Technology Updates Crops, Environment and Land Use

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Assessing the greenhouse gas budget of tillage mitigation options for arable systems.

Eddy covariance system for field CO_2 measurement

Key external stakeholders:

Arable farmers
Department of Agriculture, Food & Fisheries
Environmental Protection Agency

Practical implications for stakeholders:

This research demonstrates the impact of minimum tillage, straw incorporation and cover cropping on greenhouse gas emissions (GHG) and soil organic carbon (SOC) compared to conventional inversion ploughing in arable systems. The study demonstrates that a combination of reduced tillage combined with cover crops is the most effective strategy at conserving SOC.

- **Farmers:** This research demonstrates that minimum tillage, particularly in combination with straw incorporation and/or cover cropping can significantly reduce soil organic carbon loss in arable systems. In addition, it can significantly reduce the C footprint of cereals.

- **Policymakers:** This research has quantified the abatement benefits of adopting minimum tillage and/or promoting green winter cover. Results are also feeding into a revision of the national greenhouse gas inventories.

- **Scientific:** This research quantifies the nitrous oxide and soil organic carbon losses associated with alternative cultivation techniques for the first time in Ireland.

Opportunity:

The research clearly shows the advantages of altered cultivation techniques for reducing soil organic carbon (SOC) loss as well as their impact on nitrous oxide emissions.

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 Aberdeen

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1. Project background:

Food Harvest 2020 envisages increased profitability from the tillage sector whilst simultaneously enhancing the sustainability of production. In particular, the Food Harvest 2020 Report identified reducing the greenhouse gas (GHG) intensity of agricultural activities and enhancing carbon sinks as key to maintaining sustainability. Strategies to reduce agricultural GHG's are urgently required, particularly in light of EU 2020 Climate and Energy Package and its associated Burden-sharing agreement, where Ireland has been set a 20% reduction target for its non-Emission Traded Sectors. In addition, revisions of the Good Agricultural and Environmental Conditions (GAEC) for the tillage sector are expected to focus on reducing soil carbon losses associated with cultivation.

2. Questions addressed by the project:

This project had two principle research goals.

- What are the effects of minimum tillage on GHG balance at a field scale?
- What are the effects of crop residue incorporation and cover crops on GHG emissions and carbon sequestration?
- What are the effects of these strategies in terms of life-cycle analyses for crops at a farm scale?

3. The experimental studies:

Minimum Tillage, Straw Incorporation and Cover Crops: A series of experiments were carried out on Spring Barley systems in order to assess the individual and combined effects of minimum tillage, straw incorporation and cover cropping on soil organic carbon and nitrous oxide emissions compared to conventional inversion-ploughing cultivation systems. In all treatments, minimum tillage was defined as a non-inversion till to 15cm, with straw incorporation involving all straw post-harvest incorporated to a depth of 15cm. Cover crops (mustard) were sown within two weeks post harvest (early September), sprayed off the following February, with the dead biomass incorporated into the soil during ploughing or minimum tillage in March.

The difficulty with measuring soil organic carbon changes is that they occur over a long time-scale. So two approaches were taken:

a) **The flux measurement and modeling approach:** 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 the 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. Field-scale measurements of carbon uptake and release were measured by the eddy covariance technique. Soil respired carbon and nitrous oxide emissions, following ploughing and fertilizer application, were also measured using static chambers, where emissions were calculated as the increase in gas concentration over time. These measurements were subsequently used to validate process models which simulate the carbon and nitrogen cycle.

b) **Measurement of soil carbon from long-term trials:** The soil organic carbon content (SOC) of long-term (nine-year old) winter wheat minimum tillage trials (with and without straw incorporation) was compared to soil carbon stocks from inversion-ploughed winter wheat trials. In addition, SOC from long-term cover crop trials were also measured.

Life-Cycle Analysis: A life-cycle analysis was performed in order to assess the impact of the above mitigation options on the carbon footprint (also known as Emissions Intensity) of arable systems. The carbon footprint is defined as **kg CO_2-equivalent emissions / kg production yield**. The analysis was performed at a farm gate level. The boundary of the analysis included on-farm emissions (soil carbon, direct and indirect nitrous oxide emissions, and fuel usage. It also included so-called 'up-stream' emissions which comprise of N, P and K fertilizer manufacture as well as herbicide/pesticide manufacture. As the analysis ended at the farm gate, no downstream emissions such as transport to processors or energy used for grain drying were included. All emissions were expressed as kg CO_2 equivalents.

4. Main results:

Using annual flux measurements, spring barley fields cultivated using minimum tlllage were observed to sequester more carbon compared to conventionally ploughed fields by an average of 0.3 tonnes C ha^{-1} yr^{-1}. However, there was considerable year-to-year variation, ranging from 0 – 0.7 tonnes C ha^{-1} yr^{-1}. Measurements of soil organic carbon stocks on long-term (~9 years) winter wheat trials revealed that minimum-tilled plots sequestered 0.18 t C ha^{-1} yr^{-1} in the top 15 cm of soil compared to minimum-tilled plots, mainly due to reduced rates of decomposition. Minimum tillage was observed to have only a small effect on N_2O, with emissions increasing by 0.049 tonnes C-equivalent ha^{-1} yr^{-1} (note that N_2O is eqpressed as carbon equivalents as this gas is 296 times more potent as a greenhouse gas than CO_2).

Straw incorporation was observed to increase SOC content by 0.44 t ha^{-1} yr^{-1} of C. This meant that 21% of the incorporated straw was sequestered into the soil. However, N_2O emissions increased by 0.14 tonnes C-equivalents, offsetting some of these gains. This was due to the release (as N_2O) of some of the N within the straw, as well as changes in water-holding capacity of the soil. When minimum tillage and straw incorporation were combined, the effects appeared to be additive, with sequestration increasing by 0.6 t ha^{-1} yr^{-1} of C.

Winter cover crops (mustard) were effective as they limited C loss during the fallow period. The duration of the fallow period was observed to be the principle driver of annual C balance. Values of carbon sequestration derived from annual fluxes and from SOC stocks from long-term trials were similar at 0.51 t ha^{-1} yr^{-1} of C. There was no discernible effect on N_2O emissions as any increase in soil N availability was reduced due to decreased winter N loss. The combination of cover crops and minimum tillage increased sequestration rates to circa. 0.7 t ha^{-1} yr^{-1} of C. This was significant as it converted the arable system from a carbon source to a net carbon sink. However, the combination of minimum tillage, straw incorporation and cover crops did not yield much extra benefit in terms of C sequestration (0.74 t ha^{-1} yr^{-1} of C) but did increase N_2O emissions (0.2 tonnes C-equivalent ha^{-1} yr^{-1}). The combination of all three strategies is also not economically sustainable without incentives as it meant that fuel savings associated with minimum tillage were greatly outweighed by loss of income on straw as well greater input costs for cover crops (mustard seed, sprays and associated ground preparation).

Impact on carbon footprint. Altered cultivation techniques had a significant impact on the carbon footprint of spring barley systems, once soil organic carbon was included in the analysis. In all analyses, soils carbon, field nitrous oxide, and N fertilizer manufacture emissions from were the dominant emission sources (Figure 1). Minimum tillage had a marginal impact on soil C emissions but also reduced fuel emissions significantly. Both straw incorporation and cover crops impacted greatly on soil C loss but less on other emissions. When minimum tillage and cover crops (MT+CC) were combined, this halved the C footprint and resulted in the field absorbing CO_2. However, The combination of all three strategies marginally increased the C footprint compared to MT+CC. This was due to higher nitrous oxide emissions as well as higher fuel and herbicide/pesticide usage.

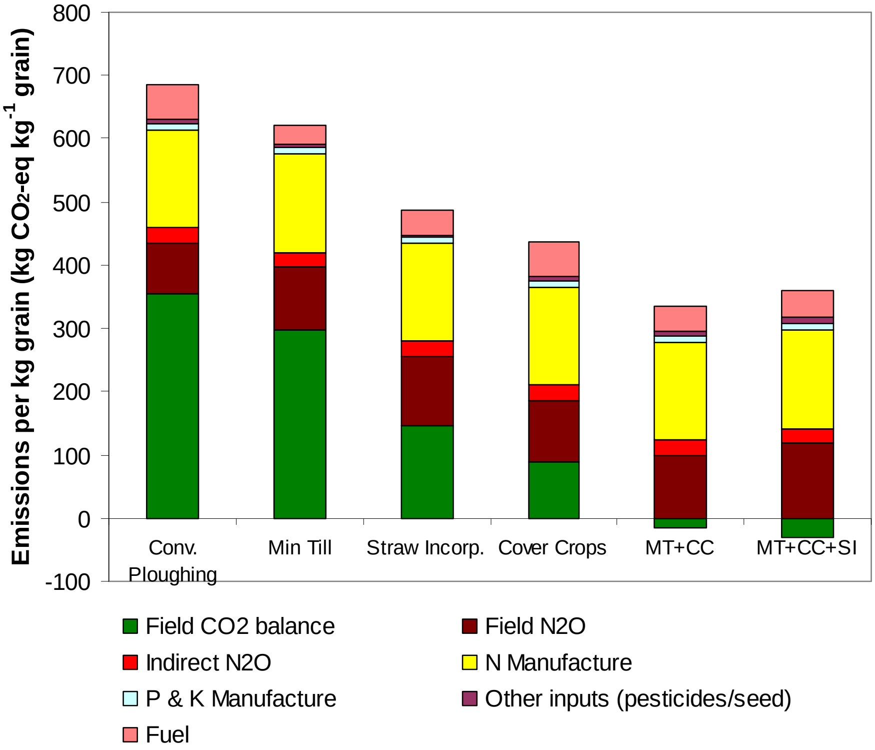

Figure 1: Carbon footprint (kg CO_2-equivalents kg^{-1} grain) for spring barley cultivated using conventional ploughing, minimum tillage, ploughing + straw incorporation, ploughing +cover crops, minimum tillage + cover crops and minimum tillage + straw incorporation + cover crops.

5. Opportunity/Benefit:

The primary stakeholders for this research are both farmers and policy makers. This research demonstrates the effectiveness of changing cultivation techniques in order to reduce soil carbon loss. In particular, it demonstrates that altering cultivation technique can reduce and indeed reverse C loss as well as significantly reducing the C footprint of cereal production.

6. Dissemination:

Main publications:

Journal Article:
Davis, P. A., Clifton Browne, J., Saunders, M., Lanigan, G., Wright, E., Fortune, T., Burke, J., Connolly, J., Jones, M. B. and Osborne, B. A. (2010). 'Assessing the effects of agricultural management practices on carbon fluxes: spatial variation and the need for replicated estimates of net ecosystem exchange.' *Agricultural and Forest Meteorology* 150: 564-574.

Conference:
Lanigan G. (2009) The carbon balance of European croplands: the influence of gross primary production during non optimal growth periods *Irish Plant Scientists Annual Meeting Proceedings. April 2009, UCD, Dublin 4.*

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