National Development Plan 2007 - 2013

Environmental Protection Agency
An Ghníomhaireacht um Chaomhnú Comhshaoil

STRIVE
Report Series No.43

Climate Change – Accounting for Greenhouse Gas Sources and Sinks in Major Irish Land-Use Categories: Towards the Establishment of a Co-ordinating Centre for FLUX Measurements (CCFLUX)

STRIVE
Environmental Protection Agency Programme
2007-2013

SSTI
Strategy for Science, Technology and Innovation

Comhshaol, Oidhreacht agus Rialtas Áitiúil
Environment, Heritage and Local Government

Environmental Protection Agency

The Environmental Protection Agency (EPA) is a statutory body responsible for protecting the environment in Ireland. We regulate and police activities that might otherwise cause pollution. We ensure there is solid information on environmental trends so that necessary actions are taken. Our priorities are protecting the Irish environment and ensuring that development is sustainable.

The EPA is an independent public body established in July 1993 under the Environmental Protection Agency Act, 1992. Its sponsor in Government is the Department of the Environment, Heritage and Local Government.

OUR RESPONSIBILITIES

LICENSING

We license the following to ensure that their emissions do not endanger human health or harm the environment:

- waste facilities (e.g., landfills, incinerators, waste transfer stations);
- large scale industrial activities (e.g., pharmaceutical manufacturing, cement manufacturing, power plants);
- intensive agriculture;
- the contained use and controlled release of Genetically Modified Organisms (GMOs);
- large petrol storage facilities.
- Waste water discharges

NATIONAL ENVIRONMENTAL ENFORCEMENT

- Conducting over 2,000 audits and inspections of EPA licensed facilities every year.
- Overseeing local authorities' environmental protection responsibilities in the areas of - air, noise, waste, waste-water and water quality.
- Working with local authorities and the Gardaí to stamp out illegal waste activity by co-ordinating a national enforcement network, targeting offenders, conducting investigations and overseeing remediation.
- Prosecuting those who flout environmental law and damage the environment as a result of their actions.

MONITORING, ANALYSING AND REPORTING ON THE ENVIRONMENT

- Monitoring air quality and the quality of rivers, lakes, tidal waters and ground waters; measuring water levels and river flows.
- Independent reporting to inform decision making by national and local government.

REGULATING IRELAND'S GREENHOUSE GAS EMISSIONS

- Quantifying Ireland's emissions of greenhouse gases in the context of our Kyoto commitments.
- Implementing the Emissions Trading Directive, involving over 100 companies who are major generators of carbon dioxide in Ireland.

ENVIRONMENTAL RESEARCH AND DEVELOPMENT

- Co-ordinating research on environmental issues (including air and water quality, climate change, biodiversity, environmental technologies).

STRATEGIC ENVIRONMENTAL ASSESSMENT

- Assessing the impact of plans and programmes on the Irish environment (such as waste management and development plans).

ENVIRONMENTAL PLANNING, EDUCATION AND GUIDANCE

- Providing guidance to the public and to industry on various environmental topics (including licence applications, waste prevention and environmental regulations).
- Generating greater environmental awareness (through environmental television programmes and primary and secondary schools' resource packs).

PROACTIVE WASTE MANAGEMENT

- Promoting waste prevention and minimisation projects through the co-ordination of the National Waste Prevention Programme, including input into the implementation of Producer Responsibility Initiatives.
- Enforcing Regulations such as Waste Electrical and Electronic Equipment (WEEE) and Restriction of Hazardous Substances (RoHS) and substances that deplete the ozone layer.
- Developing a National Hazardous Waste Management Plan to prevent and manage hazardous waste.

MANAGEMENT AND STRUCTURE OF THE EPA

The organisation is managed by a full time Board, consisting of a Director General and four Directors.

The work of the EPA is carried out across four offices:

- Office of Climate, Licensing and Resource Use
- Office of Environmental Enforcement
- Office of Environmental Assessment
- Office of Communications and Corporate Services

The EPA is assisted by an Advisory Committee of twelve members who meet several times a year to discuss issues of concern and offer advice to the Board.

EPA STRIVE Programme 2007–2013

Climate Change – Accounting for Greenhouse Gas Sources and Sinks in Major Irish Land-Use Categories: Towards the Establishment of a Co-ordinating Centre for FLUX Measurements (CCFLUX)

(2001-CC/CD-3/7)

Final Report

Prepared for the Environmental Protection Agency

by

School of Natural Sciences, Department of Botany, Trinity College Dublin, Ireland;
School of Biology and Environmental Science, University College Dublin, Ireland; and
Teagasc Crops Research Centre, Oakpark, Carlow

Authors:

Mike Jones, Bruce Osborne, Mike Williams, Matt Saunders, Gary Lanigan, James Burke, Phill Davis, Mohamed Abdalla, John Clifton-Brown, John Connolly, Suresh Kumar and Miklos Nagy

ENVIRONMENTAL PROTECTION AGENCY
An Ghníomhaireacht um Chaomhnú Comhshaoil
PO Box 3000, Johnstown Castle, Co. Wexford, Ireland

Telephone: +353 53 9160600 Fax: +353 53 9160699
Email: info@epa.ie Website: www.epa.ie

ACKNOWLEDGEMENTS

This report is published as part of the Science, Technology, Research and Innovation for the Environment (STRIVE) Programme 2007–2013. The programme is financed by the Irish Government under the National Development Plan 2007–2013. It is administered on behalf of the Department of the Environment, Heritage and Local Government by the Environmental Protection Agency which has the statutory function of co-ordinating and promoting environmental research.

DISCLAIMER

EPA STRIVE PROGRAMME 2007–2013

Published by the Environmental Protection Agency, Ireland

ISBN: 978-1-84095-333-6 **Online version**
Price: Free

Details of Project Partners

Mohamed Abdalla
School of Natural Sciences
Department of Botany
Trinity College Dublin
College Green
Dublin 2
Ireland
Tel.: 353 1 8963740
Email: abdallm@tcd.ie

John Clifton-Brown[a]
School of Natural Sciences
Department of Botany
Trinity College Dublin
College Green
Dublin 2
Ireland
Tel.: 44 1970 823191
Email: jhc@aber.ac.uk

Phill Davis[b]
School of Biology and Environmental Science
University College Dublin
Belfield
Dublin 4
Ireland
Tel.: 1 812 8552179
Email: phadavis@indiana.edu

Suresh Kumar[c]
School of Natural Sciences
Department of Botany
Trinity College Dublin
College Green
Dublin 2
Ireland
Tel.: 353 1 7083769
Email: suresh.kumar@nuim.ie

James Burke
Teagasc
Crops Research Centre
Oakpark
Carlow
Co. Carlow
Ireland
Tel.: 353 59 91 70201
Email: jim.burke@teagasc.ie

John Connolly
School of Mathematical Sciences
University College Dublin
Belfield
Dublin 4
Ireland
Tel.: 353 1 7167103
Email: john.connolly@ucd.ie

Mike Jones (PI)
School of Natural Sciences
Department of Botany
Trinity College Dublin
College Green
Dublin 2
Ireland
Tel.: 353 1 8961769
Email: mike.jones@tcd.ie

Gary Lanigan[d]
School of Natural Sciences
Department of Botany
Trinity College Dublin
College Green
Dublin 2
Ireland
Tel.: 353 53 9171216
Email: gary.lanigan@teagasc.ie

Miklos Nagy
School of Biology and
Environmental Science
University College Dublin
Belfield
Dublin 4
Ireland
Tel.: 353 1 7162249
Email: miklos.nagy@ucd.ie

Bruce Osborne
School of Biology and
Environmental Science
University College Dublin
Belfield
Dublin 4
Ireland
Tel.: 353 1 7162249
Email: Bruce.Osborne@ucd.ie

Matt Saunders[e]
School of Natural Sciences
Department of Botany
Trinity College Dublin
College Green
Dublin 2
Ireland
Tel.: 353 1 7162245
Email: matthew.saunders@ucd.ie

Mike Williams
School of Natural Sciences
Department of Botany
Trinity College Dublin
College Green
Dublin 2
Ireland
Tel.: 353 1 8962421
Email: Michael.williams@tcd.ie

[a] **Current Address**
Plant Breeding and Genetics
Institute of Biological, Environmental and Rural Sciences
Plas Gogerddan
Aberystwyth
SY23 3EB
Wales

[b] **Current Address**
Department of Biology
University of Indiana
Indiana
USA

[c] **Current Address**
Department of Geography
National University of Ireland, Maynooth
Maynooth
Co. Kildare
Ireland

[d] **Current Address**
Teagasc
Johnstown Castle Research Centre
Wexford
Ireland

[e] **Current Address**
School of Biology and Environmental Science
University College Dublin
Belfield
Dublin 4
Ireland

Table of Contents

Executive Summary

In support of the development of European post-Kyoto policies, it is important for European countries to account for the sources and sinks of greenhouse gases (GHGs) associated with major land-use classes. In 2004 agricultural land in Ireland accounted for approximately 60% of the total land cover and contributed approximately 27.7% of total national GHG emissions. The CCFLUX project, a collaborative research initiative between Trinity College Dublin, University College Dublin and Teagasc, was implemented to investigate GHG fluxes at the field scale in order to determine the net global warming potential from managed arable ecosystems. Eddy covariance techniques and static chamber measurements were employed to determine the fluxes of CO_2 and N_2O respectively from a spring barley (*Hordeum vulgare*) crop which was subject to two tillage management regimes: conventional and non-inversion tillage.

The CCFLUX project had two key objectives: (i) to provide the Environmental Protection Agency with a balance sheet detailing the GHG emissions by sources and removal by sinks for selected Irish land-use categories and to use this information as a basis for developing mitigation strategies to reduce national GHG emissions; and (ii) to equip policy-makers with the process-based knowledge, grounded on a sound scientific understanding needed to make rationally based recommendations for reducing national GHG emissions.

The key targets associated with these objectives were: (i) to provide the EPA with the capacity to establish a coordinating centre for the measurement and analysis of GHG flux measurements in Ireland; (ii) to provide standardised protocols for the measurement and modelling of CO_2 and N_2O fluxes; (iii) to integrate data from existing funded projects on GHG flux measurement in Ireland with field-scale measurements to be undertaken for arable ecosystems; (iv) to contribute data to the EPA to facilitate the production of a regional distribution map of GHG fluxes (sources and sinks) for Ireland; and (v) to identify mitigation strategies to reduce national GHG emissions.

The results of the CCFLUX project led to the following conclusions:

- The conversion from conventional to non-inversion tillage management will help to reduce carbon emissions from Irish arable ecosystems;
- The inclusion of a cover crop species during the fallow period will reduce carbon emissions further, and, depending on crop residue management, may enhance the net uptake of carbon from the atmosphere;
- Tillage management did not exert a significant influence on soil respiration;
- Respiration from arable soils is directly correlated to above-ground biomass;
- Tillage management had no significant effect on N_2O flux or grain yield;
- A reduction in N input on the non-inversion tillage treatment significantly reduced N_2O emissions having a notable influence on grain yield;
- The DeNitrification DeComposition (DNDC) model was able to predict net and peak N_2O fluxes accurately from Irish arable ecosystems.

1 Introduction

The United Nations Framework Convention on Climate Change (UNFCCC) requires that all Annex 1 signatory countries produce a National Inventory Report (NIR) in relation to the sources and sinks of all greenhouse gases (GHGs) that are not controlled under the Montreal Accord. The NIR for Ireland as compiled by the Environmental Protection Agency (EPA) details a consistent time-series GHG inventory from 1990–2004, and shows that GHG emissions from all sectors in 2004 totalled 68.46 million tonnes CO_2 equivalent – an increase of 23.1% over 1990 emissions. The breakdown of GHG emissions in 2004 showed that the agriculture sector contributed approximately 27.7% of total nationwide GHG emissions (McGettigan et al. 2006).

The high contribution to total national GHG emissions from the agricultural sector in Ireland is largely due to the importance of agriculture within the Irish economy. Agricultural land accounts for approximately 60% of the total land of Ireland, with total grassland constituting 90% and tillage agriculture constituting the majority of the remaining agricultural land cover (Central Statistics Office 2007).

GHG emissions from the agricultural sector in Ireland are derived from three major sources: enteric fermentation (49%), agricultural soils (38%) and manure management (13%), and are accounted for by three key GHGs: carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) (Ireland National Inventory Report 2006).

The overarching objectives of the CCFLUX project were to: (i) provide information on CO_2 emissions from tillage crops and to investigate the impact of tillage management on CO_2 efflux; (ii) provide comparative information on CO_2 emissions from arable and grassland agricultural soils; and (iii) investigate the impacts of varying nitrogen application on N_2O fluxes from arable soils and to utilise this information to field-test the DeNitrification DeComposition (DNDC) model in an Irish context.

2 Net Ecosystem Exchange of CO_2 over a Spring Barley Crop under Conventional and Non-Inversion Tillage

2.1 Introduction

The Irish agricultural sector contributes a significant proportion (~28%) of the total national GHG emissions. Arable lands tend to act as a net source of CO_2, as the regular disturbance of soils through conventional tillage practices enhances heterotrophic respiration, leading to a progressive reduction in organic carbon content. The reduction in soil disturbance through non-inversion tillage management has been shown to improve rates of carbon sequestration in many different soil types and cropping systems (Lal 1997; Yang and Kay 2001; Roldán et al. 2003). There is therefore considerable potential for the mitigation of carbon efflux from arable ecosystems through the conversion of conventional tillage management to low or no-till farming (Smith et al. 1998). It has been estimated that the conversion to no-till farming could reduce carbon losses on a European basis by approximately 40 Tg C y^{-1} (Smith et al. 2002).

In 2006, approximately 167,000 ha of land were utilised for the production of spring barley (*Horduem vulgare*) (Central Statistics Office 2007). Traditionally, the cultivation of spring barley in Ireland involves conventional tillage methods, consisting of a single ploughing event to a depth of 20–25 cm, approximately 1 month before sowing. However, an increasing number of farmers are converting to eco-tillage or low-tillage practices, where the soil surface is harrowed to a depth of 5–15 cm, usually after harvest, in order to reduce both the costs and time associated with conventional land management.

In addition to reducing the magnitude of carbon losses associated with heterotrophic respiration through low-tillage management, further reductions can be made by reducing the amount of carbon exported from arable ecosystems through crop residues such as straw, and promoting the reincorporation of these residues into the soil. The incorporation of straw and harvest residues into the soil has been shown to improve the physical properties of the soil and reduce rates of nitrate leaching, without influencing crop yields significantly (Zeleke et al. 2004). While the incorporation of straw has been shown to have many potential benefits, it is still a rarely practised management procedure in Ireland.

Although emissions of carbon dioxide may constitute only a small proportion of the total GHG emissions from agriculture, any reduction in GHG emissions through changes in land management could contribute to an integrated GHG emission strategy for Ireland.

2.2 Methodology

Measurements of net ecosystem exchange (NEE) of CO_2 over a spring barley crop were made at the Teagasc Crops Research Centre, Oakpark, Carlow, Ireland. The site consisted of four plots ranging in size from 2.4–2.7 ha^{-1} (Fig. 2.1). The two conventionally tilled plots (CON) were ploughed to a depth of 20–25 cm approximately 1 month before sowing, while the non-inversion tillage plots (NIT) were harrowed to a depth of 10–15 cm immediately after harvest. The experimental site represents a well-established arable system that has been utilised for long-term crop rotations since 1960; however, spring barley has been grown at this site since 2000. Eddy covariance (EC) techniques were used to measure the NEE of carbon (Aubinet et al. 2000; Moncrieff et al. 1997). The EC systems were mounted on mobile trailers (Fig. 2.2) and moved between tillage treatments on a weekly basis. These systems consisted of a closed pathway infra-red gas analyser (LI-7000, LICOR Inc., Lincoln, NE), a 3-D sonic anemometer (Solent R3, Gill Instruments Ltd, Lymington, UK) and a laptop computer for data acquisition. Data acquisition was performed using Edisol software while post-processing of the flux data was conducted using EdiRe software (University of Edinburgh, School of Geosciences). An associated meteorological station was located at the centre of the field: this measured air temperature, relative humidity (Vaisala HMP45C), incident irradiance (Skye SKP215), net radiation (Kipp and Zonen NR-Lite), soil heat flux (HFP01), soil moisture content (CS616), wind speed and direction (Young RM05103) and rainfall (TB4-L). All parameters were recorded at 30-minute intervals on a CR10X datalogger (Campbell Scientific, Shepshed, UK).

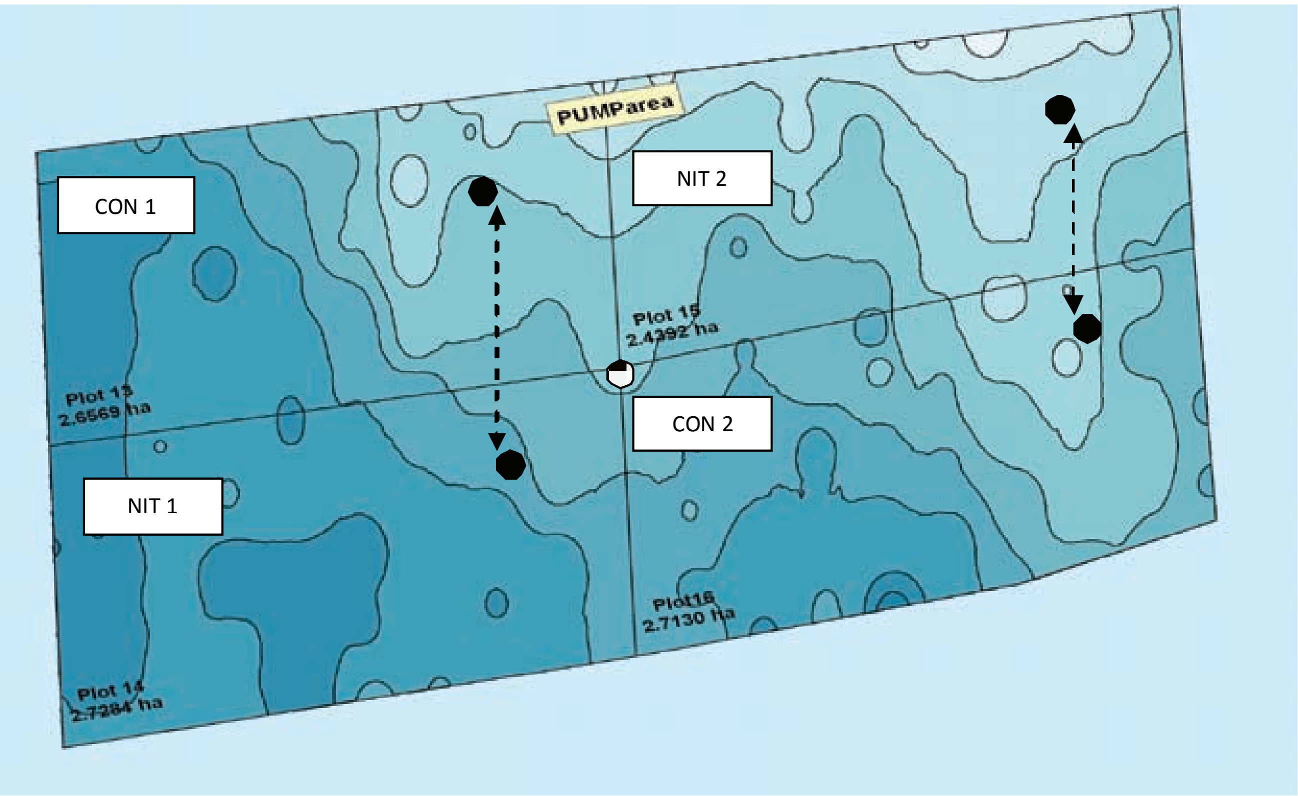

Figure 2.1. Map of field at Oakpark showing the split block design, tillage treatment and eddy covariance tower position (circles). Each system was moved at regular intervals between two plots (arrows). The meteorological tower was located at the centre of the field (hatched circle). Contour lines represent 1 m changes in altitude.

Figure 2.2. The closed path eddy covariance system mounted on the mobile trailer.

Post-processed EC data were subject to footprint analyses according to the Kormann-Meixner (2001) footprint algorithm. This ensured that at least 70% of the measured flux originated within the fetch footprint of the relevant treatment. Gaps within the EC data set arose because of the enforced trolley movements and equipment downtime due to power failure or routine calibration. A semi-empirical model was used to fill data gaps, based on the time-dependent response of NEE to temperature and light (Falge et al. 2001; Reichstein et al. 2005). Ecosystem respiration R_{eco} (based on night-time CO_2 fluxes) was modelled using the Lloyd and Taylor equation (1994) (Eqn 2.1):

$$R_{eco} = R_{10}\, e\, [E_O.\{(1/T_R - T_0) - (1/T_a - T_0\}] \qquad \text{(Eqn 2.1)}$$

where R_{10} is the respiration rate at 10 °C, E_O is set to 309 K, T_a is air temperature (K) and T_R is the reference temperature (283 K). A single value of T_0 was fitted for the whole data set. Net ecosystem gross primary production (GPP) was modelled based on the Leverenz (1995) photosynthetic light response curve (Eqn 2.2):

$$GPP = \{(\alpha.\, I + A_m) - \sqrt{[(\alpha.\, I + A_m)^2 - (4.\gamma\, .I\, .\alpha.\, A_m)]}\}/\, 2\gamma \qquad \text{(Eqn 2.2)}$$

where I was the incident photon irradiance (μmol [photon] m^{-2} s^{-1}), a is the apparent quantum yield, based on incident irradiance (mol [photons] mol [CO_2] $^{-1}$), A_m is the maximum assimilation rate (μmol [CO_2] m^{-2} s^{-1}) and γ is the curvature (set to 0.8 for this data set). To account for the seasonal changes in ecosystem light response, changes in the parameters A_m and α were modelled using linear regressions calculated between these parameters and time.

Plant biomass was estimated from a destructive sampling campaign conducted every 3 weeks during the growing season and monthly during the fallow season. On each sampling date, all plant material was collected from ten 0.25 m^2 quadrats, randomly positioned within each treatment plot. The root and shoot dry mass were determined by force-drying plant samples at 80 °C. Grain yields were measured by removing the grain by hand once total shoot mass had been determined. The green leaf area was determined by measuring incident irradiance interception by the plant canopy using a Sunscan portable solarimeter (Delta-T Devices, Burwell, Cambridge, UK).

2.3 Results

The monthly integrated measurements of precipitation from 2003–2006 are shown in Fig. 2.3 along with the 30-year monthly mean precipitation. The total precipitation recorded during the growing season (March to August) in 2003 was 11% higher than the 30-year mean for the same period, while the total precipitation during the growing periods in 2004, 2005 and 2006 were 7.9%, 37.2% and 32.2% lower than the 30-year mean for the same period.

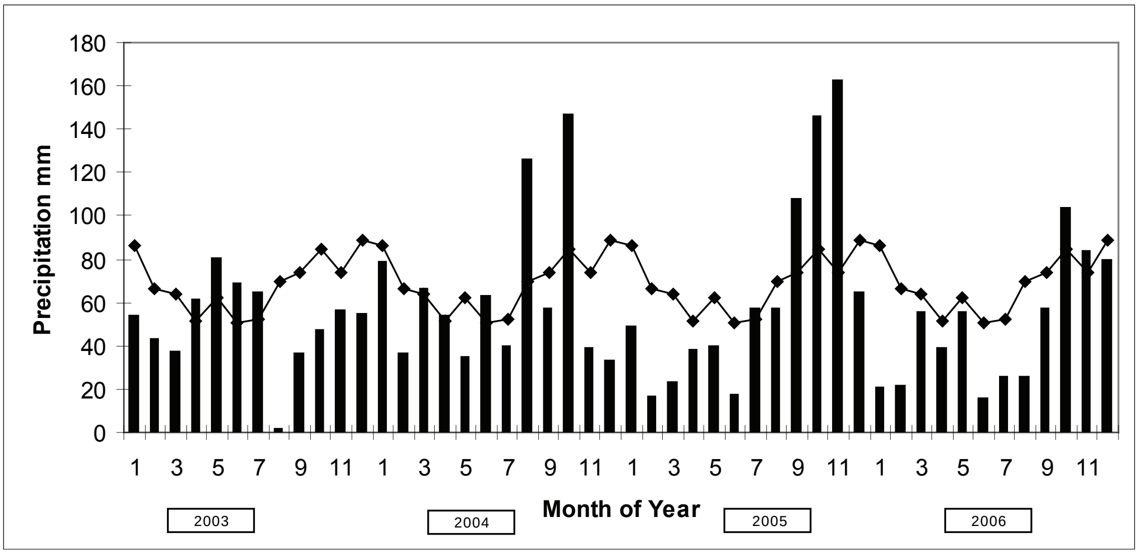

Figure 2.3. Monthly precipitation for the period 2003–2006 at Oakpark Crops Research Centre, Carlow, Ireland. (Columns represent monthly data collected at Oakpark; solid line represents monthly 30-year mean precipitation, data collected at the MET Éireann climate station, Kilkenny, Ireland.)

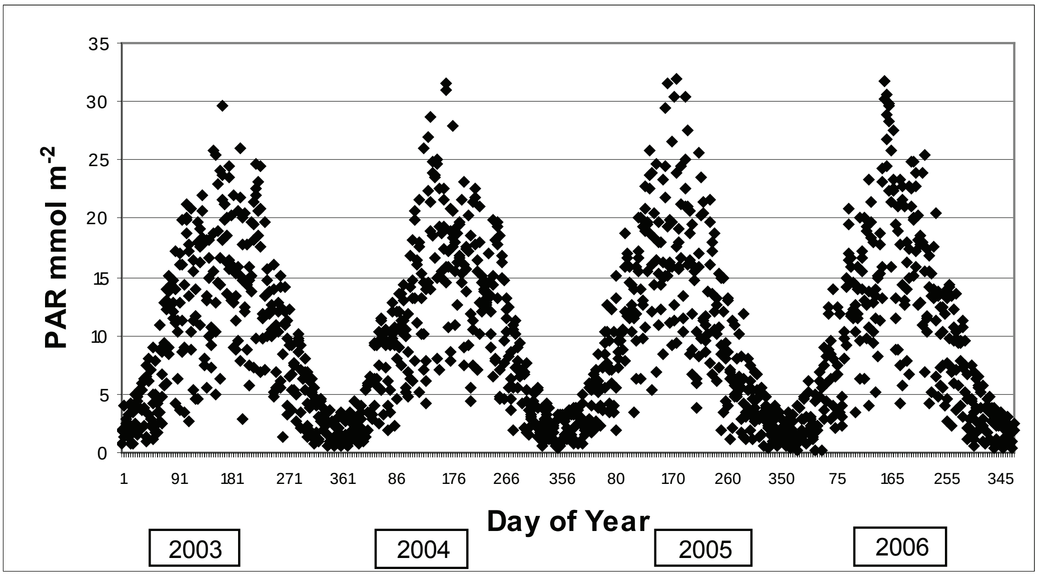

Figure 2.4. Daily integrated measurements of photosynthetic active radiation for the period 2003–2006 recorded at Oakpark Crops Research Centre, Carlow, Ireland.

The daily integrated measurements of photosynthetically active radiation (PAR) and air temperature are shown in Figs 2.4 and 2.5 respectively. The annual patterns of daily incident PAR were similar between years, with peak values of 50–60 mol m^{-2} recorded during the summer season. The annual patterns of air temperatures also exhibited similar variations between years, with air temperatures ranging between -3 and +10 °C recorded during the fallow season (September to February) and between 10 and 22 °C recorded during the growing season.

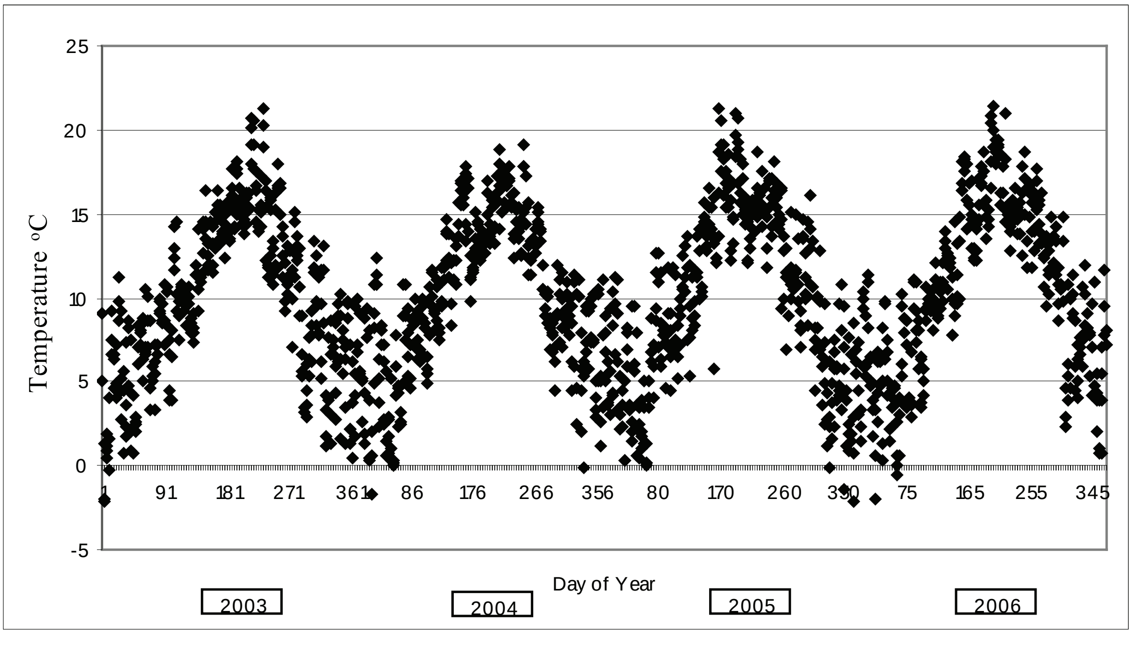

Figure 2.5. Daily average air temperature for the period 2003–2006 recorded at Oakpark Crops Research Centre, Carlow, Ireland.

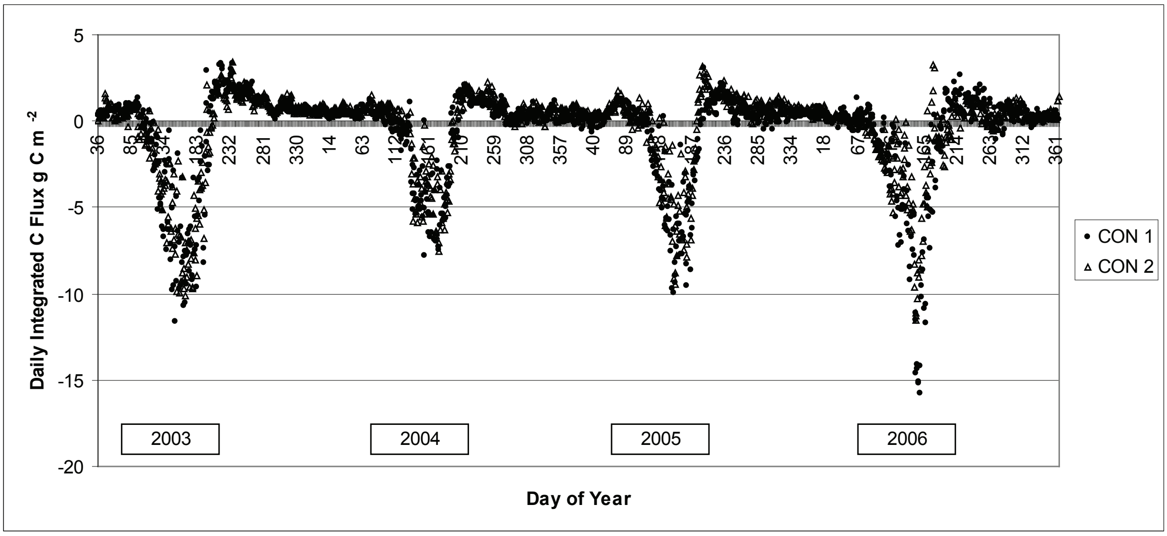

Figure 2.6. Daily integrated carbon fluxes from eddy covariance measurements made on the replicated conventionally tilled arable plots from 2003–2006 (negative values indicate the net uptake of carbon, while positive values indicate the net release of carbon).

Figures 2.6 and 2.7 illustrate the daily integrated carbon flux measured by the EC systems over both the CON and NIT plots. In 2003 and 2004, both treatments exhibited similar seasonal patterns of carbon flux – a net release of carbon during the fallow period and a net uptake of carbon during the growing season. During the fallow period (October 2003–March 2004), an increase in volunteer growth of barley seedlings occurred on the NIT plots. This resulted in a reduction in the magnitude of carbon loss of approximately 37 g C m^{-2} in comparison to the CON plots. Owing to the positive impact of plant cover on fallow period carbon fluxes, a cover crop of mustard was introduced onto the NIT plots during the 2005–2006 and 2006–2007 fallow periods. The cover crop was sown on both NIT plots after the grain harvest in September where conditions allowed and was sprayed and chopped in February before the sowing of the spring barley crop. Figure 2.7 illustrates the impact of the cover crop on the net ecosystem carbon flux during the 2005 and 2006 fallow periods. Daily carbon uptake during these periods ranged from ~0 to 3 g C m^{-2}, with peak rates of uptake recorded between early September and mid-October 2006 (Day of year 250–290). The impact of volunteer seedlings, weeds and cover crops on fallow season carbon fluxes varied between years. This is shown in Fig. 2.7, which describes how in 2006 between day 196 and 240 NIT Plot 1 acted as a net carbon source while NIT Plot 2 acted as a net carbon sink. This was because of an increased presence of weed and volunteer seedlings on NIT plot 2 during this period.

Carbon uptake owing to volunteer barley seedling growth was also observed on the CON tillage plots during the fallow period in 2006 (Fig. 2.6).

Clearly, the photosynthetic performance of the cover crop will largely determine the extent to which carbon can be sequestered during the fallow period. It was observed that the occurrence of night frosts reduces the photosynthetic performance of both volunteer barley seedlings or a mustard cover crop significantly – often for several days after the event (see Figs 2.8a–2.8c and 2.9a–2.9c). Improvements in the frost resistance of cover crops may therefore be required to maximise the amount of carbon accumulated between major cropping periods.

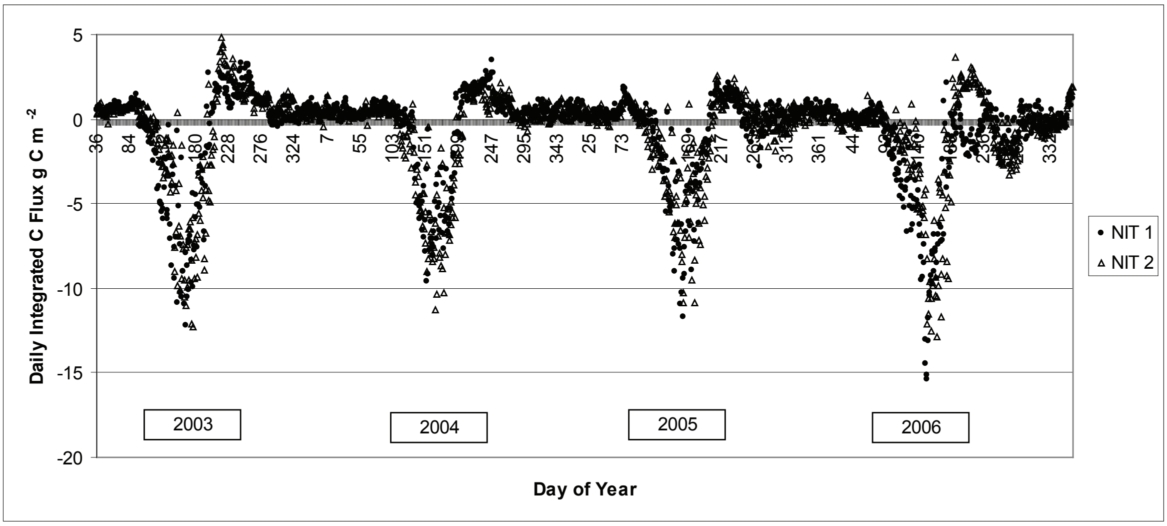

Figure 2.7. Daily integrated carbon fluxes from eddy covariance measurements made on the replicated arable plots subject to non-inversion tillage from 2003–2006 (negative values indicate the net uptake of carbon, while positive values indicate the net release of carbon).

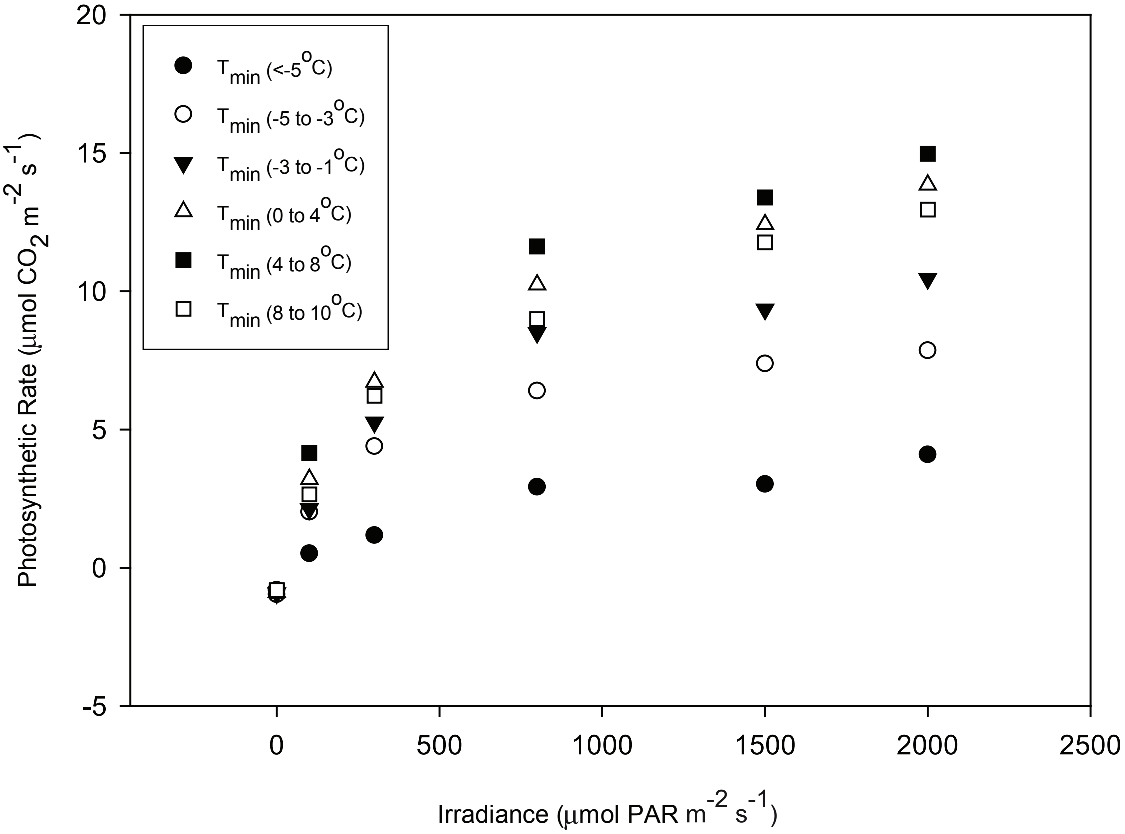

Figure 2.8(a). Effect of previous night time temperature on photosynthetic rate of volunteer barley seedlings.

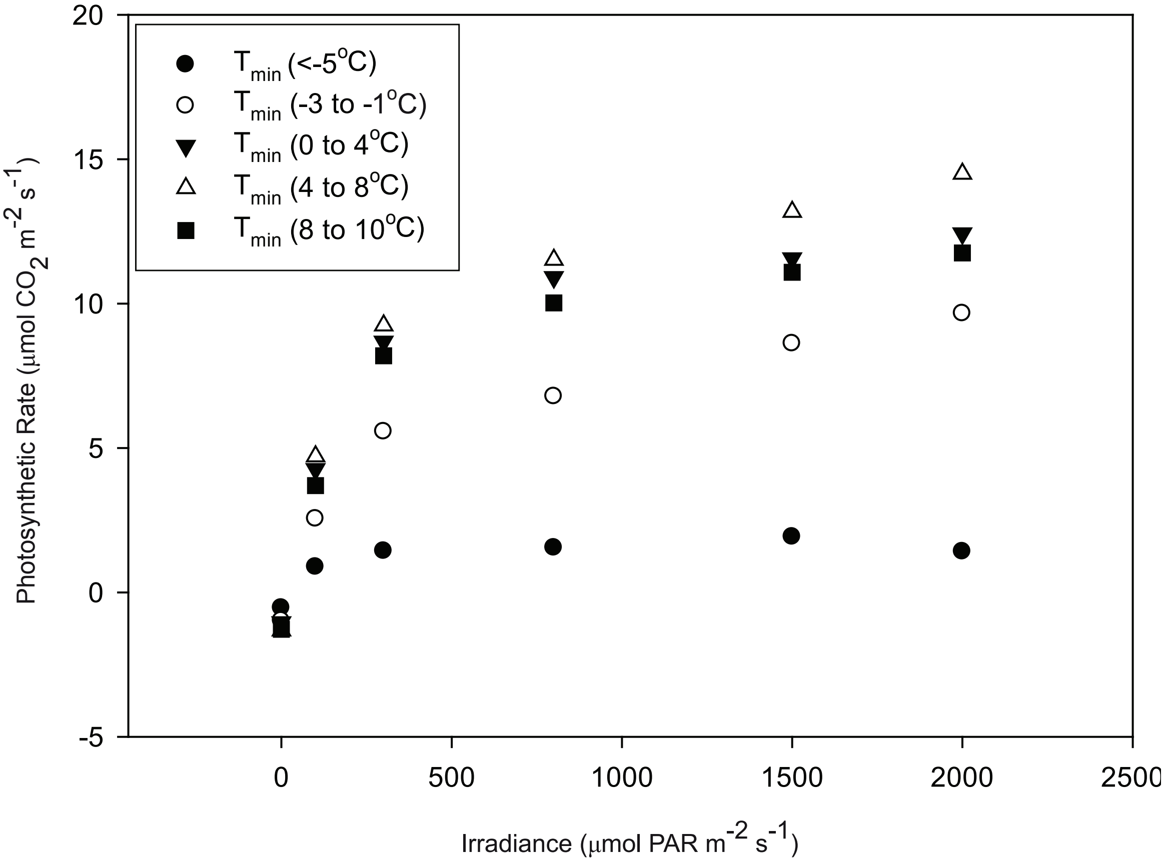

Figure 2.8(b). Effect of previous night time temperature on photosynthetic rate of top leaf of mustard cover crop.

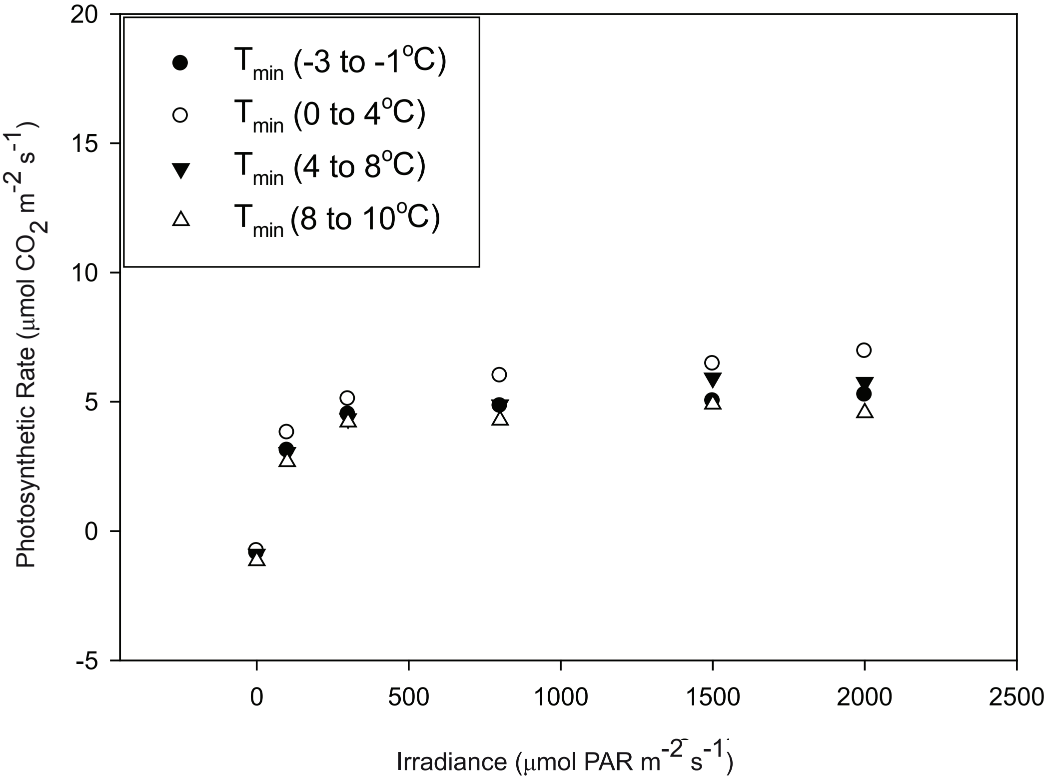

Figure 2.8(c). Effect of previous night time temperature on the photosynthetic rate of sixth leaf of mustard cover crop.

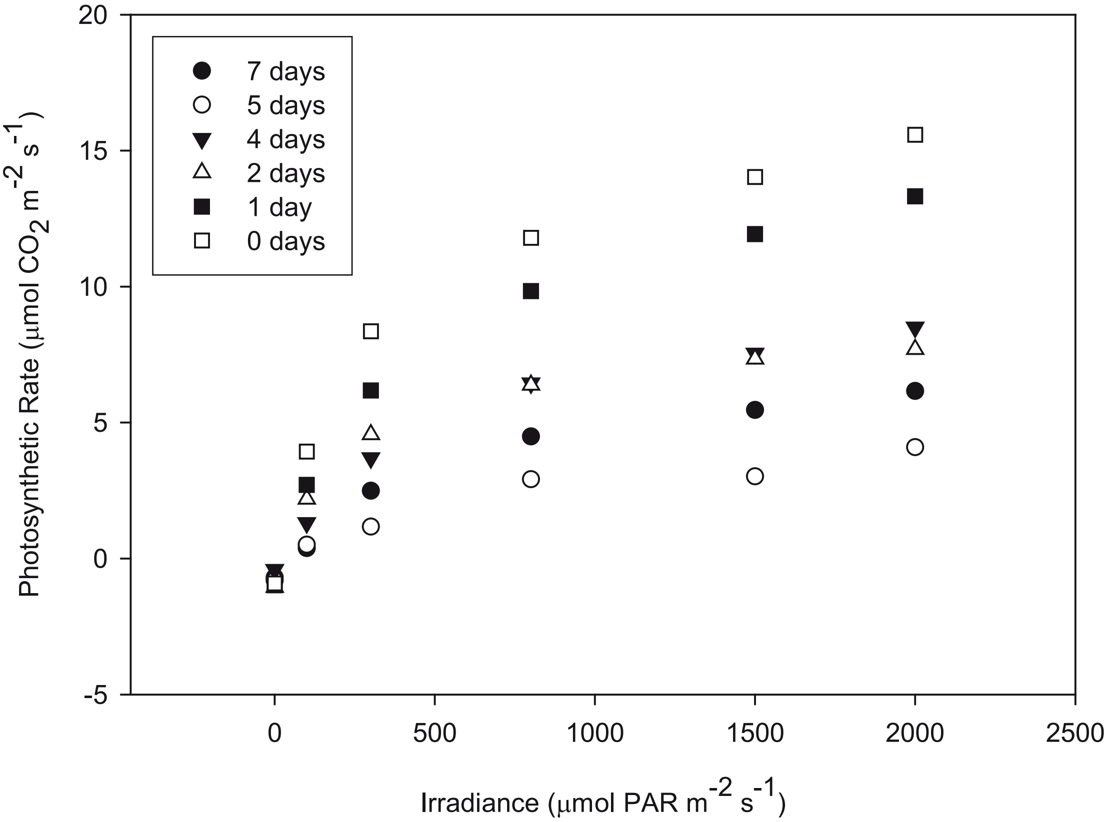

Figure 2.9(a). Effect of number of frost nights on photosynthetic rate of volunteer barley seedlings.

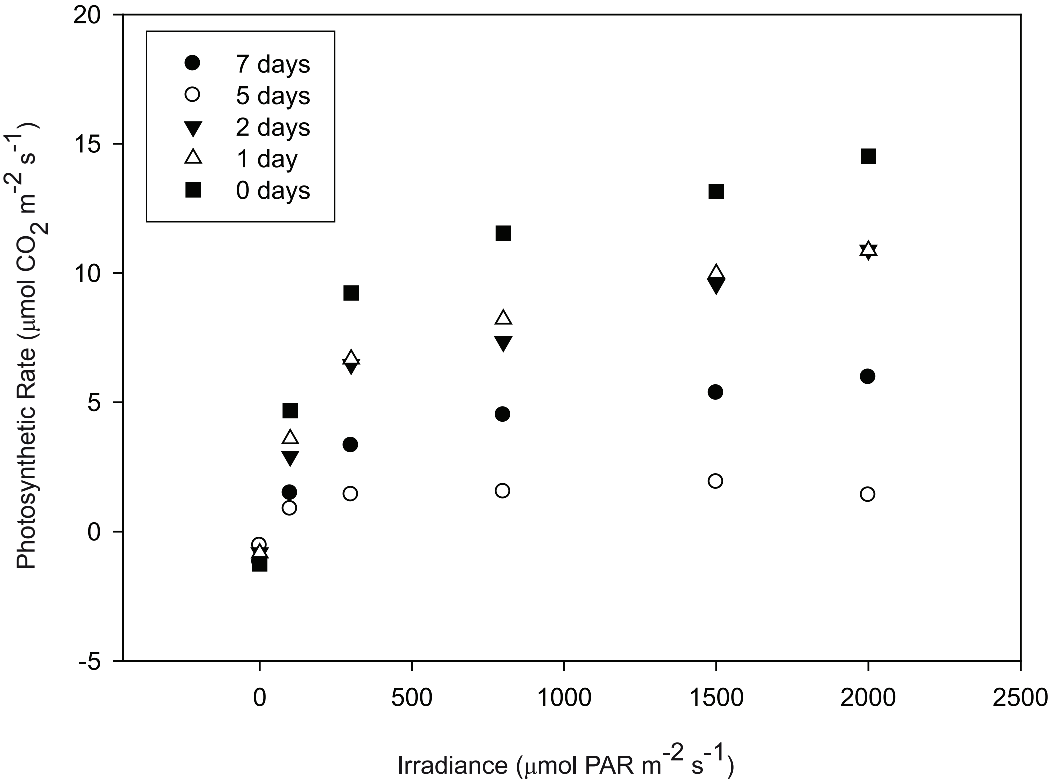

Figure 2.9(b). Effect of number of frost nights on photosynthetic rate of top leaf of mustard cover crop.

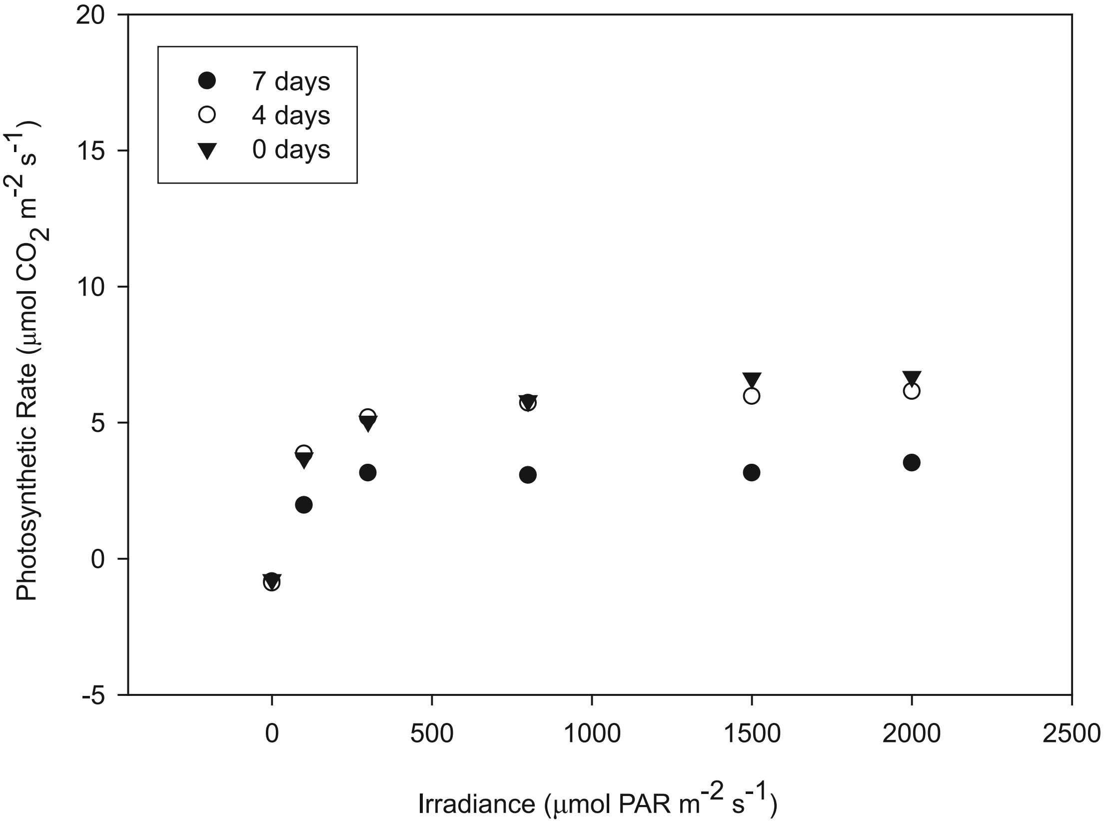

Figure 2.9(c). Effect of number of frost nights on photosynthetic rate of sixth leaf of mustard cover crop.

A summary of the total replicated carbon balance data for the four-year measurement period is shown in Table 2.1a while Table 2.1b shows the mean carbon balance for the CON and NIT treatments. Table 2.1a shows the NEE of carbon as recorded by the EC systems. NEE values for the CON treatments ranged from an annual net uptake of 0.35 to 3.56 t C ha^{-1} while NEE estimates for the NIT treatments ranged from 1.18 to 5.51 t C ha^{-1} (the upper value of carbon uptake for the NIT plots includes cover crop data). Table 2.1a also accounts for all other carbon exports from the ecosystem, including grain export, farm-traffic emissions and potential straw export. Grain yields ranged from 1.70 to 2.66 t C ha^{-1} on the CON treatments and 1.77 to 2.53 t C ha^{-1} on the NIT treatments. Carbon released from farm traffic during routine arable management events (sowing, fertiliser application, harvest, ploughing, etc.) remained constant on the CON treatments (0.27 t C ha^{-1}). However, emissions ranged from 0.17 to 0.24 t C ha^{-1} on the NIT treatments because of the increased activity associated with the management of the cover crop. The net balance between carbon sequestered by the crop and that lost through grain removal and farm traffic is described by the net biome productivity (NBP [1]) in Table 2.1a. The NBP values ranged from an uptake of 1.13 t C ha^{-1} to a net release of 1.62 t C ha^{-1} on the CON treatments and ranged from a net uptake of 3.23 t C ha^{-1} to a net release of 0.79 t C ha^{-1} on the NIT plots (the estimate of net carbon uptake on the NIT plots includes cover crop data). Table 2.1a also includes a secondary NBP estimate (NBP [2]) to include an estimate of carbon lost through the export of straw from the ecosystem. In this experiment, the straw was reincorporated into the soil on the CON plots during tillage and remained on the soil surface on the NIT plots.

Table 2.1b shows the mean NBP for each treatment from 2003–2006. In addition, because of the replicated nature of this experiment, it is also possible to report a standard deviation for the NBP values (as mentioned previously, an NBP value that excludes the export of straw from the ecosystem is reported here). Mean NBP values ranged from a net uptake of 0.68 ± 0.64 t C ha^{-1} to a net release of 1.22 ± 0.33 t C ha^{-1} on the CON treatment and ranged from a net uptake of 2.34 ± 1.27 t C ha^{-1} to a net release of 0.43 ± 0.51 t C ha^{-1} on the NIT treatment (the NIT treatment includes cover crop data).

Table 2.1a. Summary of four years of replicated carbon balance measurements over a spring barley crop at the Oakpark Crops Research Centre, Carlow, Ireland (negative values indicate a net uptake of carbon while positive values indicate a net release of carbon).

	CON 1				CON 2				NIT 1				NIT 2			
	2003	**2004**	**2005**	**2006**	**2003**	**2004**	**2005**	**2006**	**2003**	**2004**	**2005***	**2006****	**2003**	**2004**	**2005***	**2006****
NEE t C Ha^{-1}	-2.11	-1.37	-1.87	-3.56	-2.30	-0.63	-0.35	-2.43	-2.37	-1.18	-2.01	-5.51	-1.88	-2.17	-2.69	-3.68
C export in grain t C Ha^{-1}	2.66	2.09	1.92	2.16	2.43	1.81	1.70	1.94	2.53	1.80	1.67	2.04	2.15	2.07	1.77	2.30
Emissions during tillage1 t C Ha^{-1}	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.17	0.17	0.21	0.24	0.17	0.17	0.21	0.24
NBP (1) t C Ha^{-1}	0.82	0.99	0.32	-1.13	0.40	1.45	1.62	-0.22	0.33	0.79	-0.13	-3.23	0.44	0.07	-0.71	-1.44
Potential straw export t C Ha^{-1}	2.35	1.80	2.09	2.58	2.03	1.42	1.93	2.52	2.10	1.53	1.89	3.15	1.86	1.87	2.00	3.10
NBP (2) t C Ha^{-1}	3.17	2.79	2.41	1.45	2.43	2.87	3.55	2.30	2.43	2.32	1.76	-0.08	2.30	1.94	1.29	1.66

Table 2.1b. Mean carbon balance of conventionally tilled plots and non-inversion tillage plots of spring barley crops (negative values indicate a net uptake of carbon while positive values indicate a net release of carbon).

	CON				NIT			
	2003	**2004**	**2005**	**2006**	**2003**	**2004**	**2005***	**2006****
Mean NBP (1)	0.61	1.22	0.97	-0.68	0.39	0.43	-0.42	-2.34
(± St Dev)	(0.30)	(0.33)	(0.92)	(0.64)	(0.08)	(0.51)	(0.41)	(1.27)

* Data include fallow period cover crop September–December 2005.

** Data include fallow period cover crop January–March 2006 and September –December 2006.

2.4 Discussion

This study provides a detailed insight into the impacts of tillage management on the carbon sink or source strength of Irish arable ecosystems. It also represents a first attempt at providing spatially replicated EC measurements. Measurements of daily integrated carbon flux (Figs 2.6 and 2.7) showed characteristic patterns of net carbon uptake during the growing season and net carbon release during the fallow period. Mean NEE for each treatment exhibited considerable inter-annual variation over the measurement period. The mean annual NEE for the CON treatment ranged from a net uptake of 1.00 to 2.99 t C ha^{-1}, while the net uptake of carbon for the NIT treatment ranged between 1.68 and 4.60 t C ha^{-1}. Similar magnitudes of inter-annual variation in carbon flux have been observed in a number of natural ecosystems, including grasslands (Flanagan et al. 2002) and forests (Monson et al. 2002; Barford et al. 2001). A wide range of driving parameters of underlying inter-annual variations have been cited, and these include climatic variables such as temperature, precipitation and photosynthetically active radiation, in addition to plant phenological and physiological traits. In this study, the key driver of inter-annual variability was precipitation and relative water availability in relation to the phenological development of the arable crop. Cias et al. (2005) documented the impact that increased air temperatures and drought in the summer of 2003 had on the European carbon budget. This inter-annual anomaly was not detected in the observations made during this study, as illustrated in Figs 2.4 and 2.5 where incident PAR and air temperature showed little annual variation from 2003 to 2006. Nevertheless, changing patterns of precipitation (especially during the cropping period) were observed between years. In 2003, the average total precipitation recorded during the cropping period was 11% above the 30-year mean for the same period. In addition, the low precipitation recorded during August of 2003 promoted ideal conditions for grain filling of the crop prior to harvest. In the remainder of the study period 2004–2006, the average total precipitation recorded during the growing season were consistently lower than the 30-year mean for the same period. In particular, in 2004 and 2005, a reduction in total precipitation was recorded in the month of May, a period when water availability is of significant importance to a developing crop. This is reflected in the grain-yield measurements, where the grain yields recorded for both tillage treatments were lower in 2004 and 2005 compared to 2003 and 2006. The timing of drought events during the cropping season is of significant importance and this is illustrated in 2006. Here, the total average precipitation during the growing season was approximately 32% lower than the 30-year mean for the same period. However, the recorded precipitation in the early part of the growing season (March–May) was close to the 30-year mean and therefore facilitated the development of the crop; the recorded precipitation in the latter part of the cropping season (June–August) was significantly lower than the 30-year mean but again this improved the grain filling of the crop prior to harvest.

A 15% reduction in net carbon release from the NIT treatment was observed during the fallow period of 2003–2004. This reduction was attributed to an increase in barley seedling volunteer growth on the NIT treatment. The impact of this natural plant cover during the fallow period provided the impetus for the introduction of a cover crop (*Brassica juncae*) on the NIT plots. The cover crop had a significant impact on the fallow season carbon fluxes, in particular on the non-inversion tillage plots where the magnitude of carbon losses, when compared to the CON treatments, were reduced by 54% and 92% during the 2005-2006 and 2006-2007 fallow periods respectively. The use of cover crops during fallow periods can have a number of other beneficial impacts in addition to reducing carbon losses. These include a reduction in soil compaction and erosion, improving the water-holding capacity of the soil and a reduction in nutrient leaching, thus improving the nutrient status of the soil for the subsequent crop and potentially reducing the amount of fertiliser input required for the following cropping season (Dabney et al. 2001; Jarecki and Lal 2003; Villamil et al. 2006).

The net carbon uptakes during the growing seasons of 2004, 2005 and 2006 were approximately 24%, 7% and 9% higher in the NIT treatment when compared to the CON treatment. The increased productivity observed on the NIT treatment can be attributed to the impact of both tillage treatment and residue incorporation on the water-holding capacity and nutrient availability of the soil. NIT management has been shown to improve the water-holding capacity of the soil through a reduction in soil compaction and erosion, maintaining the porosity of the soil (Lopez et al. 1996). In this study, crop residues were incorporated into the soil in the CON treatments and were left on the surface of the soil in the NIT treatments. The incorporation of crop residues, especially straw, depending on the rate and timing of decomposition within the soil, has been shown to reduce the nitrogen availability for the subsequent crop (Borreson 1999). The presence of crop residues at the soil surface in non-inversion tillage arable systems can also reduce germination rates and plant growth in spring-sown crops because of a reduction in soil-surface temperatures. However, in this study, crop residues in the NIT management did not influence the germination of the barley crop seedlings.

The NBP represents an estimate of the relative carbon source to sink strength of an ecosystem and accounts for all inputs and outputs of carbon over the measurement period. In this study, lower NBP values were observed and as a result a reduction in carbon emissions from the NIT treatments when compared to the CON treatments. In addition, the impact of improved inter-annual plant productivity during the cropping season, the presence of barley volunteer seedlings (CON treatment) and a cover crop (NIT treatment) during the fallow season and residue incorporation resulted in a net uptake of carbon in the CON treatment in 2006 and the NIT treatment in 2005 and 2006.

3 Soil CO_2 Fluxes from a Spring Barley Crop under Conventional and Non-Inversion Tillage and Cut and Grazed Pastures

3.1 Introduction

The emission of CO_2 from soils through both autotrophic and heterotrophic respiration constitutes an important part of the carbon cycle. Raich and Potter (1995) estimated that soil respiration contributes a global flux of 77×10^{15} g C year^{-1}, approximately 10 times the magnitude of industrial CO_2 emissions (Schlesinger 1997; Schlesinger and Andrews 2000). As a result, small changes in soil CO_2 flux across large areas can have a pronounced impact on global atmospheric CO_2 concentrations.

Soil respiration is a collective term encompassing a variety of sources of CO_2 flux, with biotic processes such as rhizosphere, microbial and faunal respiration being the most important. Various key factors have been identified that influence soil respiration. Of these, temperature and soil moisture are the most studied, and numerous equations that attempt to model soil or ecosystem respiration are based in the main on the empirical relationship between CO_2 efflux and soil temperature (Lloyd and Taylor 1994; Janssens et al. 2001; Rodeghiero and Cescatti 2005; Byrne and Kiely 2006). Nonetheless, above-ground biomass – particularly in intensively managed systems such as cereal crops and cut and grazed pastures – will also have a significant influence on the rate of soil respiration. Several studies have suggested that appropriate agronomic management such as non-inversion tillage practices, crop rotations (including leguminous crops and field applications of manure), may reduce soil CO_2 emissions and in the long term increase the organic matter content of the soil (Paustian et al. 2000; Follett 2001).

3.2 Methodology

Measurements of soil respiration were made on both the large plots utilised for EC measurements (Section 1) and the replicated small-plot trial (Section 3) using a CIRAS gas exchange system (PP Systems, UK) fitted with a SRC-1 soil respiration chamber. Measurements were taken fortnightly during the growing season and monthly during the fallow season (all measurements were taken from 9 a.m. to 1 p.m.). At each sampling interval, measurements of soil temperature and volumetric soil-water content at a depth of 10 cm were made using a WET sensor (Delta-T Devices, UK). Measurements of above-ground biomass were also made.

In addition to monitoring soil respiration, a small experiment was established to partition respiration between autotrophic and heterotrophic components. Here, 5×2 m^2 bare soil patches were maintained free of plant growth for the 2005 growing season. These were situated in a strip 0.5 m away from the conventional and non-inversion tillage plots. Measurements of CO_2 efflux from these plots were defined as heterotrophic respiration while the difference in respiration between the tillage and bare soil plots was defined as autotrophic respiration. On a neighbouring grassland site a more extensive field trial partitioning soil respiration into its two main components was established following the methodology of Wan and Luo (2003). Here, a randomised block design with four treatments was used: (i) control; (ii) plots clipped to ground cover; (iii) plots shaded with a double layer of black cloth; and (iv) plots clipped to ground cover and shaded. Using this series of treatments, autotrophic respiration was defined as the difference between the control and shaded plots, above-ground microbial respiration as the difference between the shaded and clipped and shaded plots, and below-ground microbial respiration as the average of the clipped and clipped and shaded plots.

3.3 Results

Figures 3.1 and 3.2 illustrate the seasonal trend in soil respiration for both the large and small plots. In both cases, peak soil respiration occurred at times of peak

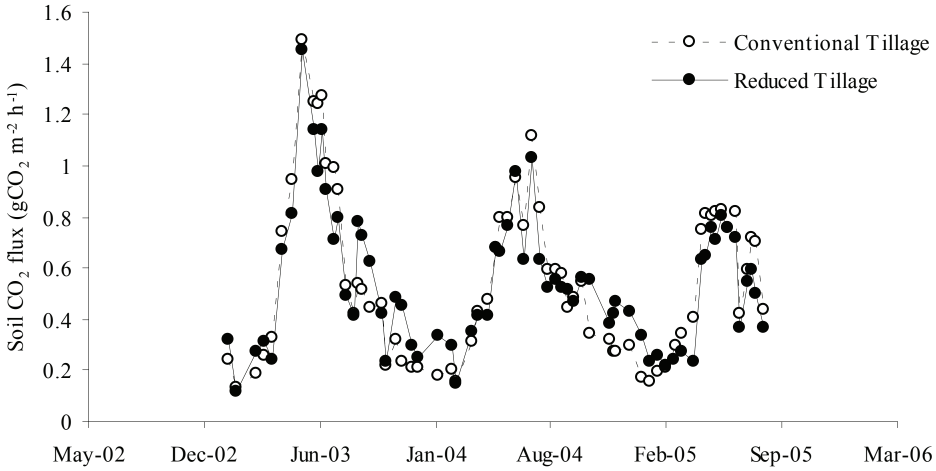

Figure 3.1. Soil respiration for the large plots measured from January 2002 to August 2005.

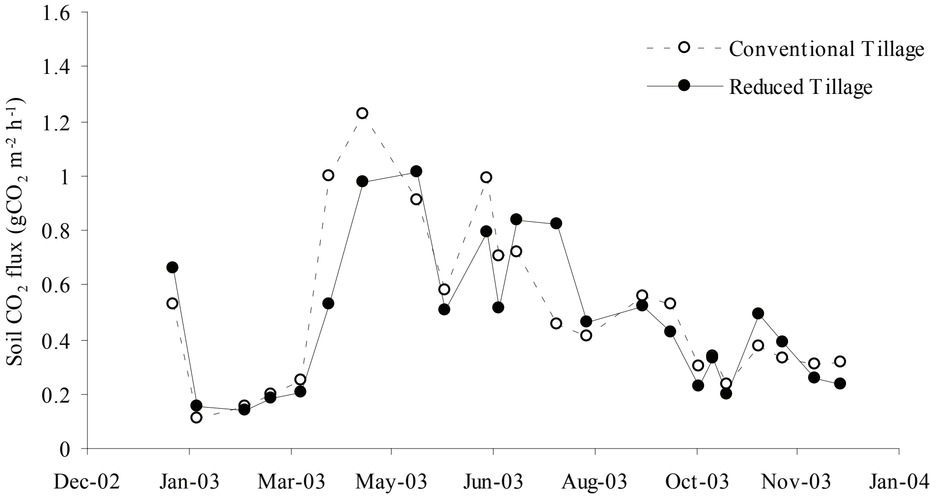

Figure 3.2. Soil respiration for the small plots measured from January 2002 to August 2005.

above-ground biomass. Statistical analysis using two-way ANOVA revealed no significant difference between tillage treatments for the daily flux values, as illustrated in Tables 3.1 and 3.2, but a significant interaction in the large plots and a significant effect of time in both sets of data. The effect of time reflects significant seasonal variations in soil respiration.

Table 3.1. Summary statistics for two-way analysis of variance of large-plot data.

Source of variation	% of total variation	P value
Interaction	3.91	<0.0001
Treatment	0.04	0.1360
Time	93.64	<0.0001

Table 3.2. Summary statistics for two-way analysis of variance of small-plot data.

Source of variation	% of total variation	P value
Interaction	3.92	0.7318
Treatment	0.12	0.4643
Time	44.36	<0.0001

Cumulative annual soil fluxes of CO_2 for the arable sites in 2003 and 2004 are shown in Table 3.3 and range from 43 to 48 t CO_2 ha^{-1} y^{-1} equivalent to 1,150 to 1,308 g C m^{-2} y^{-1}. Table 3.3 includes measurements of soil respiration made on an adjacent cut and grazed pasture. The cumulative annual CO_2 flux from this grassland ranged from 37 to 45 t CO_2 ha^{-1} y^{-1} equivalent to 998 to 1,215 g C m^{-2} y^{-1}.

Figure 3.3 illustrates the seasonal variation in both soil and above-ground biomass for both the spring barley (large plots) and a neighbouring grassland field. Rates of soil respiration in the arable ecosystem ranged from 1 to 9 µmol CO_2 m^{-2} s^{-1} with peak rates of respiration coinciding

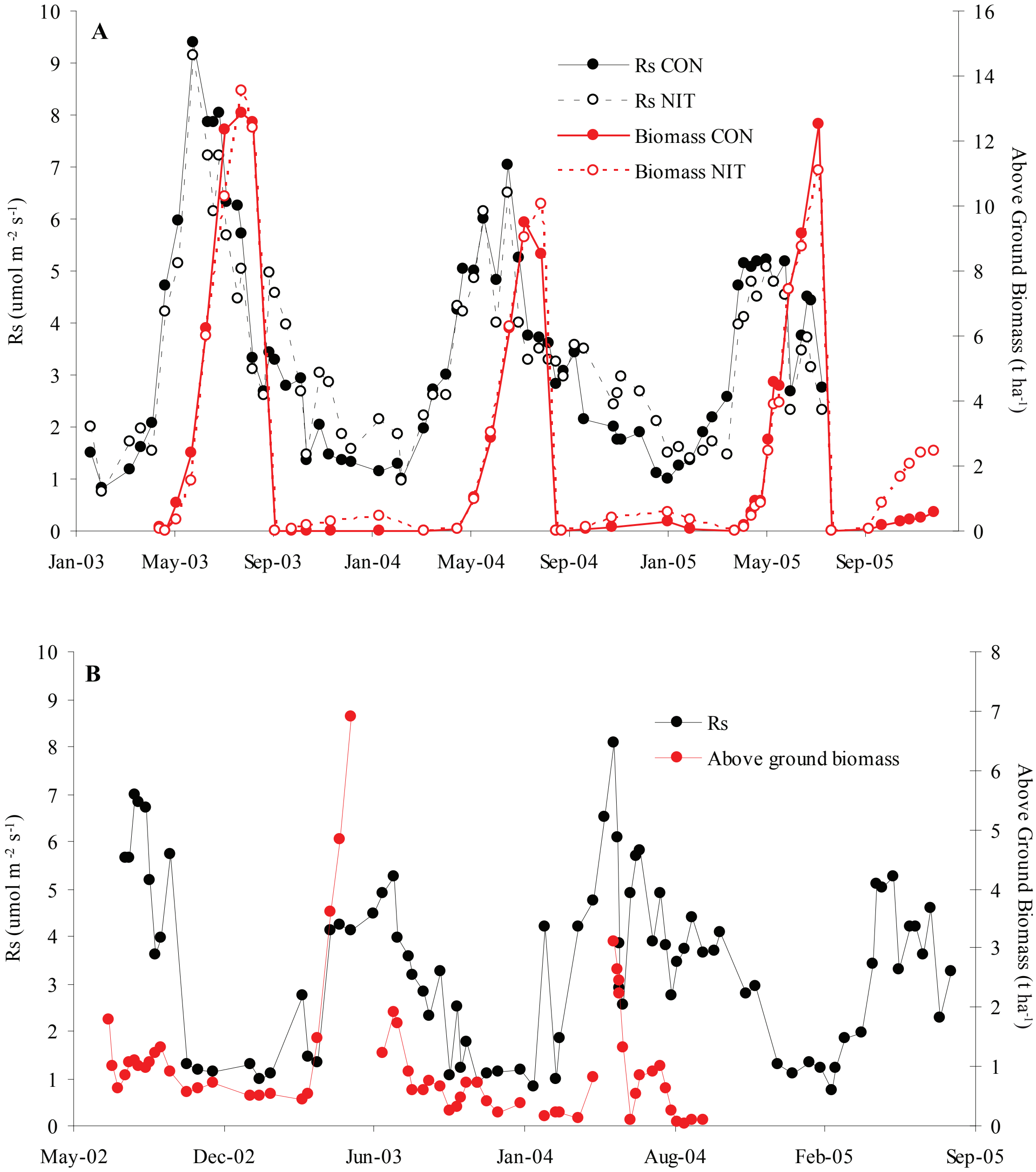

Figure 3.3. Changes in soil CO_2 flux and above-ground biomass for a spring barley field and a cut and grazed pasture. Each point represents the mean of up to 20 separate measurements. A: Spring barley field under non-inversion (NIT) and conventional (CON) tillage. B: Cut and grazed pasture (Rs = soil respiration).

with peak above-ground biomass, in the region of 7 to 13 t dw ha^{-1}. Rates of soil respiration in the grassland ecosystem ranged from 1 to 8 µmoles CO_2 m^{-2} s^{-1} and again peak rates of soil respiration were measured in conjunction with an increase in above-ground biomass.

Table 3.3. Annual CO_2 fluxes from the large and small plots.

Plot	Gross flux of CO_2 from soil (tonnes CO_2 ha^{-1} y^{-1})*	
Large plots		
Year	Conventional tillage	Non-inversion tillage
2003	48 (1308)	48 (1308)
2004	43 (1150)	45 (1207)
Small plots		
Year	Conventional tillage	Non-inversion tillage
2003	46 (1229)	44 (1185)
Grassland		
2003	37 (988)	
2004	45 (1215)	

* Figures in brackets give flux values in g C m^{-2} y^{-1}.

Figure 3.4 illustrates data collected from either root exclusion plots or clipped/shaded treatments. The data show that autotrophic soil respiration may account for between 50 and 60% of total soil respiration at times of peak above-ground biomass for both the spring barley and the neighbouring grassland field.

This point is further illustrated in Fig. 3.5 where the Lloyd and Taylor (1994) equation (Eqn 2.1 above) was found to account for at best only 35 to 44% of the variation in soil respiration vs temperature data for the cereal and grassland fields. In contrast, a multiple regression analysis for the grassland field, incorporating Leaf Area Index (LAI), below-ground biomass and temperature and moisture accounted for over 65% of the variation in the soil respiration, suggesting that LAI was the most important limiting factor. This is illustrated in Table 3.4. A similar analysis for the conventional tillage plots of the cereal field is illustrated in Table 3.5. Here, multiple regression analyses accounted for 70% of the variation in the soil respiration, suggesting again that above-ground biomass is an important contributing factor to soil respiration.

Table 3.6 shows the organic carbon and nitrogen content in the top 20 cm of soil in both the CON and NIT treatment plots. The data illustrate that after four years of the establishment of the field trial, no significant difference in either soil organic carbon or nitrogen can be detected.

Table 3.4. Multiple regression analysis of Soil respiration (Rs) with Leaf Area Index, soil temperature, soil moisture and root biomass for the grassland field.

Variable	Coefficient	Standard error	Probability
Constant	-1.587	1.101	0.158
LAI	0.598	0.122	<0.0001
Soil temperature	0.098	0.045	0.034
Soil moisture	0.054	0.028	0.061
Root biomass	0.120	0.036	0.002

Table 3.5. Multiple regression analysis of Soil respiration (Rs) with above-ground biomass, soil temperature and soil moisture for the spring barley field.

Variable	Coefficient	Standard error	Probability
Constant	5.89	3.49	0.0996
Biomass	0.875	0.179	<0.0001
Soil temperature	-0.291	0.215	0.182
Soil moisture	-0.200	0.144	0.173
Soil temperature × Soil moisture	0.025	0.009	0.012

Table 3.6. Organic carbon and nitrogen content of the top 20 cm of soil for the conventional and non-inversion tillage plots. Measurements were taken in summer 2007, four years after the establishment of the trial. Each value represents the mean ± SE of four replicate values.

Treatment	Organic C (%)	Standard error	Organic N (%)	Standard error
Conventional tillage				
159 kg N ha^{-1}	1.57	0.09	0.17	0.01
79 kg N ha^{-1}	1.70	0.17	0.18	0.02
0 kg N ha^{-1}	1.50	0.06	0.16	0.01
Non-inversion tillage				
159 kg N ha^{-1}	1.69	0.04	0.18	0.01
79 kg N ha^{-1}	1.70	0.05	0.17	0.01
0 kg N ha^{-1}	1.66	0.07	0.18	0.01

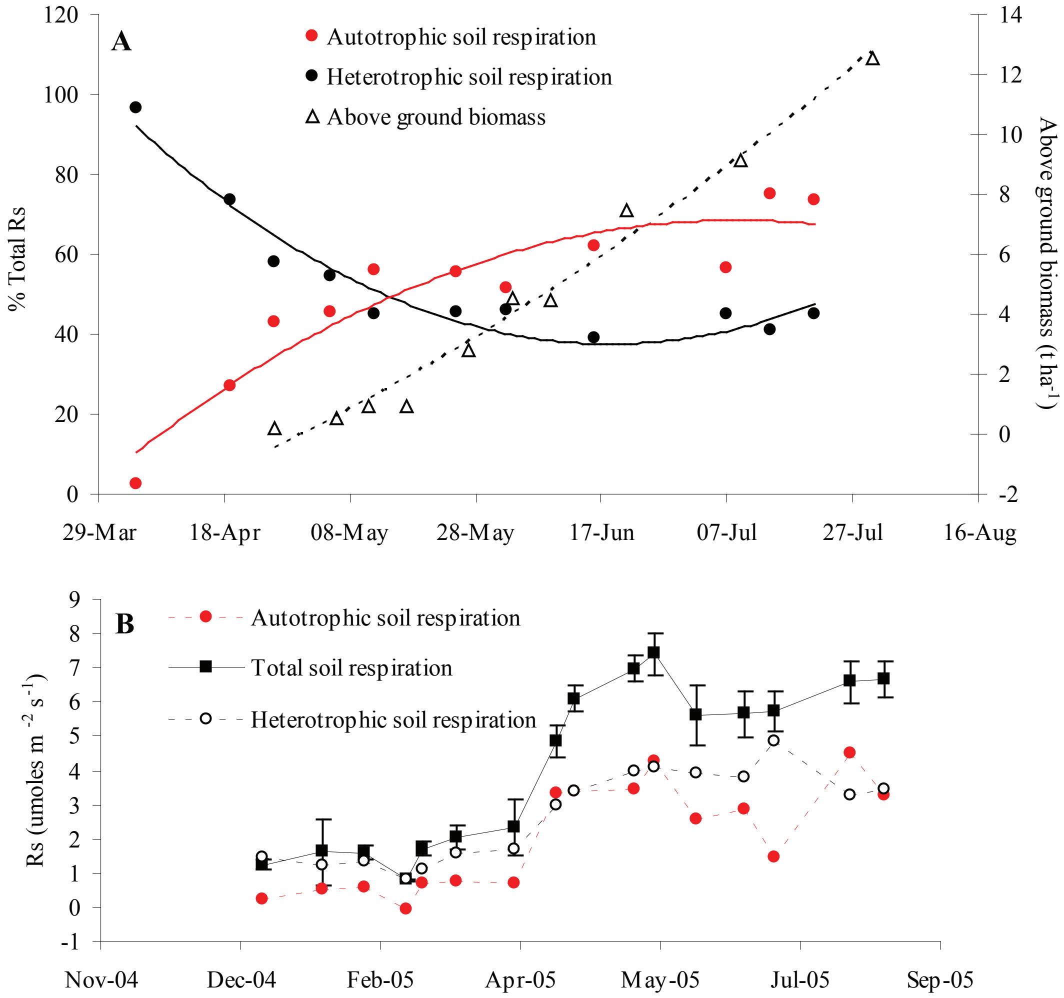

Figure 3.4. Estimation of autotrophic soil respiration using either root exclusion plots or clipping and shading treatments. A: Spring barley field, conventional tillage. B: Cut and grazed pasture.

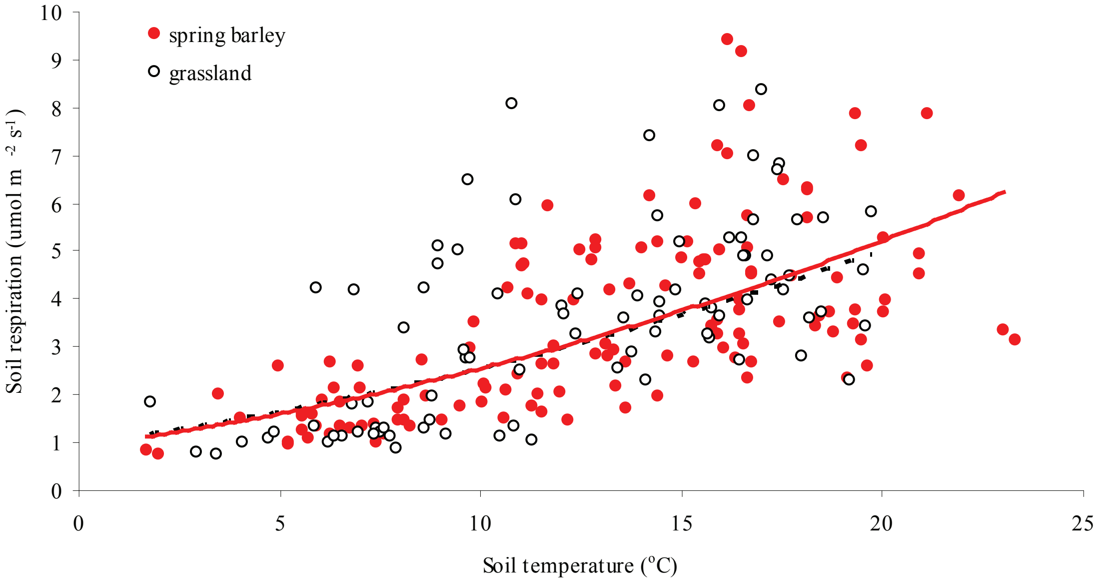

Figure 3.5. Soil CO_2 flux vs soil temperature for the cereal and grassland fields. Lines indicate the Lloyd and Taylor (1994) function. Regression coefficients for the spring barley and grassland fields are 0.44 and 0.35 respectively.

3.4 Discussion

The rates of soil respiration recorded on both the large and small arable plots are well within the range of published values for cereal crops and temperate grasslands (Pilegaard et al. 1998; Epron et al. 1999; Davidson et al. 2000; Bahn et al. 2008). Indeed, in the current study, soil fluxes of CO_2 did not differ significantly between the spring barley field and the neighbouring cut and grazed pasture, indicating that crop type had little effect on soil respiration (Table 3.3). Further, no statistically significant differences were detected in rates of soil respiration between the conventional and non-inversion tillage treatments. In addition, no statistically significant differences were detected between annual soil fluxes of CO_2 from the conventional and non-inversion tillage treatments. This is not surprising given that, for the small-plot trial, measurable differences in soil organic carbon and nitrogen between the two management regimes have yet to be detected (Table 3.6).

A strong correlation was identified between rates of soil respiration and above-ground biomass. This not only suggests that autotrophic soil respiration contributes a significant proportion to the total CO_2 efflux from the soil, but also highlights the need to incorporate crop phenological characteristics, such as LAI, into soil respiration models which to date are driven largely by environmental constraints such as soil temperature and moisture content. In addition, this study highlights the seasonal nature of soil carbon fluxes in arable ecosystems. A variation in above-ground biomass between the cropping and fallow periods will have a significant influence on the relative rate of soil CO_2 efflux, and will also effect the partitioning of soil respiration between autotrophic and heterotrophic fluxes.

4 Nitrous Oxide Emissions from a Spring Barley Crop under Conventional and Non-Inversion Tillage: The Effects of Varying Nitrogen Application

4.1 Introduction

Over the past century the increased use of nitrogen fertiliser in agricultural ecosystems has altered the global nitrogen budget dramatically (Vitousek et al. 1997). Synthetic nitrogen inputs have increased from 4 Tg N to 82 Tg N since the 1960s and this figure is considered to be equal to the total global biological nitrogen fixation (Galloway 1998). The increasing use of nutrient nitrogen in agriculture is perceived as being necessary in order to maintain optimum crop yields: however, excess nitrogen within these ecosystems can have a significant effect on a number of other environmental factors, including water quality and the increased atmospheric concentration of nitrous oxide (N_2O). Tillage management practices can also have a significant impact on N_2O production and emission from soils through the alteration of soil structural quality and water-holding capacity (Ball and Ritchie 1999).

The rate of N_2O production and emission from agricultural soils is governed by a complex interaction between soil properties, climatic factors and agricultural practices. In particular, soil aeration, water content, pH, temperature and microbial activity all play an important role in N_2O production. Nitrogen input into the soil through fertilisation also has an important impact on N_2O production, where nitrification and denitrification processes exhibit a threshold response to nitrogen input.

There is a lack of country-specific data on N_2O emission factors from high nitrogen-input agricultural systems and at present Ireland uses the Intergovernmental Panel on Climate Change (IPCC) default emission factor of 1.25% of applied fertiliser nitrogen in the National Inventory Report. It has been suggested, however, that the use of this default value may result in an unreliable countrywide estimate of N_2O production (Hyde et al. 2005) as trends in land use, fertiliser type and application, irrigation, soil type and cropping system vary significantly across the country.

The aim of this research was to investigate the impact of tillage management and non-inversion nitrogen input on seasonal N_2O fluxes and to refine N_2O emission factors for this cropping system.

4.2 Methodology

Measurements of N_2O flux were made on a spring barley crop located at the Teagasc, Crops Research Centre, Oakpark, Carlow. Measurements were made for two consecutive growing seasons (April–August 2004 and April–August 2005) on a spring barley crop subject to conventional and non-inversion tillage treatments, and a range of fertiliser applications. Three rates of nitrogen fertilisation were used in this experiment: (i) N_1 (full field capacity); (ii) N_2 (half field capacity); and (iii) N_3 (zero). In 2004, the fertiliser treatments of N_1 (140 kg N ha^{-1}), N_2 (70 kg N ha^{-1}) and N_3 (0 kg N ha^{-1}) were administered in a single dose on 27 April. However, a dual-application approach was used in 2005, on 12 April and on 10 May, where N_1 (106 kg N ha^{-1}), N_2 (53 kg N ha^{-1}), N_3 (0 kg N ha^{-1}), and N_1 (53 kg N ha^{-1}), N_2 (26 kg N ha^{-1}), N_3 (0 kg N ha^{-1}) were added, respectively, this being a more typical fertiliser regime adopted for spring barley.

Twenty-four 6 m × 25 m plots were used in this experiment: 12 plots were subject to CON and the other 12 to NIT. Four replications of fertiliser treatment were then applied to the conventional and non-inversion tillage plots. This small-plot experiment was located directly adjacent to the large-plot experiment described in Section 2.

Nitrous oxide fluxes were measured on a weekly basis using the static chamber methodology of Smith et al. (1995). The chambers consisted of two parts: a 52 × 52 cm and 15 cm deep square collar which was permanently installed in the soil, over which a 50 × 50 × 30 cm chamber could be placed to collect gas samples. The chambers were sealed over the collars, using a neoprene seal, and a gas sample representing T_0 was extracted. The chambers were then left for 1 hour before further gas samples were taken. Samples were taken using a 60-ml gas-tight syringe which was flushed initially to ensure adequate mixing of the air within the chamber. The 60 ml sample taken was then injected into and flushed through a 3-ml gas-tight vial, which was then stored for subsequent analysis. Samples were taken at the same time of day in order to minimise the effects of diurnal variation. The gas samples were analysed within 1 month of collection at the Risø Research Centre in Denmark using a gas chromatograph equipped with an electron capture detector (Shimadzu GC 14B, Kyoto, Japan). Cumulative fluxes were determined from weekly measurements using the methodology utilised in the European Union Greengrass project (Flechard et al. 2007).

Emission factors for nitrogen fertilisation at this site were calculated using the following equation (IPCC 2001b) (Eqn 4.1):

$$EF = [(\text{Cumulative flux}_{\text{(fertiliser treatment)}} - \text{Cumulative flux}_{\text{(control treatment)}})/(\text{Fertiliser applied} \times k)] \times 100 \qquad \text{(Eqn 4.1)}$$

where k is 0.9 to account for synthetic nitrogen fertiliser (IPCC 2001b).

The concentration of soil nitrate was measured continuously on a monthly basis and on a weekly campaign basis after fertiliser application, following the methodology of Armstrong et al. (1976). Soil samples were homogenised manually and sieved through a 2-mm mesh. From each sample, 20 g of fresh soil was taken and added to 100 ml of 2M KCl and shaken for 1 hour on an automatic shaker. The extract was then filtered through a Whatman No. 2 filter before colorimetric analysis (Brann and Luebbe, Norderstedt, Germany).

Soil moisture was measured up to a depth of 20 cm at each gas-sampling interval. The soil samples were weighed, oven-dried to a constant mass at 105 °C, then reweighed to calculate the volumetric soil water content. The water-filled pore space (WFPS) was calculated using a constant particle size of 2.65 cm^3. Soil temperature was also measured at each gas-sampling occasion, using a digital handheld thermometer (RS Instruments, Dublin).

4.3 Results

Figures 4.1 and 4.2 illustrate the change in soil nitrate concentration for the conventional and non-inversion tillage plots from April to August 2004 and 2005, respectively. The concentration of soil nitrate corresponded with the time of fertiliser application and was significantly higher in 2005 than in 2004. Analyses of soil nitrate data revealed that soil nitrate was significantly affected by the application of nitrogen fertiliser. Statistically significant differences ($P<0.0001$) were found between the three fertiliser treatments within a single tillage treatment. The maximum differences between the control and highest fertiliser application rate for 2004 and 2005 were approximately 8 and 40 mg kg^{-1} dry soil, respectively.

Accepting a threshold probability of 95%, the best fit multiple regression analysis showed that the major determinants of N_2O flux from soil were soil moisture ($P<0.05$), and the combined effects of soil moisture and soil nitrate ($P<0.0001$) (Table 4.1). N_2O flux could be described in terms of the interaction between soil nitrate and soil moisture; this accounted for 65.4% of the variance in the data.

Figure 4.3 illustrates the daily average emissions of N_2O measured on a weekly basis, from April to August 2004, for the conventional and non-inversion tillage plots. Nitrogen fertiliser was incorporated once during the barley-growing season, on 27 April 2004. The emissions of N_2O showed a typical pattern throughout the experimental period. Emissions from the unfertilised plots were consistently low, with values ranging from -9.5 to 4.9 g N_2O-N ha^{-1} d^{-1} and from -2.5 to 4.6 g N_2O-N ha^{-1} d^{-1} for the conventional and non-inversion tillage plots, respectively. For both tillage systems, emissions of N_2O from fertilised plots (N_1 and N_2) peaked after N_2O application, but these increases were short-lived and the fluxes returned back to background level approximately 4 weeks after fertiliser application. The highest peaks observed were 56 and 19.3 g N_2O-N ha^{-1} d^{-1} for conventional tillage nitrogen treatment 1 (CN_1) and conventional tillage nitrogen treatment 2 (CN_2) and 56.1 and 33.1 g N_2O-N ha^{-1} d^{-1} for non-inversion tillage nitrogen treatment 1 and 2 (NIT NT_1 and NIT NT_2) respectively. These peaks were observed 1 day following the fertiliser application.

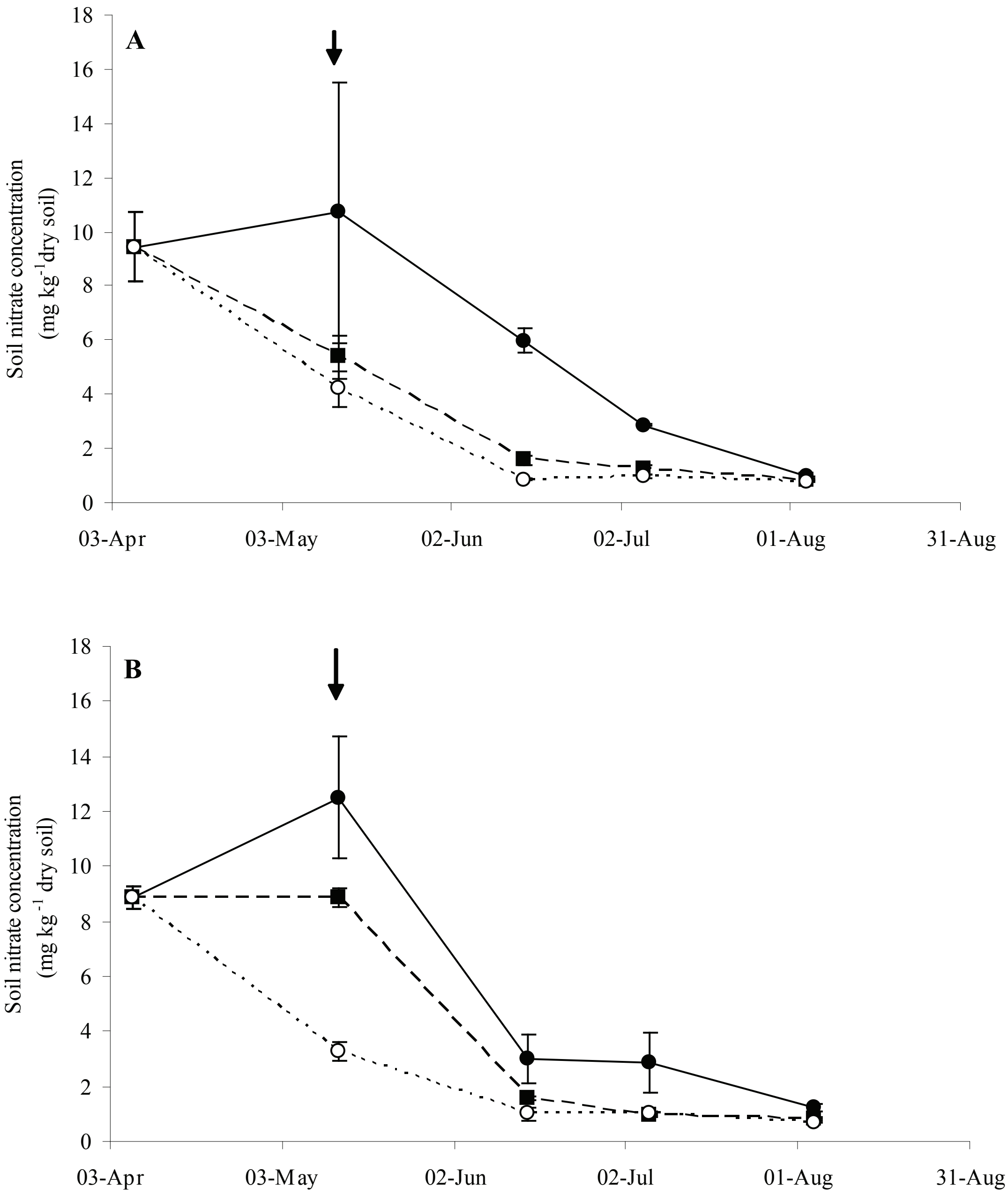

Figure 4.1. Soil nitrate concentration of the conventional (A) and non-inversion (B) tillage plots for 2004. Symbols indicate the soil nitrate concentration at different fertiliser rates: N_1 (●), N_2 (■) and N_3 (○) as detailed in the text. Arrows indicate the first measurements following fertiliser application. Each point represents the mean ± SE of four measurements.

Figure 4.4 illustrates the average daily emissions of N_2O measured on a weekly basis, from April to August 2005, for the conventional and non-inversion tillage plots, respectively. Nitrogen fertiliser was incorporated twice during the barley growing season, on 12 April and 10 May. As in 2004, N_2O emissions showed a typical pattern throughout the experimental period. Emissions from the unfertilised plots were consistently low, with values ranging from -0.2 to 4.6 g N_2O-N ha^{-1} d^{-1} and from -2.5 to 8.8 g N_2O-N ha^{-1} d^{-1} for conventional and non-inversion tillage respectively. For both tillage systems, emissions of N_2O from the fertilised plots (N_1 and N_2) also peaked after each fertiliser application, but the peaks were short-lived and the fluxes returned back to background level 3–6 weeks following fertiliser application. The highest N_2O peaks observed were 28.8 and 19.3 g N_2O-N ha^{-1} d^{-1} for CN_1 and CN_2 and 32.1 and 20.6 g N_2O-N ha^{-1} d^{-1} for NT_1 and NT_2 respectively. These peaks were observed 9 days following the second fertiliser application.

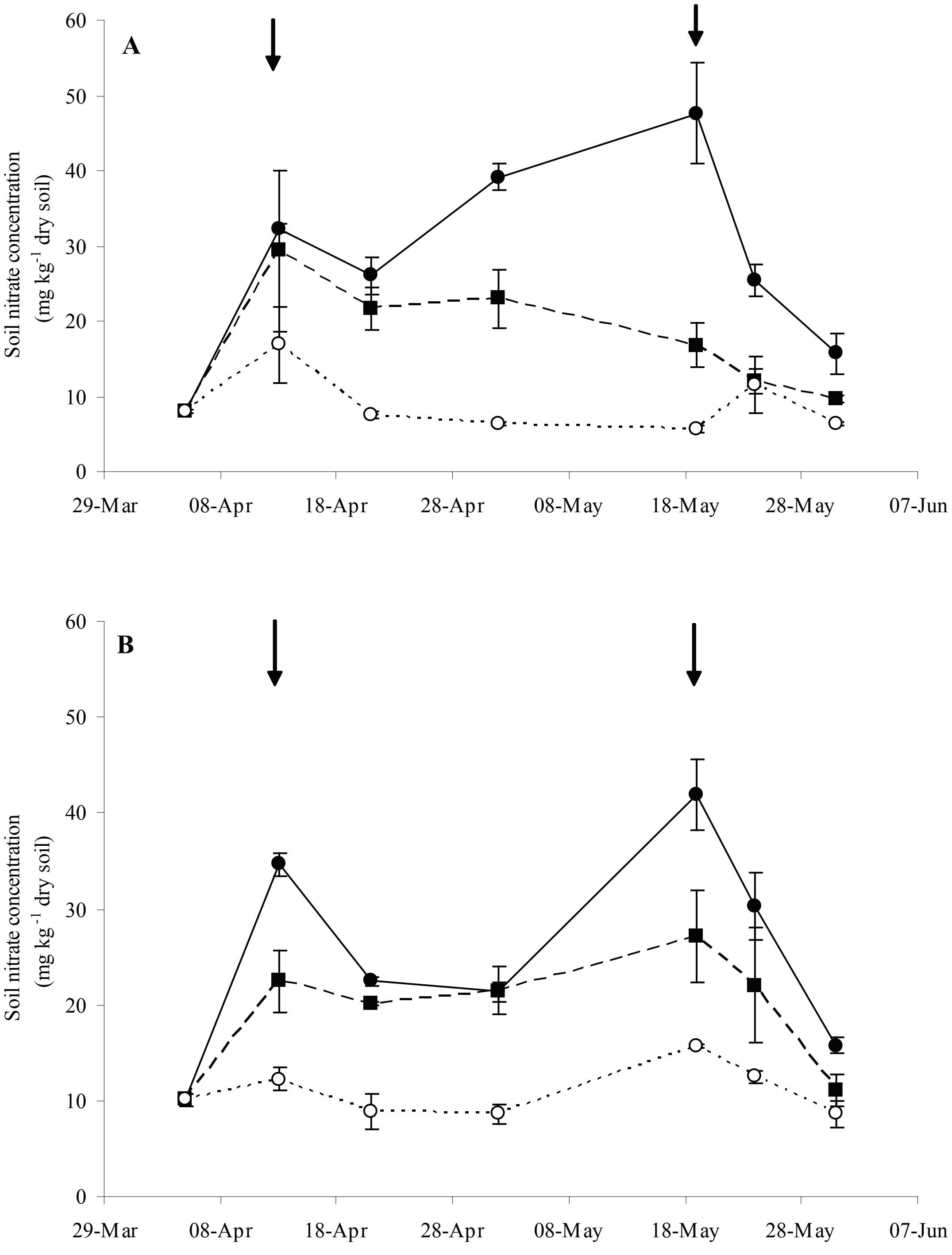

Figure 4.2. Soil nitrate concentration of the conventional (A) and non-inversion (B) tillage plots for 2005. Symbols indicate the soil nitrate concentration at different fertiliser rates: N_1 (●), N_2 (■) and N_3 (○) as detailed in the text. Arrows indicate the first measurements following fertiliser application. Each point represents the mean ± SE of four measurements.

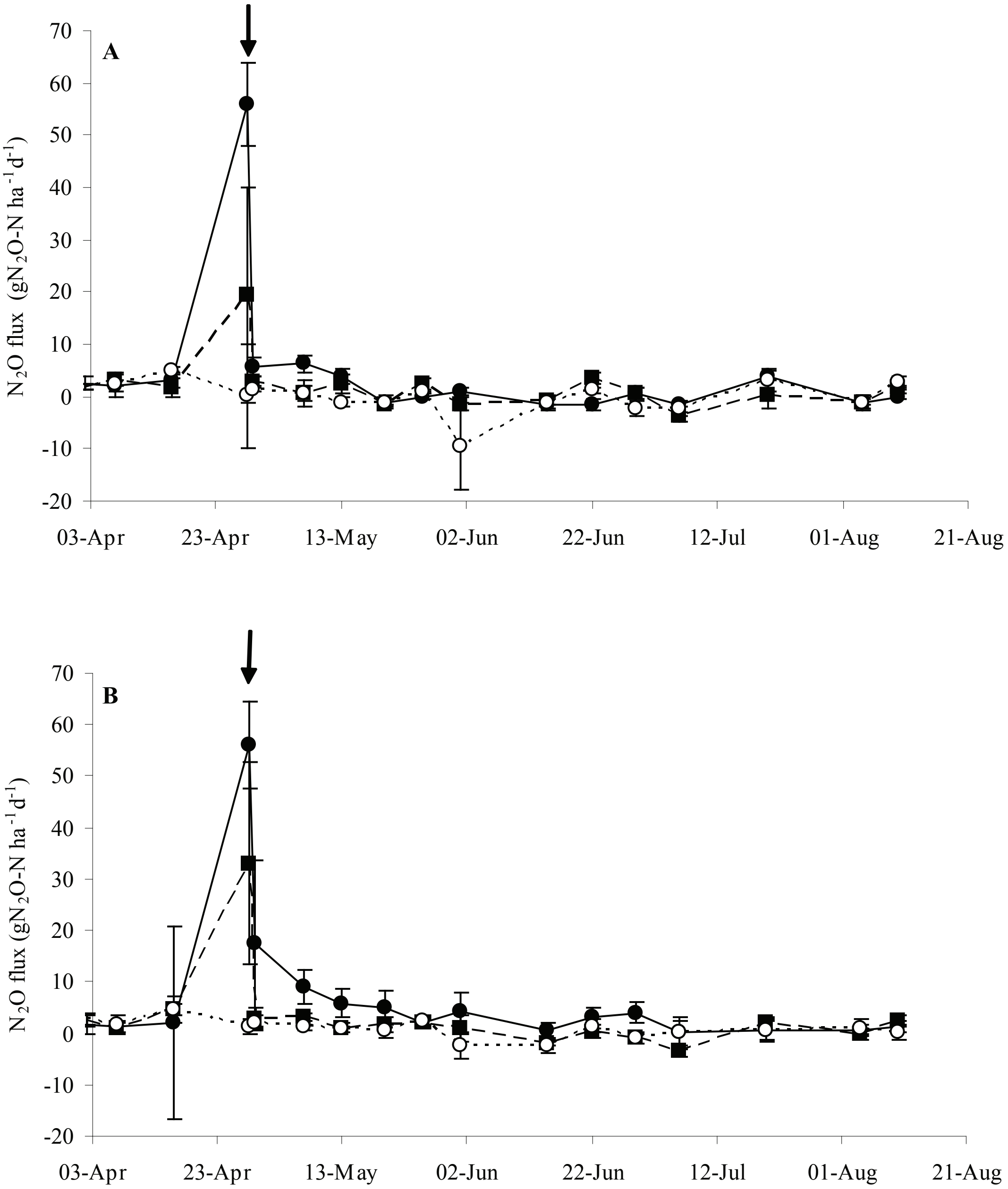

Figure 4.3. Daily fluxes of N_2O from the conventional (A) and non-inversion (B) tillage plots measured on a weekly basis in 2004. Symbols indicate the different fertiliser rates: N_1 (●), N_2 (■) and N_3 (○) as detailed in the text. Arrows indicate the first measurements following fertiliser application. Each point represents the mean ± SE of four measurements.

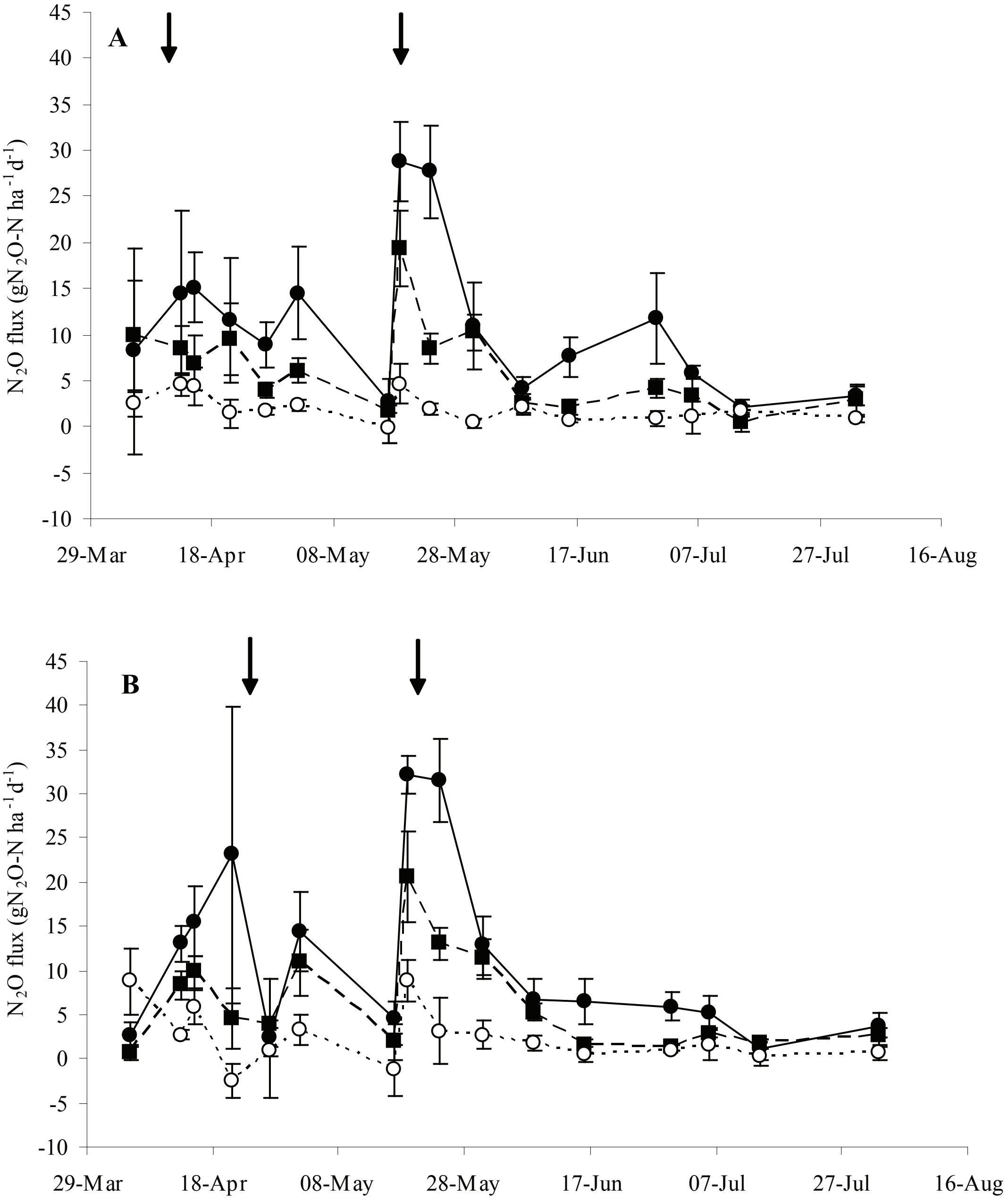

Figure 4.4. Daily fluxes of N$_2$O from the conventional (A) and non-inversion (B) tillage plots measured on a weekly basis in 2005. Symbols indicate the different fertiliser rates: N$_1$ (●), N$_2$ (■) and N$_3$ (○) as detailed in the text. Arrows indicate the first measurements following fertiliser application. Each point represents the mean ± SE of four measurements.

Table 4.1. Cumulative N_2O-N emissions for the conventional and non-inversion tillage plots for 2004/2005. Each value represents the mean ± SE of four replicate values.

Year/ treatment	Cumulative N_2O emissions (kg N_2O-N ha^{-1})	
2004	**Conventional tillage**	**Non-inversion tillage**
140 kg N ha^{-1}	0.79 ± 0.08	0.98 ± 0.21
70 kg N ha^{-1}	0.26 ± 0.26	0.49 ± 0.28
0 kg N ha^{-1}	0.01 ± 0.13	0.09 ± 0.03
2005		
159 kg N ha^{-1}	0.87 ± 0.04	0.94 ± 0.2
79 kg N ha^{-1}	0.39 ± 0.097	0.42 ± 0.02
0 kg N ha^{-1}	0.16 ± 0.03	0.13 ± 0.09

For both years, analysis of variance of the flux data revealed that time, fertiliser application, plots and interaction between time and fertiliser application were all significant. No significant difference was found between the N_2O flux from the conventional and non-inversion tillage plots. However, N_2O fluxes were significantly higher between fertiliser treatments within each tillage regime. The fluxes from the higher and medium fertilised plots were significantly higher ($P<0.001$) than from the control plots.

Tables 4.2 and 4.3 show the fertiliser application rate, cumulative emissions of N_2O and emission factors (EFs), for the April to August 2004/05 growing season, respectively. The effect of fertiliser application on the cumulative flux is very apparent. For 2004, CON_1 was significantly higher than CON_3 ($P<0.05$) and NIT_1 was significantly higher than NIT_3 ($P<0.05$). For 2005, CON_1 was significantly higher than CON_2 ($P<0.05$) and CON_3 ($P<0.01$), and NIT_1 was significantly higher than NIT_2 ($P<0.05$) and NIT_3 ($P<0.001$).

Nitrous oxide fluxes were influenced by nitrogen supply and, consequently, were correlated with soil nitrate concentrations. The significant differences in cumulative N_2O emissions observed between different nitrogen fertilised plots are due to peaks in N_2O fluxes following fertiliser application. Hence, higher application rates yield higher fluxes of N_2O. If these data sets are pooled together, as in Fig. 4.5 (corrected for zero nitrogen application), the relationship between cumulative flux

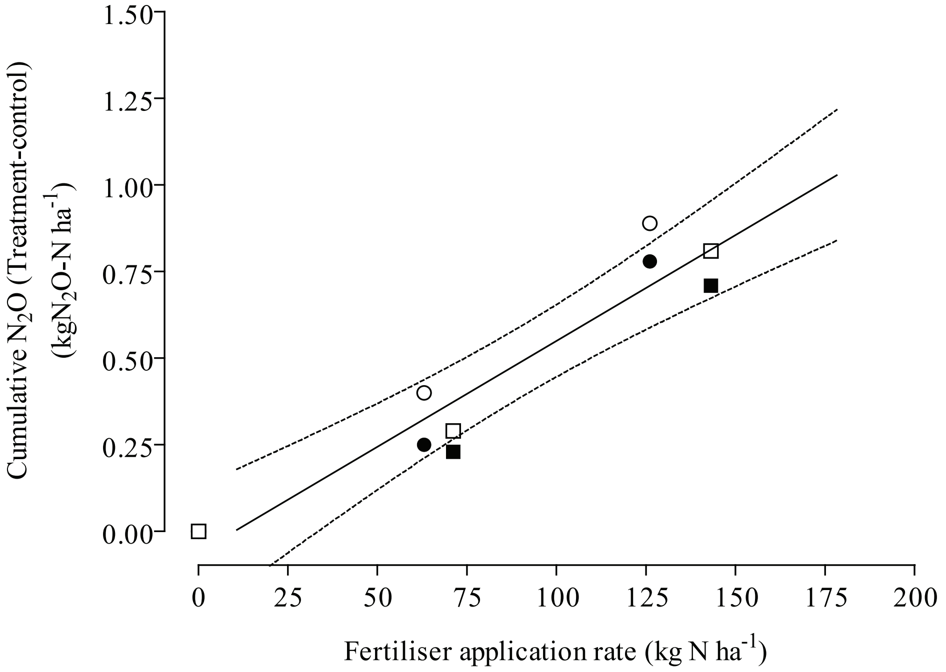

Figure 4.5. Relationship between fertiliser application rate and cumulative N_2O flux over the growing seasons 2004 and 2005. Each point represents the mean ± SE of 4 values. Symbols indicate: CON 2004 (●), NIT 2004 (○), CON 2005 (■) and NIT 2005 (□). Y = 0.0061 ± (0.0008) × –0.0613 ± (0.0079) and ($r^2 = 0.77$).

and fertiliser application rate is linear and, when the individual slopes are compared, there is no significant difference between them (P = 0.25), such that an overall equation can be calculated which accounts for 93% of the variation of the data (Eqn 4.2):

Cumulative flux =
0.0052*(fertiliser application rate) – 0.003 (Eqn 4.2)

In effect, the gradient of this relationship is the overall proportion of applied fertiliser that is given off as N_2O (or 0.5%). By changing the values for the fertiliser application rate to represent the 10% of calcium ammonium nitrate (CAN) that is lost because of ammonia volatilisation, the slope becomes the overall emission factor for the 2004/05 growing seasons. This gives a slope of 0.0058 ± 0.0005, or an EF of 0.58 ± 0.05%.

Tables 4.2 and 4.3 give the separate EFs for each tillage, fertiliser treatment and year, and show that these range from 0.42 to 0.65%. As tillage treatment did not affect EF significantly, and there was no significant difference between the EFs for the two years, the EF determined as the slope of cumulative flux vs fertiliser application rate represents a more accurate determination of this value. This value is actually less than 50% of the default EF of 1.25% of the applied nitrogen fertiliser proposed by the IPCC and used for calculating N_2O emissions from Irish agriculture. Given the free-draining nature of the soil at this site (*Calcic luvisol* and silty loam), it is considered unlikely that the persistence of fertiliser in the soil from one year to the next would result in significant fallow season losses of gaseous N_2O owing to the removal of residual nitrogen compounds in soil water solution. This is, however, dependent on nitrogen utilisation by the previous crop and inter-annual climatic conditions during the fallow period, which influence both nitrogen transformations in the soil and soil WFPS.

As illustrated in Fig. 4.6, grain yield (at 15% moisture) for both tillage treatments in response to nitrogen fertiliser in 2004/05 increased non-linearly with the increasing nitrogen fertiliser. In both years, the proportional increase in grain yield was highest at the lower fertiliser application rate. Statistical analysis revealed that only fertiliser treatment and not tillage treatment was significant. Significant differences (P<0.001) between the N_1 and N_3 and the N_2 and N_3 treatments within each tillage system were observed. However, no significant difference between N_1 and N_2 was found. An examination of yield as a function of fertiliser application rate indicates that reducing the field rate of CAN-nitrogen application by 50% had no significant effect on the grain yield (at 15% moisture), although effects on the nutritional quality or protein content of the grain are unknown because these parameters were not measured (Fig. 4.7).

The relationship between the final grain yield and the cumulative flux of N_2O in 2004/05 is shown in Fig. 4.7, for both the conventional and non-inversion tillage plots combined. The line of best fit ($r^2 = 0.69$) is an exponential curve, such that proportionally less N_2O is emitted

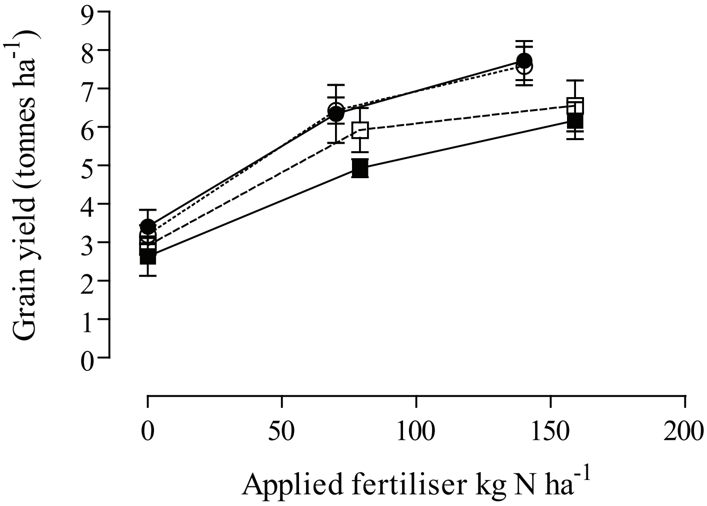

Figure 4.6. Grain yield from the conventional and non-inversion tillage for 2004 and 2005. Symbols indicate tillage/year combination: CON 2004 (●), NIT 2004 (○), CON 2005 (■) and NIT 2005 (□). Each point represents the mean ± SE of four measurements.

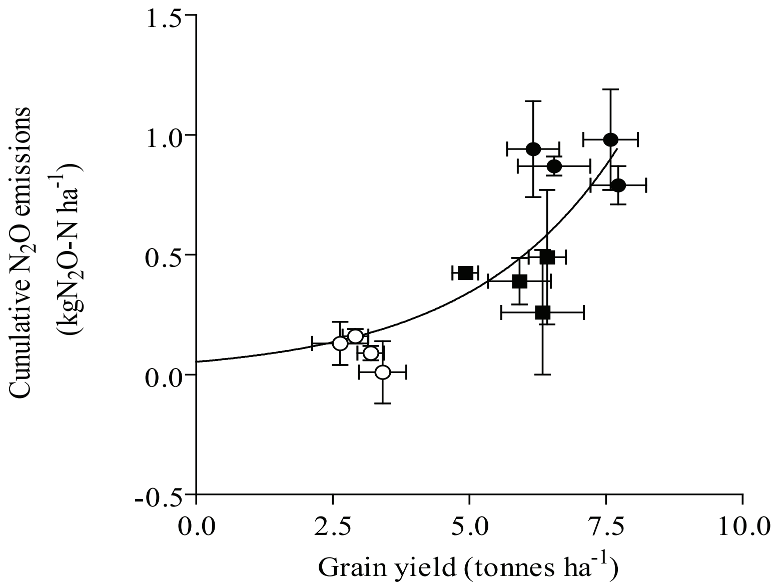

Figure 4.7. Relationship between grain yield of spring barley (at 15% moisture) and the cumulative flux of N_2O over the growing season for 2004 and 2005 combined. Each point represents the mean ± SE of 4 values. Symbols indicate fertiliser rate levels: N_1 (●), N_2 (■) and N_3 (○). The line indicates the curve of best fit, where $y = 0.053e^{0.373x}$, ($r^2 = 0.69$).

from the soil at low fertiliser application rates, but the proportional increase in crop yield was higher at the lower fertiliser application rates. Hence, a reduction in fertiliser application of 50% below the normal field rates resulted only in a reduction in yield of approximately 16%, but decreased the cumulative N_2O emissions by 57%.

Table 4.2. Total amount of nitrogen applied, cumulative N_2O-N emitted and emission factors for the conventional and non-inversion tillage plots in 2004.

Treatment	N_2O cumulative emissions (kg N_2O-N ha^{-1})	Emission factor (%)
Conventional tillage		
140 kg N ha^{-1}	0.79 ± 0.08	0.63 ± 0.06
70 kg N ha^{-1}	0.26 ± 0.26	0.42 ± 0.41
0 kg N ha^{-1}	0.01 ± 0.13	–
Non-inversion tillage		
140 kg N ha^{-1}	0.98 ± 0.21	0.63 ± 0.2
70 kg N ha^{-1}	0.49 ± 0.28	0.65 ± 0.45
0 kg N ha^{-1}	0.09 ± 0.03	–

Table 4.3. Total amount of nitrogen applied, cumulative N_2O-N emitted and emission factors for the conventional and non-inversion tillage in 2005.

Treatment	N_2O cumulative emissions (kg N_2O- N ha^{-1})	Emission factor (%)
Conventional tillage		
159 kg N ha^{-1}	0.870 ± 0.04	0.61 ± 0.03
79 kg N ha^{-1}	0.39 ± 0.097	0.54 ± 0.13
0 kg N ha^{-1}	0.16 ± 0.03	–
Non-inversion tillage		
159 kg N ha^{-1}	0.941 ± 0.2	0.65 ± 0.14
79 kg N ha^{-1}	0.424 ± 0.02	0.59 ± 0.03
0 kg N ha^{-1}	0.13 ± 0.09	–

4.4 Discussion

The results obtained from this study describe the impacts of soil tillage practices and varying nitrogen fertilisation rate on N_2O emissions and EFs from a spring barley crop. In addition, the relationship between crop yield and N-induced flux is also discussed. The estimation of an annual cumulative flux from this experiment using the EF and control plot data is not possible. This is because N_2O flux measurements for both 2004/05 took place only from April to August, when crop growth occurred, and not throughout the whole year (Bouwman 1996; Bouwman et al. 2002).

Non-inversion tillage treatments had no statistically significant effects on N_2O flux, grain yield or soil nitrate. Therefore, the adoption of non-inversion tillage as a means of mitigating N_2O emissions from the field in this study was not successful. With respect to the cumulative N_2O fluxes, a slight increase was found for the non-inversion tillage plots. An initial increase in N_2O flux from non-inversion or no-tillage plots has been a consistent observation in the literature (Aulakh et al. 1984; Bouwman 1996; Baggs et al. 2000; Linn and Doran 1984; Baggs et al. 2003). A long-term study by Six et al. (2004) has also shown an increase in N_2O flux from non-inversion tillage plots over the first 10 years, following which emissions declined. Therefore, such an experiment may need to be continued for several more years to find any significant difference, although Six et al. (2004) have suggested a period of 20 years to see mitigation effects of non-inversion tillage on GHG emissions in general. As N_2O emissions from nitrification and denitrification are linked closely to other nitrogen transformations and loss processes (Whitehead 1995), management options to reduce one loss process could potentially enhance other losses. A good mitigation system for reducing N_2O emissions may require the nitrogen cycle of agricultural systems as a whole to be considered (Jarvis et al. 1996). Longer term studies considering all these factors should be undertaken.

Although a reduction in N_2O emissions through tillage management was not identified in this study, a reduction in N_2O emissions as a function of fertiliser application was highlighted, which importantly had no significant effect on grain yield. This was also reported by others (McTaggart and Smith 1995), who suggested that grain yields don't increase linearly with increments of applied N, but leveled off at 90–120 kg nitrogen ha^{-1}. Chantigny et al. (1998) found that increases in N from 120 to 180 kg N ha^{-1} hardly affected maize yields and Sehy et al. (2003) reported no significant increase in maize yields when N was increased from 125 to 175 kg N ha^{-1}.

The decrease in cumulative N_2O emissions in response to a reduction in fertiliser application suggests that N_2O has a threshold response to nitrogen fertilisation where the amount of nitrogen lost to the atmosphere depends on the amount of nitrogen taken up by the crop. Exceeding this threshold value results in a higher release of N_2O to the atmosphere. This was also observed by McSwiney and Robertson (2005), who suggested that agricultural N_2O fluxes could be non-inversion with no or little yield penalty by reducing nitrogen fertiliser inputs to levels that just satisfy crop needs.

This study also shows that the emission factors associated with N_2O fluxes were not significantly different because of the varying rate of fertiliser application. Site-specific factors such as soil type and structure along with localised climatic parameters will have a larger influence on the calculation of emission factors.

The method used for measuring N_2O has significant effects on the results obtained. The use of EC techniques, such as in the Cork study of Scanlon and Kiely (2003) and Hsieh et al. (2005) give continuous measurements and can be used on a large footprint with less labour intensity but, depending on wind speed, direction and down time of the system, significant gaps in the data must be filled by estimation. Moreover, the instrument installation and maintenance are expensive. On the other hand, a static chamber, such as that used in the Wexford study of Hyde et al. (2005), or in this study, is technically simpler with less cost, and can be used on a known sample area with better replication. However, the chamber used in the Wexford study was 11.5 cm diameter by 15 cm high, and is very small compared with the 50 × 50 × 30 cm chamber used in this study. The chamber size and height are required to improve gas linearity inside the chamber, although too high a chamber relative to the footprint dilutes the N_2O signal (Conen and Smith 2000). The disadvantages of static chambers are the high labour intensity and the possibility of missing many peaks, such as those associated with either farm management or extreme climatic events, thereby underestimating N_2O flux. However, in this study, measurement frequency was increased during key management events such as fertilisation in order to measure peak N_2O emissions adequately. For better estimates of N_2O fluxes from soils, this study suggests a continuous measurement programme using an automated chamber, as a large proportion of N_2O emissions occur during short events, such as those immediately following nitrogen fertiliser application or rainfall.

5 Field Testing of the DeNitrification DeComposition Model for Trace Gas Emissions from Arable Soils in Ireland

5.1 Introduction

National inventories of N_2O fluxes from agricultural soils, as required by signatory countries to the UNFCCC, are largely derived from the use of the default IPCC protocol where 1.25% of applied inorganic nitrogen to agricultural soils is assumed to be released to the atmosphere as N_2O (Bouwman 1996; IPCC 2001). This standard reporting procedure has advantages in collating annual inventories but may mask significant variations in EFs on a regional scale (Schmid et al. 2001; Laegreid and Aastveit 2002). For instance, in Ireland, published EFs derived from field measurements of N_2O using either EC or static chamber methods vary from 0.7 to 4.9% of the applied nitrogen fertiliser depending on soil type, land management, climate and year (Hsieh et al. 2005; Hyde et al. 2005; Flechard et al. 2007).

Given the considerable expense of establishing and maintaining relevant flux measurement sites, on a national basis the use of simulation models to estimate N_2O fluxes from agricultural soils using soil and climate data has obvious benefits. Modelling also allows clearer interpretation of the complex links between soil physical, chemical and microbial processes that underpin nitrification, denitrification and decomposition. Here models can simulate the processes responsible for production, consumption and transport of N_2O in both the long and short terms and also on a spatial scale (Williams et al. 1992).

Simulation models range from simple empirical relationships based on statistical analyses to complex mechanistic models that consider all factors affecting N_2O production in the soil (Li et al. 1992; Frolking et al. 1998; Stenger et al. 1999). Variations in soil moisture, soil temperature, carbon and nitrogen availability for microbial nitrification and denitrification are critical to the determination of N_2O emissions (Leffelaar and Wessel 1988). One widely used mechanistic model is DNDC, which was developed to assess N_2O, NO, N_2 and CO_2 emissions from agricultural soils (Li et al. 1992). The advantages of this model are that it has been tested extensively and has shown reasonable agreement between measured and modelled results for many different ecosystems, such as grassland (Hsieh et al. 2005; Saggar et al. 2007), cropland (Jagadeesh Babu et al. 2006) and forest (Keisk et al. 2006).

This study presents a field validation of the DNDC model for an Irish midlands soil under arable crops and different fertiliser and tillage regimes.

5.2 Methodology

Measurements of N_2O flux were carried out for a spring barley field from April to August for two consecutive seasons (2004/05). The arable site was located at the Oakpark Research Centre, Carlow, Ireland and is described in detail in Section 1. The arable field was seeded with spring barley (cv. Tavern) at a density of 140 kg ha^{-1} and managed under two different tillage regimes: CON and NIT. The field was sprayed with weed killer (Roundup Sting) at 4.0 l ha^{-1}, three times per season, once pre- and twice post-planting. During 2004, three rates of N-fertilisation 140 (N_1), 70 (N_2) and 0 (N_3) kg N ha^{-1}, were applied once on 27 April, whereas in 2005, two fertiliser applications took place on 12 April, 106 (N_1), 53 (N_2) and 0 (N_3) kg N ha^{-1}, and on 10 May, 53 (N_1), 26 (N_2) and 0 (N_3) kg N ha^{-1}. The total amount of N-fertilisation applied in 2005 was therefore 159 (N_1), 79 (N_2) and 0 (N_3) kg N ha^{-1}.

The DNDC model (version 8.9) was used and was tested by: (i) comparing the measured and modelled temporal pattern of N_2O flux, (ii) comparing the measured and modelled cumulative N_2O flux, and (iii) comparing the measured and modelled EFs.

The relative deviation (Y) of the modelled flux from those measured was calculated using the following equation (Eqn 5.1):

$$Y = (X_S - X_O)/X_O \times 100 \qquad \text{(Eqn 5.1)}$$

where X_O and X_S are the measured and modelled fluxes, respectively. Annual and seasonal cumulative fluxes for DNDC outputs were calculated as the sum of simulated daily fluxes (Cai et al. 2003). Emission factors for the modelled data were calculated by subtracting the cumulative DNDC flux data for unfertilised soils from that of the fertilised soils and dividing by the nitrogen fertiliser input, corrected for ammonia volatilisation (10%).

Non-inversion tillage characteristics were implemented in the DNDC model by specifically changing the input tillage parameters such as the depth and timing of the tillage event. The only restriction with this in the DNDC model was that the tillage depth function for NIT had to be set to 10 cm, whereas in the field situation the NIT plots were tilled to a depth of 15 cm.

Model runs were performed on an annual timescale; however, in order to compare the model output with measured data, the output values were compared with the measurements made during the 2004 and 2005 growing seasons.

Sensitivity analyses were carried out by varying a single determinant factor while keeping other factors constant for one annual cycle of the model.

5.3 Results

Table 5.1 summarises the soil properties and climate input data used in testing the DNDC model. The model was tested on the arable site only during the period of crop growth.

The determinant factors used in the DNDC model sensitivity analysis are illustrated in Table 5.2.

Figures 5.1a to 5.1f illustrate both the DNDC model-simulated and field-measured N_2O fluxes from the high, medium and low fertilised, conventionally tilled plot, while Figs 5.2a to 5.2f illustrate the model-simulated and field-measured N_2O fluxes from the various fertiliser treatments on the non-inversion tillage plot. Modelled fluxes of N_2O at high nitrogen fertiliser application (140 and 159 kg N ha^{-1}) gave relative deviations from the measured values of –1 and –6% for conventional tillage (Figs 5.1a and 5.1b) and –40 and –25% for non-inversion tillage, respectively (Figs 5.2a and 5.2b). However, modelled fluxes of N_2O at medium nitrogen fertiliser application (70 and 79 kg N ha^{-1}) gave the best fit for conventional tillage with relative deviations of 30 and –20% (Figs 5.1c and 5.1d), but less satisfactory results for non-inversion tillage with relative deviations of –55 and –44% (Figs 5.2c and 5.2d). Fluxes from the zero fertiliser plots (control plots) of both the conventional and non-inversion tillage treatments were poorly described by DNDC, with relative deviations of the simulated from the observed, ranging from –35% to more than 5000% (Figs 5.1e–5.1f, 5.2e–5.2f). However, these differences are associated with a small range of flux values for N_2O (–0.1 to 0.1 kg N ha^{-1}).

Table 5.1. DNDC model input data for both the conventional and non-inversion tillage spring barley fields.

Climate data	Spring barley field
Latitude (degree)	52.86 °N
Yearly maximum of average Daily temperature (°C)	13
Yearly minimum of average Daily temperature (°C)	4.0
Yearly accumulated precipitation (mm).	792
N concentration in rainfall (mg N l^{-1})	0.001
Atmospheric CO_2 concentrations (ppm)	380*
Soil properties (0–10 cm depth)	
Vegetation type	Barley crop
Soil texture	Sandy loam
Bulk density (g cm^{-3})	1.4
Clay fraction	0.19*
Soil pH	7
Initial organic C content at surface soil (kg C kg^{-1})	0.019
Harvest	Grain harvest, mulch/till
Soil tillage	Conventional and reduced
WFPS at field capacity	0.68
WFPS at wilting point	0.12
Depth of water-retention layer (cm)	100
Slope (%)	0.0

* Default values.

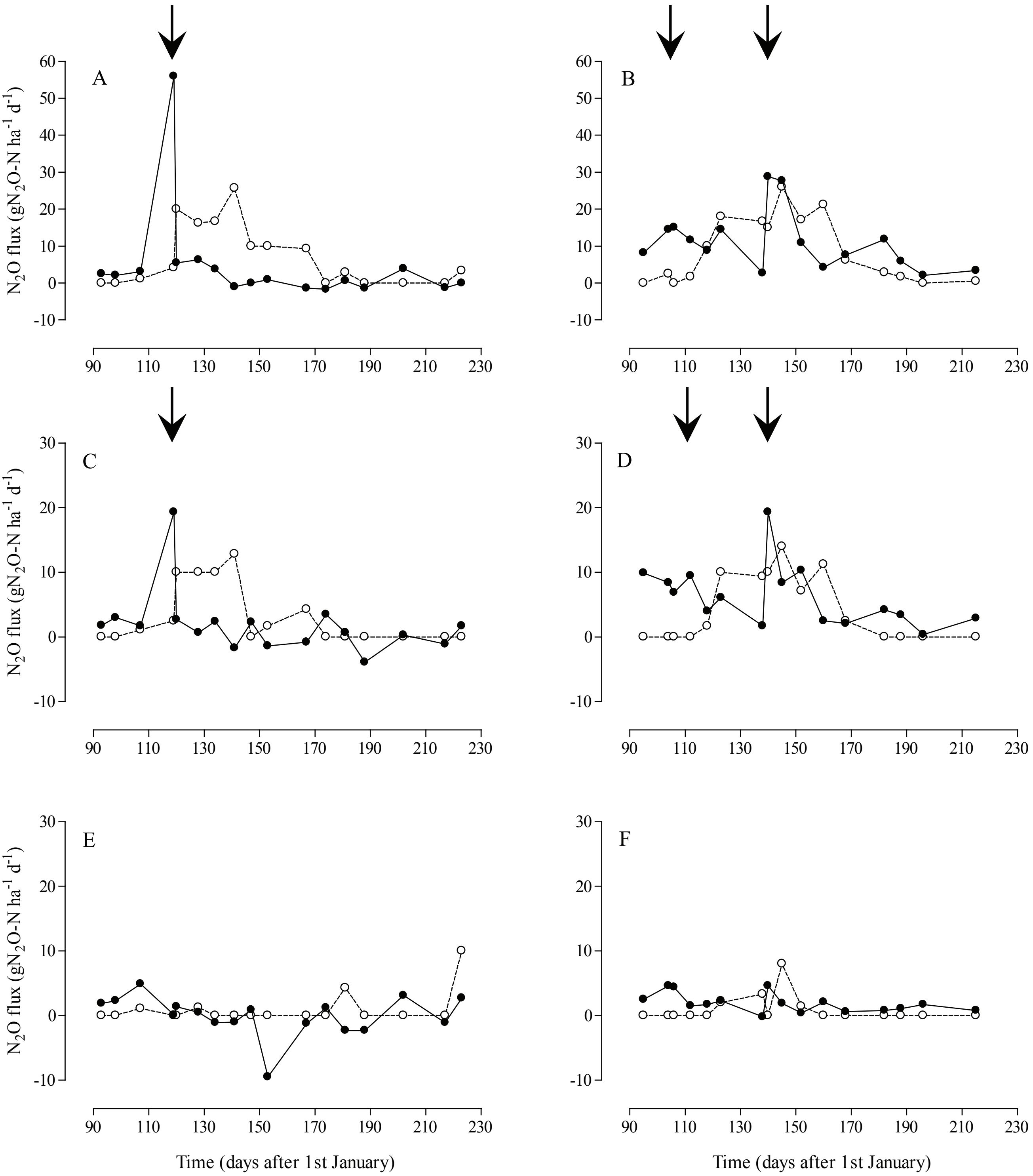

Figure 5.1. Comparison of model-simulated (○) and field-measured (●) N_2O fluxes from the high (upper), medium (bottom) and low (lower) fertilised conventional tillage in 2004 (A, C and E) and 2005 (B,D and F). Arrows show time of fertiliser application.

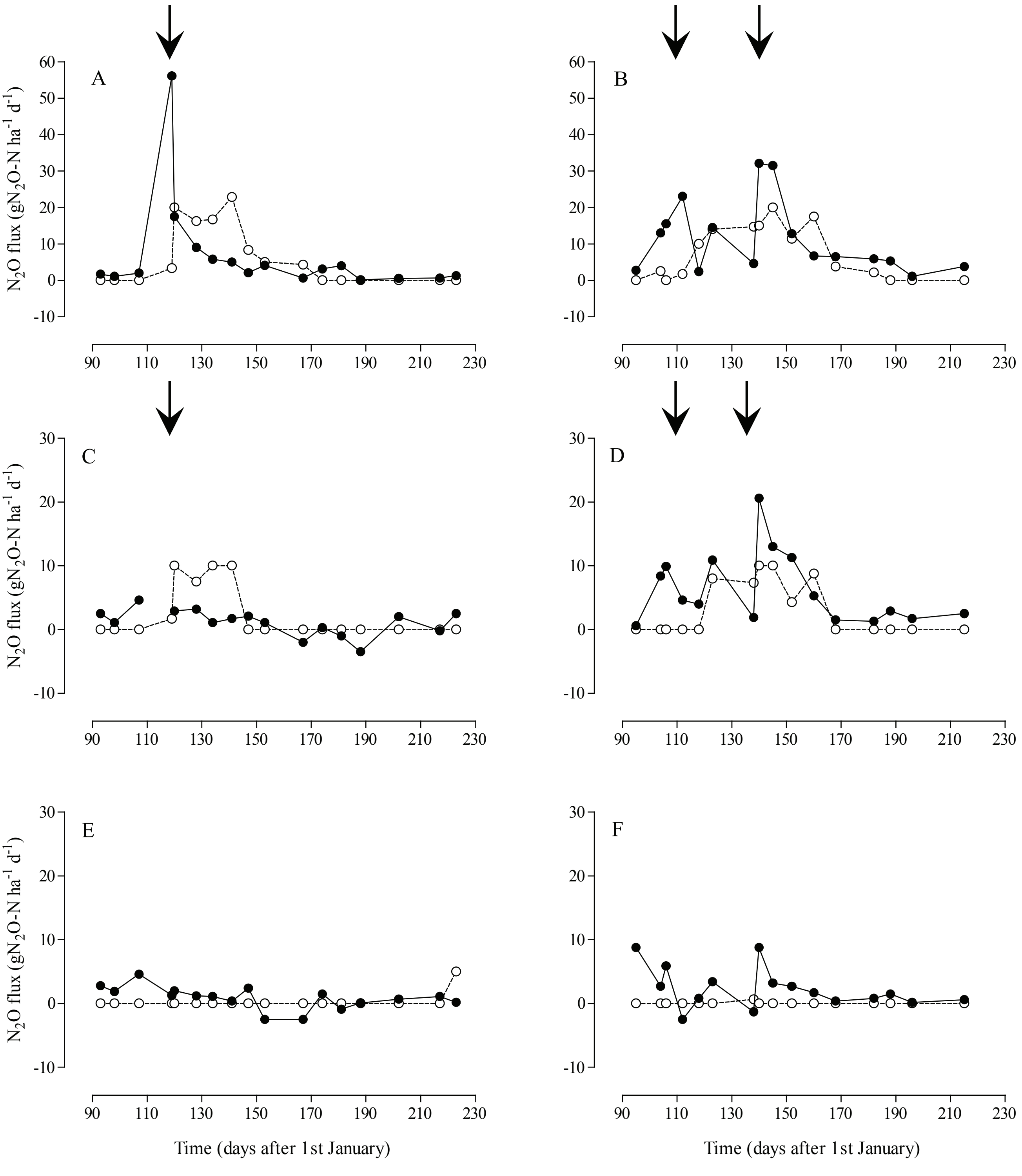

Figure 5.2. Comparison of model-simulated (○) and field-measured (●) N_2O fluxes from the high (upper), medium (bottom) and low (lower) fertilised non-inversion tillage in 2004 (A, C and E) and 2005 (B, D and F). Arrows show time of fertiliser application.

Table 5.2. Sensitivity of DNDC to changes in soil characteristics, management and climate for the spring barley field (conventional tillage, 2004).

Scenario	**Mineralisation annual flux (kg N ha^{-1} y^{-1}) ratio**				
	Rate kg	**N ha^{-1} y^{-1} N_2O**	**N_2**	**$N_2O + N_2$**	**($N_2O/N_2O + N_2$)**
*Baseline	257.4	1.6	2.4	4	0.4
Bulk density (g cm^{-1})					
1	194	0.67	1.00	1.67	0.40
1.6	290.8	2.11	2.22	4.33	0.45
1.8	324.2	2.65	3.48	6.13	0.43
Soil pH					
4	257.4	0.09	0.18	0.27	0.33
6	257.4	1.62	2.05	3.67	0.44
8	257.4	1.00	1.76	2.76	0.36
Initial soil organic carbon					
+20%	305.8	2.59	3.51	6.1	0.42
-20%	211.1	0.69	1.05	1.74	0.40
Fertiliser amount (kg N ha^{-1}y^{-1})					
210	259.8	2.41	2.46	4.87	0.49
70	257.4	1.03	2.06	3.09	0.33
Fertiliser type					
Urea	257.4	2.46	2.35	4.81	0.51
Ammonium bicarbonate	257.2	1.4	2.06	3.46	0.40
Ammonium sulphate	257.4	2.54	2.36	4.9	0.52
Rainfall					
+20%	267.1	1.76	2.75	4.51	0.39
-20%	244.5	1.41	1.57	2.98	0.47
Air temperature					
+20%	269.6	2.65	4.27	6.92	0.38
-20%	243.2	0.93	1.41	2.34	0.40

* Baseline scenario: Bulk density 1.4 gc m^{-3}, soil pH 7.0, SOC 0.0194 kg C kg^{-1}, fertiliser applied and timing (140 kg N/ha CAN, on 27 April), annual average max. and min. air temperature 13.7 and 4.8 ^{o}C and average daily precipitation 2.2 cm and soil tillage to 22 cm depth carried in March 5 weeks before planting.

The observed and modelled seasonal trends in N_2O emissions from the conventional and non-inversion tillage treatments are detailed in Table 5.3. The differences between the modelled and measured fluxes for both treatments ranged from –0.4 to 0.1 kg N ha$^{–1}$.

5.4 Discussion

The DNDC model performed well in describing the general pattern of N_2O emissions from fertilised conventional and non-inversion tillage plots. The mean relative deviation for all fertiliser treatments was approximately 20% and was because of an underestimation by the model when compared to the measured fluxes. The model was able to predict peak N_2O emissions accurately, although the exact timing of the modelled peaks and the duration of the peaks showed some variability when compared to the field data. In addition, the model showed a tendency to overestimate the WFPS at certain points within the seasonal cycle. For example, the maximum measured WFPS for the conventional tillage plot was 57% while the DNDC model estimated the WFPS for this period to be 67%. This overestimation may account for the observed discrepancies at certain periods during the cropping season. Fluxes of N_2O from the fertilised control plots were poorly described by the DNDC model for both tillage treatments. This may highlight the inability of the model to describe accurately situations where the N_2O fluxes are low.

Table 5.3. Observed and modelled seasonal N_2O emissions from the conventional and non-inversion tillage plots.

		Seasonal emissions (g N_2O-N ha^{-1})			Relative deviation (%)
	Treatment	Observation	Model	Difference	
2004 season					
Conventional tillage	140 kg N ha^{-1}	788	780	–8	–1
	70 kg N ha^{-1}	269	350	+81	30
	0 kg N ha^{-1}	2	110	+108	5400
Non–inversion tillage	140 kg N ha^{-1}	978	590	–388	–40
	70 kg N ha^{-1}	494	220	–274	–55
	0 kg N ha^{-1}	87	30	–57	–66
2005 season					
Conventional tillage	159 kg N ha^{-1}	1053	993	–60	–6
	79 kg N ha^{-1}	563	450	–113	–20
	0 kg N ha^{-1}	170	110	–60	–35
Non-inversion tillage	159 kg N ha^{-1}	1058	793	–265	–25
	79 kg N ha^{-1}	567	320	–247	–44
	0 kg N ha^{-1}	135	10	–125	–93

The analysis of the model in relation to soil characteristics, tillage management and climate showed that the model is most sensitive to nitrogen inputs. The application of nitrogen fertiliser as a driving parameter behind the N_2O fluxes was confirmed by both the measured data and the model output. In this study an increase in nitrogen input by 50% resulted in a similar increase in N_2O flux and an increase in the N_2O: denitrification ratio of 22.5%.

Nitrous oxide fluxes from the conventional tillage plots subject to zero nitrogen application were exceptionally low in 2004 compared to the same treatment in 2005. This was mainly due to the high negative flux values observed in 2004 (–9.5 g N_2O-N ha^{-1} d^{-1}) in comparison to 2005 (–0.2 g N_2O-N ha^{-1} d^{-1}). The observed negative fluxes occurred during periods where the soil was acting as a N_2O sink (Ryden 1981; Cicerone 1989; Donoso et al. 1993); however, these fluxes were poorly simulated by the DNDC model and represent a potential model limitation.

In relation to the climatic drivers of the N_2O fluxes, the DNDC model showed that N_2O emissions were most sensitive to increases in air temperature. The model suggested that an increase in air temperature of approximately 1.5 °C would result in a 66% increase in the annual N_2O flux. However, it is important to make detailed seasonal and diurnal flux measurements in order to identify the effects of temperature on N_2O flux accurately and to validate the model predictions. The DNDC model also indicated that a reduction in the total daily rainfall of 20% would lead to a 12% reduction in the annual N_2O flux.

References

Armstrong, F., Sterns, C., and Strickland, J. (1976). The measurement of up-welling and subsequent biological processes by means of the Technicon automatic analyser and associated equipment. *Journal of Deep Sea Research*, **14**, 381–389.

Aubinet, M., Grelle, A., Ibrom, A., Rannil, U., Moncrieff, J., Foken, T., Kowalski, A., Martin, P., Berbigier, P., Bernhofer, C., Clement, R., Elbers, J., Granier, A., Grunwald, T., Morgenstern, K., Pilegaard, K., Rebmann, K., Snijders, W., Valentini, R., and Vesala, T. (2000). Estimates of the annual net carbon and water exchange of forests: The EUROFLUX Methodology. *Advances in Ecological Research*, **30**, 113–175.

Aulakh, M., Rennie D., and Paul, E. (1984). The influence of plant residues of denitrification rates on conventional and zero-tilled soils. *Soil Science Society of America Journal*, **48**, 790–794.

Baggs, E., Rees, R., Smith, K., and Vinten, A. (2000). Nitrous oxide emission from soil after incorporating crop residues. *Journal of Soil Use and Management*, **16**, 82–87.

Baggs, E., Stevenson, M., Pihlatie, M., Regar, A., Cook, H., and Cadish, G. (2003). Nitrous oxide emissions following application of residues and fertilizer under zero and conventional tillage. *Journal of Plant Soil*, **254**, 361–370.

Bahn, M., Anderson, M., Dore, S., Gimeno, C., Drösler, M., Williams, M., Acosta, M., Ammann, C., Berninger, F., Flechard, C., Jones, S., Kumar, S., Newesely, R.S., Pavelka, M., Priwitzer, T., Raschi, A., Siegwolf, R., Susiluto, S., Tenhunen, J., Wohlfahrt, G., and Cernusca, A. (2008). Soil respiration in European grasslands in relation to climate and assimilate supply, *Ecosystems*, **11**, 2008, 1352–1367.

Ball, B. and Ritchie, R. (1999). Soil and residue management effects on cropping conditions and nitrous oxide fluxes under controlled traffic in Scotland. Soil and crop responses. *Soil Tillage Research*, **52**, 177–189.

Barford, C., Wofsy, S., Goulden, M., Munger, J., Pyle, E., Urbanski, S., Hutyra, L., Saleska, S., Fitzjarrald, D., and Moore, K. (2001). Factors controlling long- and short-term sequestration of atmospheric CO_2 in a mid-latitude forest. *Science*, **294**, 1688–1691.

Borresen, T. (1999). The effect of straw management and non-inversion tillage on soil properties and crop yields of spring sown cereals on two loam soils in Norway. *Soil and Tillage Research*, **51**, 91–102.

Bouwman, A. (1996). Direct emissions of nitrous oxide from agricultural soils. *Nutrient Cycling in Agro-ecosystems*, **46**, 53–70.

Bouwman, A., Bouwmans, L., and Batjes, N. (2002). Modelling global annual N_2O and NO emissions from fertilized fields. *Global Biogeochemical Cycles*, **16**, 1080, doi: 10.1029/2001 GB001812.

Byrne, K.A. and Kiely, G. (2006). Partitioning of respiration in an intensively managed grassland. *Plant and Soil*, **282**, 281–289.

Cai, Z., Swamoto, T., Li, C., Kang, G., Boonjawat, J., Mosier, A., Wassmann, R., and Tsuruta, H. (2003). Field validation of the DNDC-model for greenhouse gas emissions in East Asian cropping systems. *Global Biogeochemical Cycles*, **17**, 1107.

Chantigny, M., Prevest, D., Angers, D., Simard, R., and Califour, F. (1998). Nitrous oxide production in soils cropped to corn with varying N fertilization. *Canadian Journal of Soil Science*, **78**, 589–596.

Cias, P., Reichstein, M., Viovy, N., Granier, A., Ogee, J., Allard, V., Aubinet, M., Buchmann, N., Bernhofer, C., Carrara, A., Chevallier, F., De Noblet, N., Friend, A., Friedlingstein, P., Grunwald, T., Heinesch, B., Keronen, P., Knohl, A., Krinner, G., Lousteau, D., Manca, G., Matteucci, G., Miglietta, F., Ourcival, J., Papale, D., Pilegaard, K., Rambal, S., Suefert, G., Soussana, J-F., Sanz, M., Schulze, E-D., Vesala, T., and Valentini, R. (2005). Europe-wide reduction in primary productivity caused by heat and drought in 2003. *Nature*, **437**, 529–533.

Cicerone, R. (1989). Analysis of sources and sinks of atmospheric nitrous oxide. *Geophysical Research*, **94**, 18265–18271.

Conen, F., Dobbie, K., and Smith, K. (2000). Predicting N_2O emissions from agricultural land through related soil parameters. *Global Change Biology*, **6**, 417–426.

Central Statistics Office (2007). *Area, Yield and Production of Selected Crops 2007*, Central Statistics Office, Cork. Available at: http://www.cso.ie/statistics/areayieldprodselectedcrops.htm, accessed 22 November 2009.

Dabney, A., Delgado, J., and Reeves, D. (2001). Using winter cover crops to improve soil and water quality. *Communications in Soil Science and Plant Analysis*, **32**, 1221–1250.

Davidson, E.A., Trumbore, S.E., and Amundson, R. (2000). Soil warming and organic carbon content. *Nature*, **408**, 789–790.

Donoso, L., Santana, R., and Sanhueza, E. (1993). Seasonal variation of N_2O fluxes at a tropical savanna site: soil consumption of N_2O during the dry season. *Geophysical Research Letters*, **20**, 1379–1382.

Epron, D., Farque, L., Lucot, E., and Badot, P.M. (1999). Soil CO_2 efflux in a beech forest: dependence on soil temperature and soil water content. *Annals of Forest Science*, **56**, 221–226.

Flanagan, L., Wever, L., and Carlson, P. (2002). Seasonal and interannual variation in carbon dioxide exchange and carbon balance in a northern temperate grassland. *Global Change Biol*ogy, **8**, 599–615.

Flechard, C., Ambus, P., Skiba, U., Rees, R., Hensen, A., Van den Pol, A., Soussana, J.F., Jones, M., Clifton-Brown, J., Raschi, A., Horvath, L., Van Amstel, A., Neftel, A., Jocher, M., Ammann, C., Fuhrer, J., Calanca, P., Thalman, E., Pilegaard, K., Di Marco, C., Campbell, C., Nemitz, E., Hargreaves, K., Levy, P., Ball, B., Jones, S., Van de Bulk, W., Groot, T., Blom, M., Gunnink, H., Kasper, G., Allard, V., Cellier, P., Laville, P., Henault, C., Bizouard, F., Jolivot, D., Abdalla, M., Williams, M., Baronti, S., Berretti, F., Grosz, B., and Dominques, R. (2007). Effects of climate and management intensity on nitrous oxide emissions in grassland systems across Europe. *Journal of Agriculture, Ecosystems and Environment*, **121**, 135–152.

Follett, R.F. (2001). Soil management concepts and carbon sequestration in cropland soils. *Soil and Tillage Research*, **61**, 77–92.

Frolking, S., Mosier, A., Ojima, D., Li, C., Parton, W., Potter, C., Priesack, E., Stenger, R., Haberbosch, C., Dorsch, P., Flessa, H., and Smith, K. (1998). Comparisons of N_2O emissions from soils at three temperate agricultural sites: simulations of year-round measurements by four models. *Journal of Nutrients Cycling in Agroecosystems*, **52**, 77–105.

Galloway, J. (1998). The global N-cycle: changes and consequences. *Environmental Pollution*, **102**, 15–24.

Hsieh, C., Leahy, P., Kiely, G., and Li, C. (2005). The effect of future climate perturbations on N_2O emissions from a fertilized humid grassland. *Nutrient Cycling in Agro-ecosystems*, **73**, 15–23.

Hyde, B., Ryan, M., Hawkins, M., Connolly, J., and Carton, O. (2005). Nitrous oxide emissions. End of Project Report. RMIS 4974. Teagasc, Johnstown Castle Research Centre, Co. Wexford.

IPCC. (Intergovernmental Panel on Climate Change) (2001). *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*. IPCC, Tokyo, Japan.

Jagadeesh Babu, Y., Li, C., Frolking, S., Nayak, D., and Adhya, D. (2006). Field validation of DNDC model for methane and nitrous oxide emissions from rice-based production systems of India. *Nutrients Cycling in Agro-ecosystems*, **74**, 157–174.

Janssens, I.A., Kowalski, A.S. and Ceulemans, R. (2001). Forest floor CO_2 fluxes estimated by eddy covariance and chamber-based model. *Agricultural and Forest Meteorology*, **106**, 61–69.

Jarecki, M. and Lal, R. (2003). Crop management for soil carbon sequestration. *Critical Reviews in Plant Sciences*, **22**, 471–502.

Jarvis, S.C., Wilkins, R., and Pain, B. (1996). Opportunities of reducing the environmental impact of dairy farming managements: a system approach. *Journal of Grass and Forage Science*, **51**, 21–31.

Keisk, M., Ambus, P., Baritz, R., Bruggemann, N., Butterbach-bahl, K., Damm, M.,Duyzer, J., Hovarth, L., Kiese, R., Kitzler, B., Leip, A., Li, C., Pihlatie, M., Pilegaard, K., Seufert, G., Simpson, D., Smaiatek, G., Skiba, U., Vesala, T., and Zechmeisster-Boltenstern, S. (2006). Inventory of N_2O and NO emissions from European forest soils. *Biogeosciences. Journal of Physiological Research*, **111**, 353–375, GO2018.

Kormann, R. and Meixner, F.X. (2001). An analytical footprint model for non-neutral stratification. *Boundary-Layer Meteorology*, **99**, 207–224.

Laegreid, M. and Aastveit, A. (2002). Nitrous oxide emissions from field applied fertilizers. In: Petersen, S.O. and Olesen, J.E. (eds). Greenhouse gas inventories for agric. In the Nordic Countries, DIAS Report. Plant production no, 81. *Danish Institute of Agric. Journal of Sciences*, 122–134.

Lal, R. (1997). Residue management, conservation tillage and soil restoration for mitigation of the green house effect by CO_2–enrichment. *Soil & Tillage Research*, **43**, 18–107.

Leffelaar, P. and Wessel, W. (1988). Denitrification in a homogenous closed system: experiment and simulation. *Journal of Soil Science*, **146**, 335–349.

Leverenz, J.W. (1995). Shade shoot structure of conifers and the photosynthetic response to light at two CO_2 partial pressure. *Functional Ecology*, **9**, 413–421.

Li, C., Frolking, S., and Frolking, T. (1992). A model of nitrous oxide evolution from soil driven by rainfall events.1. Model structure and sensitivity. *Journal of Geophysical Research*, **97**, 9759–9776.

Linn, D. and Doran, J. (1984). Effect of water filled pore space on carbon dioxide and nitrous oxide production in tilled and non-tilled soils. *Soil Science Society of America Journal*, **48**, 1276–1272.

Lloyd, J. and Taylor, J. (1994). On the temperature dependence of soil respiration. *Functional Ecology*, **8**, 315–323.

Lopez, M., Arrue, J., and Sanchez-Giron, V. (1996). A comparison between seasonal changes in soil water storage and penetration resistance under conventional and conservation tillage systems in Aragon. *Soil and Tillage Research*, **37**, 251–271.

McGettigan, M., Duffy, P., Connolly, N., and O'Brien, P. (2006). Ireland National Inventory Report; Greenhouse Gas Emissions 1990-2004; Reported to the United Nations Framework Convention on Climate Change. Environmental Protection Agency, Johnstown Castle. Wexford. Ireland.

McSwiney, C. and Robertson, G. (2005). Non-linear response of N_2O flux to incremental fertilizer addition in a continuous maize (*Zea mays L.*) cropping system. *Global Change Biology*, **11**, 1712–1719.

McTaggart, J. and Smith, K. (1995). The effect of rate, form and timing of fertilizer N on nitrogen uptake and grain N content of spring malting barley. *Journal of Agricultural Sciences*, Cambridge, **125**, 341–353.

Moncrieff, J., Massheder, J., de Bruin, H., Elbers, J., Friborg, T., Heusinkveld, B., Kabat, P., Scott, S., Soegaard, H., and Verhoef, A. (1997). A system to measure surface fluxes of momentum, sensible heat, water vapour and carbon dioxide. *Journal of Hydrology*, **188–189**, 589–611.

Monson, R., Turnipseed A., Sparks, J., Harley, P., Scott-Denton, L., Sparks, K., Huxman, T. (2002). Carbon sequestration in a high-elevation, subalpine forest. *Global Change Biology*, **8**, 459–478.

Paustian, K., Six, J., Elliott, E.T., and Hunt, H.W. (2000). Management options for reducing CO_2 emissions from agricultural soils. *Biogeochemistry*, **48**, 147–163.

Pilegaard, K., Hummelshoj, P., Jensen, N.O., and Chen, Z. (1998). Identification of soil physical processes. *Soil Science Society of America Journal*, **60**, 740–747.

Raich, J. and Potter, C. (1995). Global patterns of carbon dioxide emissions from soils. *Global Biogeochemical Cycles*, **9**, 23–26.

Reichstein, M., Falge, E., Baldocchi, D., Papale, D., Aubinet, M., Berbigier, P., Bernhofer, C., Buchmann, N., Gilmanov, T., Granier, A., Grünwald, T., Havránková, K., Ilvesniemi, H., Janous, D., Knohl, A., Laurila, T., Lohila, A., Loustau, D., Matteucci, G., Meyers, T., Miglietta, F., Ourcival, J.-M., Pumpanen, J., Rambal, S., Rotenberg, E., Sanz, M., Tenhunen, J., Seufert, G., Vaccari, F., Vesala, T., Yakir, D. and Valentini, R. (2005) On the separation of net ecosystem exchange into assimilation and ecosystem respiration: review and improved algorithm. *Global Change Biology*, **11**, 1424–1439.

Rodegheiro, M. and Cescatti, A. (2005). Main determinants of forest soil respiration along an elevation/temperature gradient in the Italian Alps. *Global Change Biology*, **11**, 1024–1041.

Roldán, A., Caravaca, F., Hernández, M.T., García, C., Sánchez-Brito, C., Velásquez, M., and Tiscareño, M. (2003). No-tillage, crop residue additions, and legume cover cropping effects on soil quality characteristics under maize in Patzcuaro watershed (Mexico). *Soil & Tillage Research*, **72**, 65–73.

Ryden, J. (1981). N_2O exchange between a grassland soil and the atmosphere. *Nature*, **292**, 235–237.

Saggar. S, Giltrap. D.L., Li. C., and Tate, K.R. (2007). Modelling nitrous oxide missions from grazed grassland in New Zealand. *Agricultural Ecosystems and Environment*, **119**, 205–216

Scanlon, T. and Kiely, G. (2003). Ecosystem-scale measurements of nitrous oxide fluxes for an intensely grazed, fertilized grassland. *Journal of Geographical Research Letters*, **30**, 1852.

Schlesinger, W.H. (1997). *Biogeochemistry: An Analysis of Global Change*, 2nd edn, Academic Press, San Diego.

Schlesinger, W.H. and Andrews, J.A. (2000). Soil respiration and the global carbon cycle. *Biogeochemistry*, **48**, 7–20.

Schmid, M., Neftel, A., Riedo, M., and Fuhrer, J. (2001). Process-based modelling of nitrous oxide emissions from different nitrogen sources in mown grassland. *Journal of Nutrient Cycling of Agro-ecosystem*, **60**, 177–187.

Sehy, U., Ruser, R., and Munch, J. (2003). Nitrous oxide fluxes from maize fields: relationship to yield, site specific fertilization and soil conditions. *Agriculture, Ecosystems and Environment*, **99**, 97–111.

Smith, K., Claton, H., and McTaggart, I. (1995). The measurement of nitrous oxide emissions from soil using chambers. *Philosophical Transactions of the Royal Society of London*. Series A, **351**, 327–337.

Smith P., Powlson, D.S., Glendining, M.J., and Smith, J. (1998). Preliminary estimates of the potential for carbon mitigation in European soils through no-till farming. *Global Change Biology*, **4**, 679–685.

Smith P., Powlson, D.S., Smith, J., Falloon, P., and Coleman, K. (2000). Meeting Europe's climate change commitments: quantitative estimates of the potential carbon mitigation by agriculture. *Global Change Biology*, **6**, 525–539.

Smith, P., Falloon, P.D., Körschens, M., Shevtsova, L.K., Franko, U., Romanenkov, V., Coleman, K, Rodionova, V, Smith, J.U. and Schramm, G. 2002. EuroSOMNET - a European database of long-term experiments on soil organic matter: the WWW metadatabase. *Journal of Agricultural Science, Cambridge,* **138**, 123–134.

Stenger R., Priesack E., Barkle G., and Sperr, C. (1999). A tool for simulating nitrogen and carbon dynamics in the soil –plant –atmosphere systems. NZ land treatment collective. *Proceedings Technical Session 20: Modelling of land treatment systems*. M. Tomer, M. Robinson, G. Gielen (eds). New Plymouth, 14–15 October 1999, pp. 19–28.

Villamil, M., Bollero, G., Darmody, R., Simmons, F., and Bullock, D. (2006). No-till corn/soybean systems including winter cover crops: Effects on soil properties. *Soil Science Society of America*, **70**, 1936–1944.

Vitousek, P., Aber, J., Howarth, R., Likens, G., Matson, P., Schindler, D., Schlesinger, W., and Tilman, D. (1997). Human alteration of the global nitrogen cycle: causes and consequences. *Issues in Ecology*, **1**, 1–15.

Wan, S., and Luo, Y. (2003). Substrate regulation of soil respiration in a tallgrass prairie: results of a clipping and shading experiment. *Global Biogeochemical Cycles*, **17**, 1–12.

Whitehead, D.C. (1995). *Grassland Nitrogen*. Wallingford. CAB international. 397 p.

Williams, E., Hutchinson, G., and Feshsenfeld, F. (1992). NO_x and N_2O emissions from soil. *Global Biogeochemical Cycles*, **6**, 351–388.

Yang, X.M. and Kay, B.D. (2001). Rotation and tillage effect on soil organic carbon sequestration in a typic Hapludalf in Southern Ontario. *Soil & Tillage Research*, **59**, 107–114.

Zeleke, T., Grevers, M., Si, B., Mermut, A., and Beyene, S. (2004). Effect of residue incorporation on physical properties of the surface soil in the South Central Rift Valley of Ethiopia. *Soil & Tillage Research*, **77**, 35–46.

Acronyms and Annotations

CAN	Calcium ammonium nitrate
CON	Conventionally tilled plots
DNDC	DeNitrification DeComposition
EC	Eddy covariance
EFs	Emission factors
EPA	Environmental Protection Agency
GHGs	Greenhouse gases
NBP	Net biome productivity
NEE	Net ecosystem exchange
NIR	National Inventory Report
NIT	Non-inversion tillage plots
PAR	Photosynthetically active radiation
WFPS	Water-filled pore space

An Ghníomhaireacht um Chaomhnú Comhshaoil

Is í an Gníomhaireacht um Chaomhnú Comhshaoil (EPA) comhlachta reachtúil a chosnaíonn an comhshaol do mhuintir na tíre go léir. Rialaímid agus déanaimid maoirsiú ar ghníomhaíochtaí a d'fhéadfadh truailliú a chruthú murach sin. Cinntímid go bhfuil eolas cruinn ann ar threochtaí comhshaoil ionas go nglactar aon chéim is gá. Is iad na príomh-nithe a bhfuilimid gníomhach leo ná comhshaol na hÉireann a chosaint agus cinntiú go bhfuil forbairt inbhuanaithe.

Is comhlacht poiblí neamhspleách í an Ghníomhaireacht um Chaomhnú Comhshaoil (EPA) a bunaíodh i mí Iúil 1993 faoin Acht fán nGníomhaireacht um Chaomhnú Comhshaoil 1992. Ó thaobh an Rialtais, is í an Roinn Comhshaoil agus Rialtais Áitiúil a dhéanann urraíocht uirthi.

ÁR bhFREAGRACHTAÍ

CEADÚNÚ

Bíonn ceadúnais á n-eisiúint againn i gcomhair na nithe seo a leanas chun a chinntiú nach mbíonn astuithe uathu ag cur sláinte an phobail ná an comhshaol i mbaol:

- áiseanna dramhaíola (m.sh., líonadh talún, loisceoirí, stáisiúin aistrithe dramhaíola);
- gníomhaíochtaí tionsclaíocha ar scála mór (m.sh., déantúsaíocht cógaisíochta, déantúsaíocht stroighne, stáisiúin chumhachta);
- diantalmhaíocht;
- úsáid faoi shrian agus scaoileadh smachtaithe Orgánach Géinathraithe (GMO);
- mór-áiseanna stórais peitreail.
- Scardadh dramhuisce

FEIDHMIÚ COMHSHAOIL NÁISIÚNTA

- Stiúradh os cionn 2,000 iniúchadh agus cigireacht de áiseanna a fuair ceadúnas ón nGníomhaireacht gach bliain.
- Maoirsiú freagrachtaí cosanta comhshaoil údarás áitiúla thar sé earnáil - aer, fuaim, dramhaíl, dramhuisce agus caighdeán uisce.
- Obair le húdaráis áitiúla agus leis na Gardaí chun stop a chur le gníomhaíocht mhídhleathach dramhaíola trí comhordú a dhéanamh ar líonra forfheidhmithe náisiúnta, díriú isteach ar chiontóirí, stiúradh fiosrúcháin agus maoirsiú leigheas na bhfadhbanna.
- An dlí a chur orthu siúd a bhriseann dlí comhshaoil agus a dhéanann dochar don chomhshaol mar thoradh ar a ngníomhaíochtaí.

MONATÓIREACHT, ANAILÍS AGUS TUAIRISCIÚ AR AN GCOMHSHAOL

- Monatóireacht ar chaighdeán aeir agus caighdeáin aibhneacha, locha, uiscí taoide agus uiscí talaimh; leibhéil agus sruth aibhneacha a thomhas.
- Tuairisciú neamhspleách chun cabhrú le rialtais náisiúnta agus áitiúla cinntí a dhéanamh.

RIALÚ ASTUITHE GÁIS CEAPTHA TEASA NA HÉIREANN

- Cainníochtú astuithe gáis ceaptha teasa na hÉireann i gcomhthéacs ár dtiomantas Kyoto.
- Cur i bhfeidhm na Treorach um Thrádáil Astuithe, a bhfuil baint aige le hos cionn 100 cuideachta atá ina mór-ghineadóirí dé-ocsaíd charbóin in Éirinn.

TAIGHDE AGUS FORBAIRT COMHSHAOIL

- Taighde ar shaincheisteanna comhshaoil a chomhordú (cosúil le caighdéan aeir agus uisce, athrú aeráide, bithéagsúlacht, teicneolaíochtaí comhshaoil).

MEASÚNÚ STRAITÉISEACH COMHSHAOIL

- Ag déanamh measúnú ar thionchar phleananna agus chláracha ar chomhshaol na hÉireann (cosúil le pleananna bainistíochta dramhaíola agus forbartha).

PLEANÁIL, OIDEACHAS AGUS TREOIR CHOMHSHAOIL

- Treoir a thabhairt don phobal agus do thionscal ar cheisteanna comhshaoil éagsúla (m.sh., iarratais ar cheadúnais, seachaint dramhaíola agus rialacháin chomhshaoil).
- Eolas níos fearr ar an gcomhshaol a scaipeadh (trí cláracha teilifíse comhshaoil agus pacáistí acmhainne do bhunscoileanna agus do mheánscoileanna).

BAINISTÍOCHT DRAMHAÍOLA FHORGHNÍOMHACH

- Cur chun cinn seachaint agus laghdú dramhaíola trí chomhordú An Chláir Náisiúnta um Chosc Dramhaíola, lena n-áirítear cur i bhfeidhm na dTionscnamh Freagrachta Táirgeoirí.
- Cur i bhfeidhm Rialachán ar nós na treoracha maidir le Trealamh Leictreach agus Leictreonach Caite agus le Srianadh Substaintí Guaiseacha agus substaintí a dhéanann ídiú ar an gcrios ózóin.
- Plean Náisiúnta Bainistíochta um Dramhaíl Ghuaiseach a fhorbairt chun dramhaíl ghuaiseach a sheachaint agus a bhainistiú.

STRUCHTÚR NA GNÍOMHAIREACHTA

Bunaíodh an Ghníomhaireacht i 1993 chun comhshaol na hÉireann a chosaint. Tá an eagraíocht á bhainistiú ag Bord lánaimseartha, ar a bhfuil Príomhstiúrthóir agus ceithre Stiúrthóir.

Tá obair na Gníomhaireachta ar siúl trí ceithre Oifig:

- An Oifig Aeráide, Ceadúnaithe agus Úsáide Acmhainní
- An Oifig um Fhorfheidhmiúchán Comhshaoil
- An Oifig um Measúnacht Comhshaoil
- An Oifig Cumarsáide agus Seirbhísí Corparáide

Tá Coiste Comhairleach ag an nGníomhaireacht le cabhrú léi. Tá dáréag ball air agus tagann siad le chéile cúpla uair in aghaidh na bliana le plé a dhéanamh ar cheisteanna ar ábhar imní iad agus le comhairle a thabhairt don Bhord.

NDP
National Development Plan 2007 - 2013

Science, Technology, Research and Innovation for the Environment (STRIVE) 2007-2013

The Science, Technology, Research and Innovation for the Environment (STRIVE) programme covers the period 2007 to 2013.

The programme comprises three key measures: Sustainable Development, Cleaner Production and Environmental Technologies, and A Healthy Environment; together with two supporting measures: EPA Environmental Research Centre (ERC) and Capacity & Capability Building. The seven principal thematic areas for the programme are Climate Change; Waste, Resource Management and Chemicals; Water Quality and the Aquatic Environment; Air Quality, Atmospheric Deposition and Noise; Impacts on Biodiversity; Soils and Land-use; and Socio-economic Considerations. In addition, other emerging issues will be addressed as the need arises.

The funding for the programme (approximately €100 million) comes from the Environmental Research Sub-Programme of the National Development Plan (NDP), the Inter-Departmental Committee for the Strategy for Science, Technology and Innovation (IDC-SSTI); and EPA core funding and co-funding by economic sectors.

The EPA has a statutory role to co-ordinate environmental research in Ireland and is organising and administering the STRIVE programme on behalf of the Department of the Environment, Heritage and Local Government.

epa
Environmental Protection Agency
An Ghníomhaireacht um Chaomhnú Comhshaoil

ENVIRONMENTAL PROTECTION AGENCY
PO Box 3000, Johnstown Castle Estate, Co. Wexford, Ireland
t 053 916 0600 f 053 916 0699
LoCall 1890 33 55 99
e info@epa.ie w http://www.epa.ie

SSTI
Strategy for Science, Technology and Innovation

Comhshaol, Oidhreacht agus Rialtas Áitiúil
Environment, Heritage and Local Government