plots were established with Italian ryegrass, perennial ryegrass, tall fescue, timothy, cocksfoot or red clover. These were grown with either a low or a high input of inorganic nitrogen fertiliser, and harvested at five stages of the primary growth (early May to early July). In each case a representative sample was ensiled in a laboratory silo.

Silages were fractionated into press-cake and press-juice fractions, and the impact of temperature, pressure, detergent and number of washing steps on the efficiency of this hydrothermal conditioning process was determined.

Three potential applications for the fibre-rich press-cake fraction were investigated: ruminant feedstuff, biomass fuel for combustion and a fibre-reinforcement for cement mortars.

The methane production potential of these herbages and the impact of grassland management practices and ensiling were determined in small-scale (160 ml), high-throughput batch digestion tests.

Hydrolytic pre-treatment processes for grass and grass silage feedstocks were compared and optimised to maximise biogas yield and solids destruction. (Questor)

Grass silage was digested in a bespoke design two stage wet continuously stirred tank reactor (CSTR) at a scale of 300 L for a period of ca. 12 months. The organic loading rate was increased and the hydraulic retention time decreased to assess optimal operation. (UCC)

Furthermore, an innovative leach-bed reactor configuration was investigated to produce soluble organic matter-rich leachate from grass silage feedstocks. The leachate was subsequently fed to a high-rate upflow

anaerobic sludge bed reactor (UASB) where the organic matter was converted to methane. This liquor from the UASB was also further re-circulated over the leach beds. This system was termed a Sequencing fed Leach Bed Reactor system coupled to an Upflow Anaerobic Sludge Bed (SLBR-UASB). The system operated at increasing loading rates for ca. 12 months. (UCC)
Mathematical modelling was used to assess the impact of a significant number of operational variables on the stability of the processes. (UCC)
The costs of providing feedstocks for anaerobic digestion were calculated, as was the average availability of grass for anaerobic digestion in Ireland.

4. Main results:

Agronomic traits that resulted in perennial ryegrass becoming the dominant grass species for ruminant production were also important for industrial use. However, timothy showed potential for fibre production. Neither red clover, tall fescue nor cocksfoot (in particular) showed an advantage for yield or compositional traits.
A fibre-rich press-cake fraction was isolated from a range of silages (mechanical pressure applied and repeated washings were particularly important) across a range of harvest dates and from contrasting grass species.
The low available energy and protein value of the separated press-cake fraction, especially at later growth stages, limits its use as a ruminant feed.
The substantial reduction in ash, N, Cl and K during fractionation improved the suitability of the press-cake fraction for combustion compared with the parent material.
The fibre-rich press-cake fraction supported tensile stresses of the order of magnitude experienced in laboratory-scale tests when cement mortars were subjected to major shrinkage under restrained conditions.
The specific methane yield of a feedstock during anaerobic digestion was determined by its digestible energy content. Hence, grass growth stage at harvest was of primary importance, while only small differences in specific methane yield were observed between common grassland species at the same growth stage.
Digestion of grass silage in a CSTR was initially problematic due to the tendency of the grass silage to float on top of the liquor surface within the first digester. This was overcome by modification of the mixing system. The CSTR system yielded 451 L methane/kg volatile solids at an organic loading rate of 2 kg volatile solids/m^3/d and a retention time of 50 days. This is equivalent to 90% destruction of volatile solids and is close to the maximum value achieved in the biochemical methane potential (BMP) assay. The SLBR-UASB achieved 350 L methane/kg volatile solids (equivalent to 70% destruction of volatiles) at a retention time of 30 days. (UCC)
Hydrolytic treatments prior to anaerobic digestion increased methane production by up to 30% at a short (21 day) hydraulic retention time. (Questor)
Directing the silage effluent stream to the digester (€4/t decrease in feedstock cost) and employing the digestate as a biofertiliser (€3/t decrease in feedstock cost) had a significant impact on feedstock cost.
It was calculated that there is a current national average annual grassland resource of *ca.* 1.7 million tonne dry matter available in excess of livestock requirements, and this could be increased by the widespread use of good grassland management technologies.

5. Opportunity/Benefit:

Circumstances were identified where grass species, growth stage at harvest, conservation methodology and fractionation methodology could (or could not) be exploited for biomass production and/or for anaerobic digestion or the utilisation of a separated fibre-rich press-cake fraction.
The inclusion of fibre-rich press-cake can reduce surface cracking of cement mortars.
Improved designs and operation of anaerobic digesters utilising grass silage as a feedstock, and the potential of hydrolytic pre-treatment, have been demonstrated. (UCC; Questor)
Practical opportunities were identified for reducing the cost of providing grass for anaerobic digestion.
Anaerobic digestion and biorefining would not necessarily have to compete for grass with traditional agricultural production systems. This could allow for additional farm enterprises and thus improve income.

6. Dissemination:

Main publications (Teagasc only):

King, C., McEniry, J, Richardson, M. and O'Kiely, P. (2012). Yield and chemical composition of five common grassland species in response to nitrogen fertiliser application and phenological growth stage. *Acta Agriculturae Scandinavica, Section B - Soil & Plant Science*, 62 (7): 644-658.
King, C., McEniry, J., Richardson, M. and O'Kiely, P. (2013). Silage fermentation characteristics of grass species

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grown under two nitrogen fertiliser inputs and harvested at advancing maturity in the spring growth. *Grassland Science*, 59: 30-43.
McEniry, J., O'Kiely, P., Crosson, P., Groom, E. and Murphy, J.D. (2011). The effect of feedstock cost on biofuel cost as exemplified by biomethane production from grass silage. *Biofuels, Bioproducts and Biorefining*, 5 (6; Nov./Dec.): 670-682.

Popular publications (Teagasc only):

McEniry, J., King, C. and O'Kiely, P. (2011). The grass is greener. *TResearch*, 6 (2): 26-27.
O'Kiely, P. and McEniry, J. (2010). Production of grass for biomethane. EPA funded conference hosted by Environmental Research Institute at University College Cork. Cork, Thursday 15 April, 2010.
O'Kiely, P., McEniry, J., King, C. and Lenehan, JJ. (2011). Biogas research at Teagasc Grange. International Energy Agency Task 37 Energy from Biogas. Cork 15 September, 2011.

7. Compiled by: Padraig O'Kiely, Joseph McEniry and Colman King

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