Research Stimulus Fund

Final Report

Assessing GHG impacts of establishing biomass and biofuel crops

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Please tick below the appropriate area on the research continuum where you feel this project fits

BASIC/FUNDMENTAL ⟶ APPLIED/PRE COMMERCIAL

x		

Key words: *(max 4)*

Carbon balance, nitrous oxide, biomass crops

1. Rationale for Undertaking the Research

Legislation demands that energy policy and climate change goals are closely aligned. The EU Climate and Energy Package has set twin goals of both a 20% increase in renewable energy production and a 20% decrease in greenhouse gas (GHG) emissions by 2020. Meeting both these targets will involve a large element of land-use change and as 90% of agricultural land is grassland, the most likely scenario is that biomass/biofuel cultivation will be at the expense of grassland. Associated with this land-use change will be an alteration in GHG emissions. Biomass currently accounts for almost two-thirds of the total renewable energy and 18% of renewable electricity in Europe. At a national level, the three peat burning power stations are required to adopt 30% co-firing by 2015. However, the total land area under biomass production is currently less than 3,000 hectares, the majority of which is miscanthus. Land-use change to biomass production can contribute towards meeting both national and international renewable energy and emissions targets. Already, land-use change to forestry (LULUCF) offsets almost 1.5 million tonnes of emissions per annum and the conversion of pasture or annual cropland to perennial biomass crops and/or short rotation coppice (SRC) also has the potential to become a significant component to meeting future Greenhouse Gas (GHG) targets. However, realisation of this mitigation potential is dependent on a) the conversion of a substantial portion of land to biomass, b) selection of suitable crop types, c) development of reliable combustion systems, and d) rigorous measurement of emissions and carbon sequestration during cultivation.

2. Research Approach

The impacts of establishing miscanthus and reed canary grass (RCG) were studied by ploughing and cultivating four hectares of permanent pasture on a well to moderately drained brown earth soil at Johnstown Castle, Wexford. Measurements were made prior to, during and after establishment on two miscanthus fields and two RCG fields, with each field approximately one hectare in area, over a three year period. Grassland fields were also monitored as a control. In order to investigate the impacts of annual crop cultivation, emissions were also measured from maize plots (1.5 ha) at Johnstown Castle and Oil Seed Rape (OSR, 3 ha) plots at Ballycarney, Co. Wexford.

Field-scale measurements of carbon dioxide (CO2) uptake and release were measured by the eddy covariance technique. This technique enabled the measurement of CO2 and water fluxes at a one hectare scale. Soil respired carbon and nitrous oxide emissions were also measured before and after cultivation using static chambers, where emissions were calculated as the increase in gas concentration over time.

The Net Carbon Balance of the system was defined as:

Net Carbon Balance = P – (Reco + Cexport)

where P is amount of carbon taken up by the crops during photosynthesis, Reco is the carbon released by the soil and plants and Cexport is the carbon removed in grain and straw from the field at harvest. The difference between P and the sum of Reco and Cexport is the net carbon remaining in the soil.

3. Research Achievements

The impact of ploughing of permanent pasture

Most of this carbon loss during pasture conversion to other land-uses is assumed to be associated with both ploughing and extended fallow period, with losses of over 10 t CO_2 ha^{-1} being associated with pasture conversion. However, our measurements demonstrated that the initial C loss after ploughing was much lower (20-100 kg CO_2 ha^{-1}) and that total site preparation carbon losses could be limited to 2 t CO_2 –eq ha^{-1} yr^{-1} provided the fallow period is minimised. However, nitrous oxide emissions associated with pasture conversion were found to be considerable at 18 kg ha-1 yr-1 of N_2O -N. As N_2O is 296 times more potent a GHG than CO_2, this corresponded to 5.3 t t CO_2 –eq ha^{-1} yr^{-1}. This high level of emissions was probably due to mineralization of high levels of soil organic N in the grassland upon ploughing.

Carbon Sequestration and Nitrous oxide Emissions

Pasture was observed to sequester 4.4 t CO_2 ha^{-1} yr^{-1}, with nitrous oxide emissions emitting 1.5 t CO_2 –eq ha^{-1} yr^{-1} (Figure 1). This resulted in net GHG uptake of 2.9 t CO_2 ha^{-1} yr^{-1}. In contrast, annual crops (maize and OSR) were net GHG sources, with the majority of these losses associated with soil carbon loss. Upon conversion, miscanthus was observed to be a large net GHG source (t CO_2 ha^{-1} yr^{-1}), with most of this due to N_2O release. Miscanthus also established slowly, with growth energy directed into the rhizome for the first two years. However, these emissions lasted for only one year, with miscanthus being carbon neutral in the second year after establishment and by the third year, miscanthus stands had matured and were strong GHG sinks (-14.6 t CO_2 ha^{-1} yr^{-1}). This was due to both a very high leaf area index by year 3 and high N use efficiency, resulting in low N_2O emissions as only 80 kg ha^{-1} of N was required for fertilization. Indeed, this sink should increase and reach a maximum within the next 3 – 6 years. Reed canary grass (RCG) established more quickly, and even though it was still a net source of over 1 t CO_2 ha^{-1} yr^{-1}, the net CO_2 uptake was high and was similar to that of grassland. The large N_2O emissions associated with ploughing were also somewhat ameliorated by higher sward N utilization. In subsequent years, RCG exhibited large GHG uptake (-12.5 t CO_2 ha^{-1} yr^{-1}) although these values were lower than miscanthus. RCG also requires re-establishment every six years and so will not be as large a sink during its lifespan. However, it provides high yields even on wet marginal land and may provide a biomass solution in these areas.

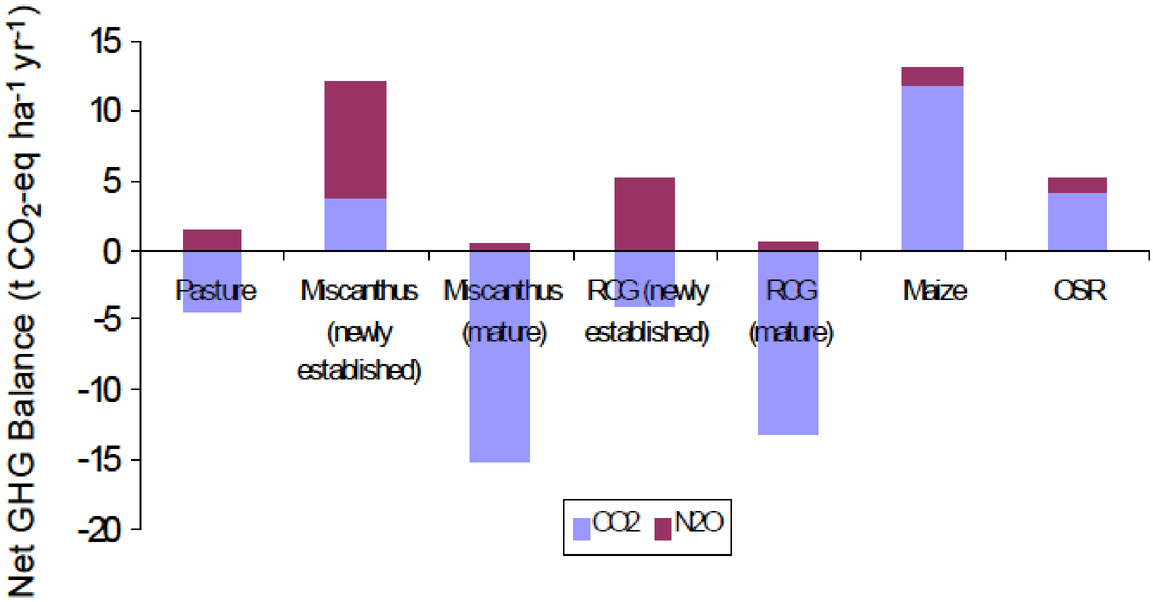

Figure 1: Net greenhouse gas (GHG) balance of various land-uses. Negative values indicate GHG uptake and positive values GHG emissions.

4. Impact of the Research

The greenhouse gas balance (both in terms of Nitrous oxide and Carbon sink activity) of biofuel and biomass crops have been quantified. These are some of the first figures for Europe. These values will be used to update the national GHG inventories and will allow the agriculture sector to count reductions associated with N_2O reduction from land conversion (form pasture or tillage) for perennial biomass crops. In addition, we have verified the 'additionality' in terms of extra C sequestered relative to arable or pasture systems and this will be inputted into the land-use factors, enabling the sector in the future to claim the associated reductions.

Furthermore, the research shows that ethanol production form maize is not a sustainable biofuel compared to OSR in terms of field GHG balance and should not be incentivised.

5. Exploitation of the Research

The primary stakeholders for this research are both farmers and policy makers. This research demonstrates that while annual biofuel crops have a poor field GHG balance, perennial biomass crops had very high rates of CO_2 sequestration and low N_2O emissions. This may provide agriculture with a strategy to 'offset' emissions during cultivation of these crops as well as displacing fossil fuels emissions during combustion. This dataset will also feed into our national greenhouse gas inventories, particularly with respect to land-use factors for the conversion of grassland/cropland to perennial biomass systems.

6. Summary of Research Outputs

(a) Intellectual Property applications/licences/patents

1. None
2.

(b) Innovations adopted by industry

1. None
2.

(c) Number of companies in receipt of information: One, Quinns of Baltinglass.

(d) Outcomes with economic potential

1. Farmers/bioenergy producers: This research demonstrates that perennial biomass crops have a much higher GHG efficiency (and lower C footprint) compared to conventional annual crops used for biofuel production (OSR, maize etc). It quantifies the offsetting potential that would be required

(e) Outcomes with national/ policy/social/environmental potential

1. This research demonstrates that perennial biomass crops have a large greenhouse gas (GHG) mitigation potential. The can offset between 12 -15 tonnes CO_2 per hectare per year (t CO_2 ha^{-1} yr^{-1}) as well as playing a vital role in displacing fossil fuel emissions.
for growers to obtain credits in the event of any domestic offsetting scheme.
2. Policymakers: This research demonstrates that land-use change to biomass production has the potential to become a significant component to meeting future Greenhouse Gas (GHG) targets.
3. Scientific: This research quantifies the nitrous oxide and soil organic carbon balance associated with miscanthus and reed canary grass cultivation in Ireland for the first time and is one of only a handful of studies worldwide.

(f) Peer-reviewed publications, International Journal/Book chapters.

1. Kromdijk, J., Schepers, H.E., Albanito, F., Fitton, N., Carroll, F., Jones, M.B., Finnan, J., Lanigan, G.J., Griffiths, H. (2008) "Bundle Sheath Leakiness and Light Limitation during C4 Leaf and Canopy CO_2 Uptake.' *Plant Physiology* **148**, 2144-2155
2. Don, A., Osborne, B.A., Hastings, A., Skiba, U., Carter, M.S., Drewer, J., Flessa, H., Freibauer, A., Jones, M.B., Lanigan, G.J., Mander, U., Monti, A., Valentine, J., Walter, T., Zenone, T. (2012) Land-use change to bioenergy production in Europe: implications for the greenhouse gas balance and soil carbon. *Global Change Biology- Bioenergy* **4**, 372-391
3. Willems, A.B, Augustenborg, C.A., Hepp, S., Lanigan, G.J., Hochstrasser, T., Kammann, C., Müller, C. (2011) Carbon dioxide emissions from spring ploughing of grassland in Ireland. *Agriculture Ecosystems & Environment* **144**, 347-351
4. Ni Chonchubhair, O., Krol, D., Richards, K., Jones, M.B., Osborne, B.A., Lanigan, G.J. (2013) Impact on carbon and nitrogen fluxes of conversion of managed pasture to bioenergy production. *Agriculture, Ecosystems & Environment* (in press).
5. Abdalla, M., Saunders, M., Lanigan, G.J., Hastings, A., Williams, M., Smith, P., Osborne, B.A., Jones, M.B. (2013) Simulating the impacts of land-use change on Net Ecosystem

Exchange: the role of arable ecosystems, grasslands and forest/biomass plantations in climate change mitigation. Science of the Total Environment (in press).

(g) Scientific abstracts or articles including those presented at conferences

1. Otero, S., Lanigan, G.J. Osborne, B.A. (2009) 'Future Climatic Conditions for Irish Energy Crops: Friend and Foe?' IPSAM Proceedings 6-7 June 2011 Trinity College Dublin
2. Otero, S., Marsh, D., Lanigan, G.J., Osborne, B.A. (2011) 'Effects of simulated climate change over energy crops in Ireland' Geophysical Research Abstracts EGU, Vienna 3-8 April 2011
3. Lanigan, G, Finnan, J., Fealy, R., Jones, M. (2010). 'Growing returns: the role of land-use change in influencing GHG emissions.' Proceedings of A Climate for Change Conference Dublin 24-25 June. Conference Book of Abstracts
4. NiChonchubair O & Lanigan G.J (2011) Impacts of climatic variation on GHG emissions from bioenergy crop ecosystems. NCGG-6 Amsterdam, Netherlands 1-4 Nov 2011
Lanigan G. (2008) Reducing GHG emissions form Irish Agriculture. TResearch 3(2): 40-43
5. J. Kromdijk, F. Albanito, N. Fitton, G. Lanigan, J. Finnan, F. Carroll, M. Jones, H. Schepers and H. Griffiths (2008). Is CO2-uptake by C4-grass canopies limited by leakage of CO2 from bundle sheath cells? Geophysical Research Abstracts Vol.10, EGU2008-A-05198.
6. Krol, D., O'Connor, O., Narayan, C., Richards, K., Williams, M., Jones, M.B., Osborne, B.A. and Lanigan, Gary (2010). The effect of ploughing intensity on grassland CO_2 and N_2O fluxes. In: Proc. British Society of Animal Science and the Ag. Research Forum . Belfast, April 2010. p78, Belfast,
7. O'Connor, O., Krol, D., Narayan, C., Osborne, B., Richards, K., Lanigan, G.J. (2010). Lysimeter study on the effect of ploughing techniques and associated CO_2 and N_2O losses. In: Ecotrons & Lysimeters Conf, Nancy, France, 29-Mar-2010, p.30 21727
8. Ni Chonchubair, O., Krol, D., Narayan, C., Richards, K., Williams, M., Jones, M.B., Osborne, B.A., Lanigan, G.J., (2010). The effect of ploughing intensity on grassland CO_2 and N_2O fluxes. Proceedings of the Agricultural Research Forum 2010, p78.
9. Crosson, P., Shalloo, L., O'Brien, D., Foley, P.A., Boland, T.M. , Kenny, D.A. and Lanigan, G.J., (2010). A review of whole farm systems models of greenhouse gas emissions. Proceeding of the Greenhouse gases in Animal Agriculture Conference, Banff, Canada 3-8 October 2010
10. Gibson, M. and Lanigan, Gary (2010). Greenhouse gas emissions from agriculture: the story so far. Proc. A Climate for Change Conf. Dublin 24-25 June. Conference Book of Abstracts p5
11. Krol, D., Richards, K., O'Connor, O., Narayan, C., Osborne, B.A., Jones, M.B., Williams, M., Lanigan, G. (2010). Lysimeter study on the effect of ploughing techniques on N2O and DON losses. Proc. A Climate for Change Conf. Dublin 24-25 June. Conference Book of Abstracts p. 24
12. Krol, D., Ní Choncubhair, Ó., Jones, M.B., Williams, M.., Osborne B.A. and Lanigan G.J. (2011) N2O emissions following conversion of grassland into bioenergy crops production. Proceedings of the Agricultural Research Forum 2011, p54

13. Krol, D., Ní Choncubhair, Ó., Jones, M.B., Williams, M.., Osborne B.A. and Lanigan G.J. (2011) N2O Emissions from Land Use Change into Bioenergy Crops. Proceedings of NitroEurope, Edinburgh 11-15 April 2011, p20

(h) National Report

1. Lanigan, G.J. , Finnan, J. (2010) Energy crops and greenhouse gases. Carlow, Teagasc.

(i) Popular non-scientific publications

1. Lanigan, G.J., NiChoncubhair, O. , Krol ,D. (2011) 'Energy Crops – Achieving a Balance' TResearch 6 (3): 12-14

2. Drivetime April 2010 – Discussion with Mary Wilson and Prof. John Sweeney on RTE Drivetime

(j) Workshops/seminars/ open days at which results were presented (excluding those in (g))

1. Bioenergy Conference Tullamore 2009
2. GHG Biomass Workshop Johnstown Castle, March 2012
3. Teagasc Seminar on GHG emissions – 28/03/08
4. Teagasc Bioenergy Open Day 2011

7. Permanent Researchers

Institution Name	Number of Permanent staff contributing to project	Total Time contribution (months)	Average time contribution per permanent staff member
Teagasc	4	16.92	4.23
UCD	1	0.72	0.72
Trinity College	2	1.44	0.72
Total			

8. Researchers Funded by RSF

Type of Researcher	Number	Total Time contribution (months)	Average time
Post Doctorates			
Contract Researchers	1	16.14	16.14
PhD postgraduates	2	86.5	43.25
Masters postgraduates			
Temporary researcher			

Other	
Total	

9. Postgraduate Research

Total Number of PhD theses: __2__

Dominika Krol. Trinity College Dublin. The impact of bioenergy crop cultivation on nitrous oxide emissions. November 2012.

Orlaith Ni Choncubhair. University College Dublin. Assessing the impact of bioenergy crops on ecosystem carbon balance. July 2013

Total Number of Masters theses: __0

Please include authors, institutions and titles of theses and submission dates. If not submitted please give the anticipated submission date

10. Project Expenditure

Total expenditure of the project: € 460,772.43

Total Award by RSF € 476,539.41

Other sources of funding (specify) €

1.
2.

Breakdown of Total Expenditure

Category	Teagasc Johnstown	UCD	Trinity College	Teagasc Oak Park	Total
Contract staff	74,602.25				74,602.25
Temporary staff					
Post doctorates					
Post graduates		89,774.12	79,669.10		169,443.22
Consumables	40,230.58	5,768.98	4,081.45		50,081.01
Travel and subsistence	18,702.06	6,354.40	2,2243.32	131.50	27,431.28
Sub total	133,534.89	101,897.50	85,993.87	131.50	321,557.76
Durable equipment	18,220.79		926.77		19,147.56
Other	23,301.32		248.45		23,549.77
Overheads	40,060.47	30,568.25	25,798.16	39.45	96,467.33
Total	**215.117.47**	**132.466.75**	**112,967.25**	**170.95**	**460,722.43**

11. Future Strategies

The dataset from this project will be incorporated into a national database being established in Work Package 4 of the Agricultural Greenhouse Gas Research Initiative-Ireland Network (AGRI-I). Once allied to cropland and pasture GHG data, it will allow us tomove to Tier 2 land-use factors and nitrous oxide emissions in the national inventories.

12. Industry Collaboration

We have worked with Quinns of Baltinglass to optimise perennial biomass crop establishment on pasture systems. This has proved quite challenging as establishment within grass systems has proved problematic. We established a management protocol for land management in conjunction with Oak Park and published a Biomass manual in 2010.