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Assessing the greenhouse gas budget of biomass and biofuel crops

The field-scale CO_2 eddy covariance monitoring equipment at Johnstown Castle, Wexford

Key external stakeholders:

Farmers/bioenergy producers
Department of Agriculture, Food & the Marine
Environmental Protection Agency

Practical implications for stakeholders:

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.

- **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 for growers to obtain credits in the event of any domestic offsetting scheme.

- **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.

- **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.

Opportunity:

The research clearly shows that the establishment of biomass crops is beneficial in terms of overall Greenhouse Gas balance compared to grassland.

Main results:

Winter cover crops, straw incorporation and minimum tillage were all observed to reduce soil organic carbon (SOC) loss, with cover crops the most effective and minimum tillage the least effective individual measure. Nitrous oxide emissions were highest for straw incorporation but were lower than the increased carbon sequestration delivered. Combinations of strategies were found to be additive and had the highest carbon sequestration levels.

Collaborating Institutions:

Trinity College Dublin, University College Dublin, University of Cambridge

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1. Project background:

Legislation demands that energy policy and climate change goals are closely aligned. The EU Cilmate 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. Questions addressed by the project:

This project assessed the impact on GHG emissions of changing from intensive pasture and marginal grassland to biomass crops, particularly:

- What is the impact of on soil carbon stocks of converting a grassland system to a perennial biomass crop (miscanthus), an intermediate perennial crop (canary grass – *Phalaris* spp.), and annual crops (oil seed rape, maize)?
- What is the impact of land conversion on nitrous oxide (N_2O) emissions?

3. The experimental studies:

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) plots at Ballycarney, Co. Wexford.

Field-scale measurements of carbon dioxide (CO_2) uptake and release were measured by the eddy covariance technique. This technique enabled the measurement of CO_2 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:

$$\textbf{Net Carbon Balance} = \mathbf{P} - (\mathbf{R_{eco}} + \mathbf{C_{export}})$$

where **P** is amount of carbon taken up by the crops during photosynthesis, $\mathbf{R_{eco}}$ is the carbon released by the soil and plants and $\mathbf{C_{export}}$ is the carbon removed in grain and straw from the field at harvest. The difference between **P** and the sum of $\mathbf{R_{eco}}$ and $\mathbf{C_{export}}$ is the net carbon remaining in the soil.

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4. Main results:

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 ha^{-1} of CO_2 being associated with pasture conversion. However, our measurements demonstrated that the initial C loss after ploughing was much lower (20-100 kg ha^{-1} of CO_2) and that total site preparation carbon losses could be limited to 2 t ha^{-1} of CO_2 - 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 ha^{-1} of CO_2 equivalents. 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 ha^{-1} yr^{-1} of CO_2, with nitrous oxide emissions emitting 1.5 t ha^{-1} yr^{-1} of CO_2 equivalents (Figure 1). This resulted in net GHG uptake of 2.9 t ha^{-1} yr^{-1} of CO_2. 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 ha^{-1} yr^{-1} of CO_2), 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 ha^{-1} yr^{-1} of CO_2). 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 ha^{-1} yr^{-1} of CO_2, 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 ha^{-1} yr^{-1} of CO_2) 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.

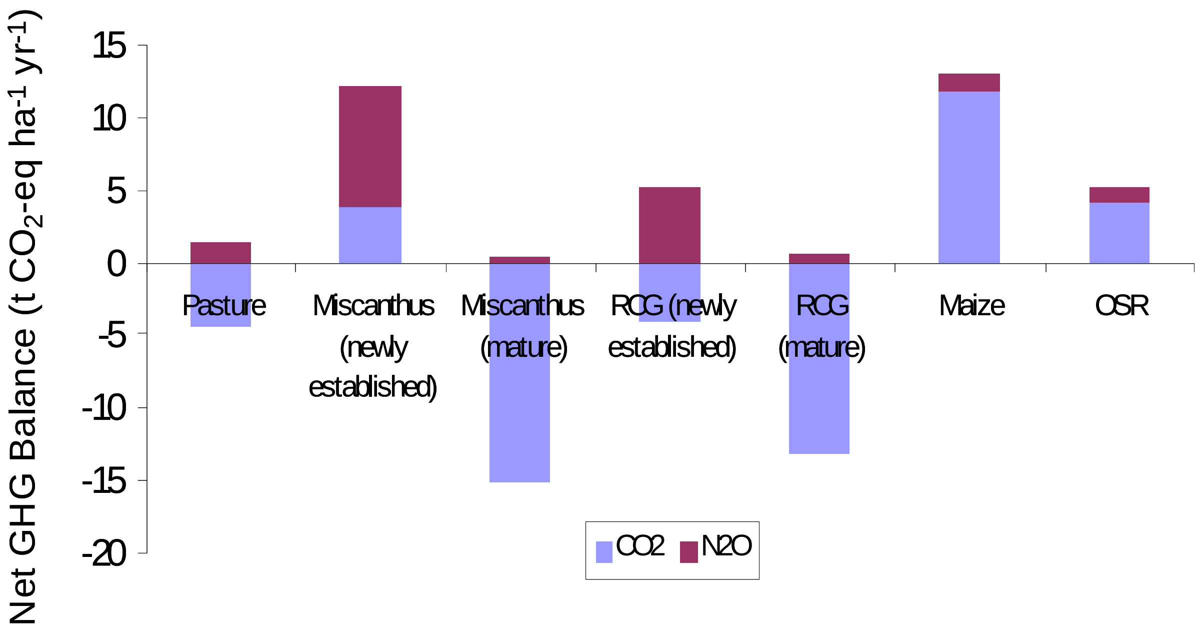

Figure 1: Net greenhouse gas (GHG) balance of various land-uses. Negative values indicate GHG uptake and positive values GHG emissions.

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5. Opportunity/Benefit:

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.

6. Dissemination:

Awareness of the project and relevant results were, and continue to be disseminated via scientific peer-reviewed journals as well as the popular press and media.

Main publications:

Journal article:

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 CO2 Uptake.' *Plant Physiology* 148: 2144-2155

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

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

Technical:

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

Conference:

Otero, S., Lanigan, G.J. and Osborne, B.A. (2009) 'Future Climatic Conditions for Irish Energy Crops: Friend and Foe?' *IPSAM Proceedings 6-7 June 2011* Trinity College Dublin

Otero, S., Marsh, D., Lanigan, G.J., and Osborne, B.A. (2011) 'Effects of simulated climate change over energy crops in Ireland' *Geophysical Research Abstracts EGU,* Vienna 3-8 April 2011

Lanigan, G, Finnan, J., Fealy, R. and 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

Popular publications:

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

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

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