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Ecosystem Land Use Modelling & Soil C Flux Trial (ELUM)

Management & Deliverable Reference: PM06.3.3

Year 2 Report for Work Package 3 – Network of Field Sites to Measure Soil C Dynamics and GHG Emissions

REPORT

V2.0

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EXECUTIVE SUMMARY

This report describes the second year of Work Package 3 (WP3) activities within the ETI's Ecosystem Land Use Modelling Project ("ELUM"). It expands upon information reported in the first year and provides a forward look to WP3 activities for the remainder of the project.

The soil C (carbon) and GHG (Greenhouse Gas) measurements recorded as part of WP3 are required to help reduce the uncertainty associated with the sustainability of bioenergy crop deployment across the UK. This data will be used to parameterise and test the underlying process models in the WP4 modelling work, as part of the development of the over-arching meta-model. A full review of all the data collected across the WP3 network sites will be reported in the D3.5 deliverable due in May 2014.

Progress with the development and testing of novel methods for GHG measurement is also included in this report; these could offer means of improving monitoring resolution, thereby enhancing the collection of GHG flux data. A complete review of this work will follow in May 2014 with the D3.4 deliverable.

The deliverable and acceptance criteria for this report are as follows:

Deliverable D3.3:	A report to ETI on Year 2 WP3 activities: including brief description of approaches, description of analyses done (lab and summary stats (not full analysis)), and description and presentation of results, and lessons-learned and forward look to year 3. Data for year 1 and 2 (cumulative) provided in excel database on CD with report. Please note this report will include a) standard SOC data, b) GHG emissions, c) novel GHG technologies.
Acceptance Criteria:	A written report detailing the Year 2 WP3 activities. To include an introductory section outlining the Year 2 objectives. Field SOC and GHG measurement data from the Network Sites to be presented in tables and graphs and summarised using appropriate statistics. Additional environmental data i.e. soil moisture, temperature and rainfall to be included. Datasets to incorporate Year 1 data. Datasets must be suitable for WP4 modelling. For novel SOC and GHG studies an overview of the methods employed, the results of, and the success of these activities will be covered. All data must be provided in an excel database with clear metadata for data archiving and dissemination through NERC/CEH EIDC Information Gateway. A concluding section will review all results and discuss Year 3 plan.

Measurements continued at the four network sites, reported in the year 1 report (PM04.3.2_WP3 Year 1 Report). Additional eddy covariance instruments have been installed at the Aberystwyth, West Sussex and Lincolnshire sites. Collecting the information about the management of the crops is ongoing to capture the current practises. Continuous meteorological measurements were made at all sites and are ongoing. These data have yet to be completely quality-controlled (QC) and gap-filled; this is anticipated to be complete by end of June 2013 for the data reported here, and will be complete for all data by the start of 2014.

Soil C measurements were made under WP2 and have been completed (Section 3). These data are required to underpin the modelling activities in combination with the GHG datasets.

The measurements of plant litter were also completed. These show that, for the transition from arable to bioenergy crops, the bioenergy crops studied here have more litter, but the situation for the grass to bioenergy crops is more variable.

The monthly measurements of soil GHG emissions and ancillary data (soil water content, soil temperature and air temperature) continued (Section 4.1). For all land cover types, CO_2 emissions contribute most to the global warming potential (GWP). N_2O emissions were generally low, except in the case of the arable crops; CH_4 emissions were low for all land covers.

Eddy covariance measurements (capable of measuring the land-surface CO_2 balance at the field scale), are being made at eight sub-sites across the four network sites (Section 4.2). These data have not been completely processed, QC and gap-filled; however, the initial results show that the data is of good quality and that there are differences between the different land cover types, e.g. winter wheat had higher productivity and respiration (May-August) than the *Miscanthus* or SRC willow at the Lincolnshire network site.

Work on advancing novel technologies for measuring GHG emissions from the land surface has continued. In Year 1 it was demonstrated that the concept was viable in the laboratory. In Year 2 the equipment was scaled up in size and tested at York University against measurements from conventional systems which confirmed that the measurements with the new system were comparable. The equipment was then deployed over a *Miscanthus* crop at the Lincolnshire field site and again demonstrated that it was viable, picking up diurnal variations in GHG fluxes.

The ^{13}C pulse labelling of *Miscanthus* and Willow at Lincolnshire has been completed and the majority of gas samples have been analysed. Instruments are now being configured to analyse for ^{13}C in plant and soil material. Emerging results suggest that more C was retained by *Miscanthus* compared to Willow at the time of the experiment.

Work on collating and designing the database, with assistance from the University of Aberdeen, is ongoing. Spreadsheets have been developed for the monthly soil GHG measurements and ancillary data, and a prototype spreadsheet has been developed for the meteorological data. Discussions are ongoing for other data types.

Year 2 activities have met all expectations, i.e. there have been no unexpected results, and so there are no recommendations for significant changes to the plans for Year 3.

The plans for Year 3 are to continue with the monthly soil GHG and ancillary data measurements, the meteorological and hydrological measurements and the eddy covariance measurements. These will all be processed, QC and, where appropriate, gaps filled. They will also be analysed to deepen our understanding of the underlying processes and mechanisms that determine the changes in Soil Organic Carbon (SOC) stocks and GHG emissions.

References to other ELUM Reports

The reader’s attention is drawn to the following additional ELUM reports which are referred to in this report:

- PM01.2.1_Chronosequence Report
- PM04.2.2_WP2 Year 1 Chronosequence Report
- PM06.2.3_WP2 Year 2 Chronosequence Report
- PM04.3.2_WP3 Year 1 Report

CONTENTS

1. INTRODUCTION

The overall objective of WP3 is to establish a network of existing and new measurement field sites in the UK, which will deepen our understanding of the underlying processes and mechanisms that determine the changes in SOC stocks and GHG emissions. This will be realised by a programme of simultaneous measurements of soil C dynamics, and turnover and GHG emissions will be made at all sites over a two-year period. It will improve the quantitative description required for parameterisation of the Land-use Change (LUC) meta model (WP4). The overall objective will be achieved through four tasks:

- ***Task 3.1:*** Develop a UK-wide set of experimental field sites to quantify SOC dynamics and GHG flux under bioenergy crops.
- ***Task 3.2:*** Quantify all background and emerging data (meteorology, hydrology) direct effects of LUC and management for these sites under different bioenergy crops on the ecosystem to provide essential inputs to the models.
- ***Task 3.3:*** Generate a mechanistic understanding of LUC/crop management impacts on soil C dynamics and storage and identify indicators for sustainable carbon sequestration under dedicated bioenergy crops to facilitate the evaluation of WP4 models.
- ***Task 3.4:*** Generate experimental data on GHG emissions at different levels of detail that will facilitate the development and evaluation of the LUC/crop management model with respect to its capacity to quantify GHG losses and mitigation potential in WP4, and to quantify uncertainty of up-scaled measurements on commercial field sites.

Table 1 gives a summary of the Year 1 and Year 2 objectives, as defined in the Technical Contract, and their status at the end of that year.

Table 1: Status of Year 1 and Year 2 WP3 Objectives

Objective	End of year 1 Status	End of year 2 Status
To select sites for the network	Complete	
To establish protocols for monthly chamber GHG determination and associated measurements	Complete	
To install any instrumentation required at the sites	Ongoing	Complete
To make measurements of soil GHG and ancillary data at monthly intervals	Ongoing	Ongoing
To make eddy covariance (EC) and meteorological measurements	Ongoing	Ongoing
To deliver a 13C pulse labelling experiment at the Lincolnshire network site		Ongoing
To collate appropriate site details required for WP4 modelling	Ongoing	Ongoing
To summarise the results and highlight lessons learnt to be applied to subsequent measurements to improve their quality	Ongoing	Ongoing

WP3 activities are being undertaken at six network sites, each with a number of sub-sites which consist of a single land cover.

The measurements being made at all the sub-sites are: monthly chamber measurements of soil GHG emissions (CO_2, CH_4 and N_2O) and monthly measurements of ancillary data (air temperature and soil water content). Continuous measurements of meteorological variables are being made at each network site. In addition, at selected network sub-sites, continuous measurements are being made of the CO_2 fluxes, using the eddy covariance method. In WP2, one-off measurements of the soil carbon (C) stocks are being made at each sub-site, and the results are included here for completeness. Litter input at each sub-site is being quantified and will be completed by January 2014. Due to the diversity of activities in this work package, summary analyses can be found in each report section.

Progress with the development and testing of novel methods for GHG measurement is included in this report; these could offer means of improving monitoring resolution, thereby enhancing the collection of GHG flux data. Also included is an account of a pulse labelling experiment that was conducted at the Lincolnshire site during August 2012.

This report incorporates samples collected during 2012, and the raw measurements made throughout 2012, allowing time for laboratory analysis of the samples and data processing and QC of measurements to be carried out. Similarly only a simple, summary analysis of these data is included here. Data recorded in 2013 will be included in the Y3 report.

Note that throughout this report the term *Miscanthus* refers to the variety *Miscanthus x giganteous* unless otherwise qualified.

The structure of this report reflects these tasks. Section 2 provides a brief description of the field sites and the meteorological data for 2013. The soil C and its dynamics for the network sites are described briefly in Section 3, since this work is being delivered through WP2. Section 4 deals with quantifying the GHG emissions and consists of four sub-sections. The first three deal with measurements: soil GHG fluxes, ancillary data and eddy covariance, whilst the fourth describes the development of novel GHG measurement technologies. Section 5 describes the collation of the database. Finally, the conclusions are presented in Section 6 and plans for the third project year are described in Section 7.

2. THE NETWORK SITES

WP3 measurements are being conducted at a network of four sites that are a mix of commercial and experimental operations, located in England, Scotland and Wales (Figure 1) and including five land covers (Table 2). Due to resource constraints the project is not attempting to follow the transition from one land cover to another, with the exception of Aberystwyth sub-site A. Instead, measurements are being made on existing land covers in order to quantify the differences in soil C and GHG emissions to inform the modelling in WP4, which will be capable of simulating the transitions. For example, at the Lincolnshire network site, measurements are informing the transitions from arable to *Miscanthus* or SRC willow, *Miscanthus* to arable or SRC willow, and SRC willow to arable or *Miscanthus*.

Two of the sites already existed - East Grange, Fife (FR) and Lincolnshire (CEH) - and have been augmented for the ELUM project. As an example, soil GHG measurements were not being made at either of the sites although some spot measurements had been made in the past. At Forest Research's East Grange site, eddy covariance (EC) measurements were being made over SRF and will now also be made over SRC willow by CEH. At the Lincolnshire commercial farm site, EC measurements were being made by CEH over *Miscanthus* and SRC willow, and a third EC system has now been added in an adjacent arable field. Aberystwyth sub-sites A and B is a newly established site on a grass field that has been converted to *Miscanthus* as part of the University's research programme. West Sussex is a new site, on a commercial farm, and has been established by the University of Southampton on grass and SRC willow. Between them, these sites achieve the aim of covering a range of "conventional" land uses (e.g. arable, pasture), second generation bioenergy crops, climates and soils. In addition, measurements of soil GHGs are being made at Aberystwyth sub-site C which consists of a series of trial plots of *Miscanthus* genotypes. The planned periods of GHG measurements using chambers and eddy covariance are shown in Figure 2.

Table 2: The location and land cover at the network sites

Network site	Sub-site	Land use	Latitude	Longitude
Aberystwyth, West Wales	A	*Miscanthus*	52°25'17" N	4° 04'14" W
	B	grass	52°25'17" N	4° 04'14" W
	C	*Miscanthus* genotype trial plots	52°24'06.2" N	4° 02'11.8" W
East Grange, Fife	A	SRF	56°05'19.4" N	3°37'33.1" W
	B	grass	56°05'19.4" N	3°37'33.1" W
	C	SRC willow	56°04'58.8" N	3°37'11.0" W
	D	arable	56°04' 48.0" N	3° 37' 37.6"W
West Sussex	A	SRC willow	50°58'49.3" N	0°27'03.7" W
	B	grass	50°58'35.3" N	0°27'20.9" W
Lincolnshire	A	*Miscanthus*	53°19′ 11.8″ N	0° 35′ 15.4″ W
	B	SRC willow	53°19′ 11.2″ N	0° 35′ 03.3″ W
	C	arable	53°19′ 19.3″ N	0° 35′ 04.3″ W

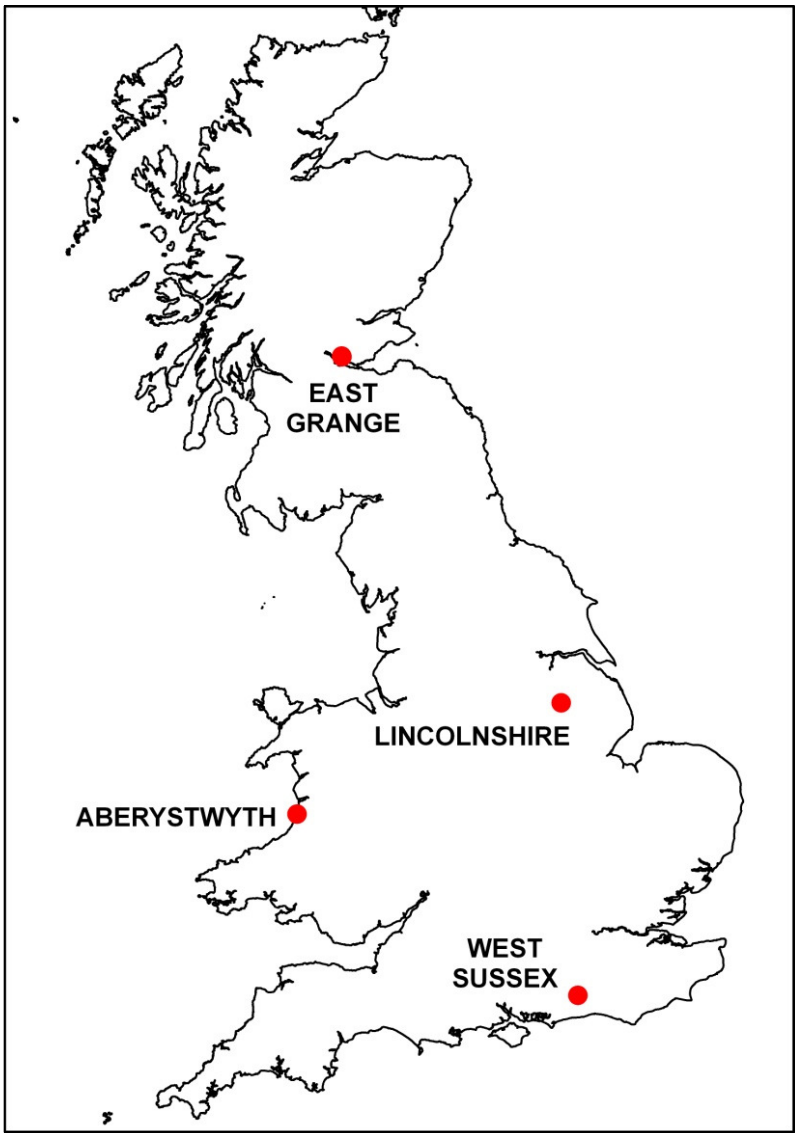


Figure 1: Location of the network sites

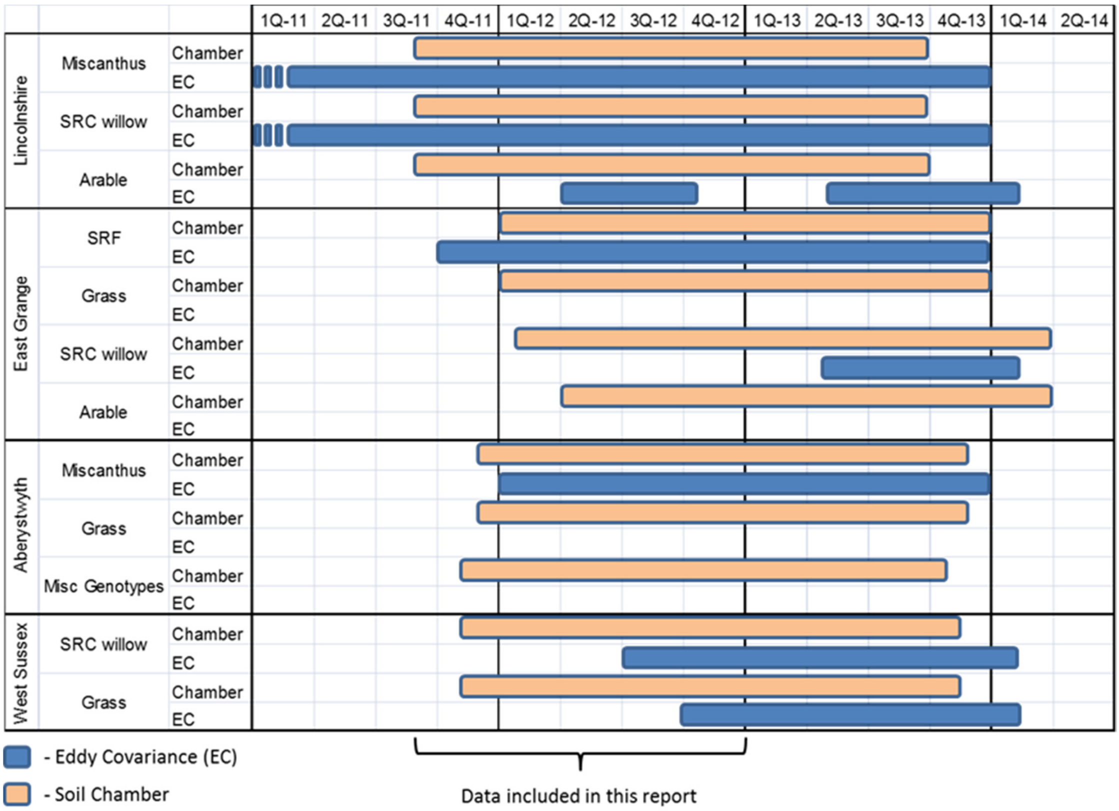


Figure 2: Time lines for the eddy covariance and GHG chamber measurements across the networks sites

2.1 Quantify all Background and Emerging Data

The management history for each site was captured and documented in the earlier ELUM report (PM04.3.2_WP3 Year 1 Report), with the exception of the arable sub-site at Lincolnshire: this will be addressed during the coming year. Other data collection at the network sites is ongoing (e.g., dates and yields of the bioenergy crop harvests) as and when appropriate.

2.2 Meteorological Data

Meteorological variables are being measured at all four sites. These data have yet to be fully quality-controlled and gaps filled. Nevertheless, they clearly show the seasonal cycle of the downward global solar radiation and air temperature, Figure 3. They also show the remarkable rainfall conditions during 2012 which was the second wettest such time series since these records began in 1910 (Met Office, 2013). At all four sites, the first three months of the year had below-average rainfall but the remainder of the year was marked by above-average rainfall.

The impact of the rainfall on ELUM project measurements was indirect, since the impact was primarily through associated land management issues. For instance, at the Lincolnshire site the ground conditions meant that farm vehicles could not get on to the arable field to plant a new crop. For the ELUM project, this challenge was resolved by moving the measurements to an adjacent arable field in spring 2013. At East Grange, the harvest of the SRC willow has been delayed until July 2013 with the result that eddy covariance instruments were not deployed until March 2013 due to initial weather-related uncertainty around the date of harvest.

Gaps in the meteorological data have resulted from problems with either the power supply, which tends to affect all the instruments, or specific instruments themselves. For instance, there were problems with the raingauge at West Sussex so that no data were obtained in 2012; this graph has not been included.

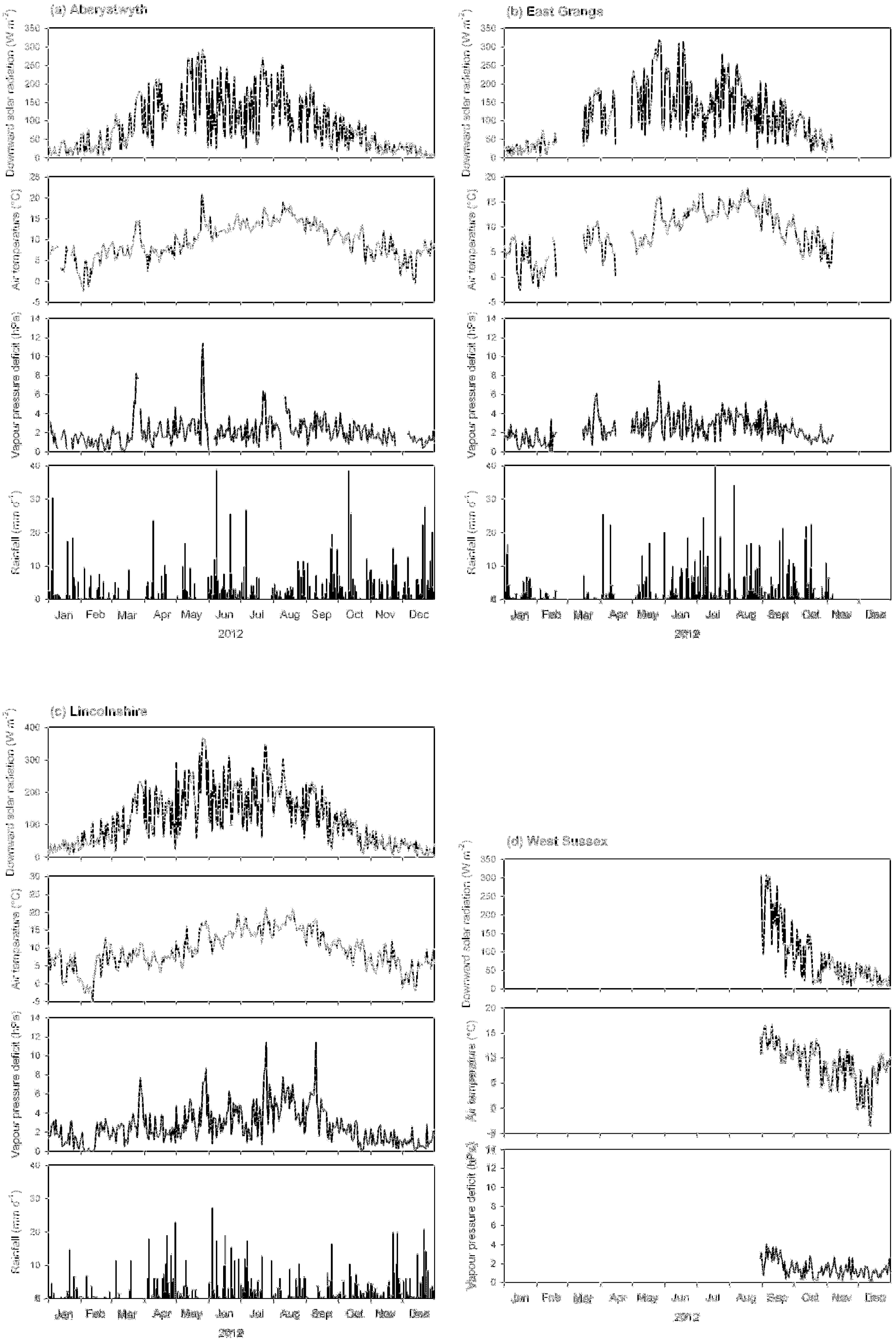


Figure 3: Daily average time series of selected meteorological variables measured at the field sites during 2012

3. ESTIMATING THE SOIL CARBON STOCK AND DYNAMIC

3.1 Quantify soil carbon stocks under bioenergy crops

Soil properties of %C, %N, bulk density (BD) and pH were estimated for each sub-site at each network site, down to a depth of 0.3 m (at intervals of 0-15 cm and 15-30cm - Table 3) and soil C stocks were estimated down to a depth of 1 m (at intervals of 0-30 cm, 30-50 cm and 50-100 cm - Table 4). These results were delivered through WP2 and the methods used are described in the deliverable D2.2 report. Sampling of most of the WP3 network sites took place in Year 2 of the WP2 chronosequence sampling (ELUM report PM06.2.3_WP2 Year 2 Chronosequence Report), with the exception of Lincolnshire which was completed in year 1 (ELUM report PM04.2.2 - WP2 Year 1 Chronosequence Report). Soil C stocks were estimated from 1 m deep cores obtained using a pneumatic coring device (Table 4). The results are required for the WP4 modelling activity. The impact of land-use change on soil C stocks is considered more fully as part of WP2 activity, where the effects are being evaluated at ca.100 field sites across the UK, 5 of which are also network sites, Lincolnshire, East Grange (two sites: SRC and SRF), west Sussex and Aberystwyth (excluding the genotype trials) the remaining sites being privately owned commercial bioenergy plantations, or in the case of SRF, a combination of experimental and commercial sites.

Table 3: Mean (± SD) %C (n=15) and %N (n=15) in fine soil, soil bulk density (n=15) and pH values (n=5) for all network sites at 0-15 cm and 15-30 cm depths *

	Total C (%)		**Total N (%)**		**Bulk Density (kg m^{-3})**		**pH**	
Network site / Sub site	**0-15 cm**	**15-30 cm**	**0-15 cm**	**15-30 cm**	**0-15 cm**	**15-30 cm**	**0-15 cm**	**15-30 cm**
Aberystwyth								
Miscanthus (A)	5.68 (0.62)	4.06 (1.03)	0.59 (0.04)	0.47 (0.07)	0.59 (0.12)	1.03 (0.12)	6.65 (0.07)	6.65 (0.09)
Grass(B)	6.19 (1.20)	4.11 (1.05)	0.63 (0.10)	0.49 (0.10)	0.63 (0.16)	1.06 (0.12)	6.44 (0.13)	6.36 (0.19)
East Grange								
SRF (A)	1.95 (0.52)	1.75 (0.52)	0.24 (0.08)	0.21 (0.05)	1.18 (0.11)	1.53 (0.08)	6.50 (0.2)	6.64 (0.18)
Grass (B)	2.24 (0.22)	1.90 (0.27)	0.23 (0.02)	0.22 (0.02)	1.20 (0.09)	1.52 (0.05)	6.74 (0.07)	6.82 (0.07)
SRC Willow (C)	3.02 (0.43)	2.81 (0.49)	0.22 (0.02)	0.22 (0.02)	1.10 (0.10)	1.38 (0.05)	6.07 (0.23)	6.11 (0.20)
Arable (D)	2.08 (0.21)	2.01 (0.25)	0.24 (0.02)	0.23 (0.02)	1.04 (0.16)	1.38 (0.08)	6.83 (0.04)	6.85 (0.09)
West Sussex								
SRC Willow (A)	1.72 (0.33)	1.06 (0.24)	0.19 (0.05)	0.15 (0.05)	1.13 (0.14)	1.49 (0.07)	6.04 (0.25)	6.25 (0.21)
Grass (B)	3.02 (0.63)	1.10 (0.37)	0.28 (0.04)	0.16 (0.02)	0.97 (0.15)	1.52 (0.03)	6.81 (0.23)	6.96 (0.15)
Lincolnshire								
Miscanthus (A)	1.81 (0.37)	1.54 (0.35)	0.29 (0.03)	0.26 (0.03)	1.38 (0.21)	1.49 (0.14)	7.35 (0.20)	7.42 (0.21)
SRC Willow (B)	1.71 (0.34)	1.11 (0.21)	0.26 (0.03)	0.22 (0.03)	1.36 (0.17)	1.48 (0.19)	6.71 (0.13)	6.80 (0.25)
Arable (C)	1.89 (0.29)	1.71 (0.26)	0.29 (0.04)	0.29 (0.03)	1.13 (0.17)	1.41 (0.15)	6.60 (0.13)	6.76 (0.17)

* (n=15) refers to the number of soil cores per sub-site: i.e., 5 sampling plots x 3 cores. This sampling strategy is explained in the WP2 report (PM01.2.1 – Chronosequence Report). (n=5) refers to the same samples which have been bulked together.

Table 4: Tonnes of C stored in soil at each network site to 1 m (n=3 in each case). Values for Average Core Depth are mean +/- standard deviation.

	Carbon (t ha^{-1})			
Network site / Sub site	**0-15 cm**	**15-30 cm**	**0-100 cm**	**Average Core depth (cm)**
Aberystwyth				
Miscanthus (A)	48.61 (11.49)	52.58 (16.59)	130.62 (16.76)	78* (9.5)
Grass (B)	56.19 (17.44)	53.01 (6.96)	108.86 (12.13)	74.5 (13.8)
East Grange				
SRF (A)	33.59 (6.85)	38.93 (10.11)	123.88 (10.68)	100 (0)
Grass (B)	40.20 (5.39)	43.01 (5.19)	181.52 (21.32)	100 (0)
SRC Willow (C)	49.54 (9.28)	57.82 (8.91)	164.22 (21.61	100 (0)
Arable (D)	32.33 (6.14)	40.77 (5.64)	179.42 (8.04)	100 (0)
West Sussex				
SRC Willow (A)	28.83 (5.34)	23.51 (4.49)	81.96 (13.50)	100 (0)
Grass (B)	43.14 (8.37)	24.66 (8.29)	67.56 (7.63)	100 (0)
Lincolnshire**				
Miscanthus (A)	33.38 (4.72)	36.01 (5.73)	256.85 (93.4)	95.7 (7.5)
SRC Willow (B)	24.43 (4.90)	34.64 (4.87)	157.13 (62.37)	78 (19.1)
Arable (C)	36.33 (6.94)	31.92 (7.61)	193.78 (40.72)	100 (0)

* Not all cores reached 1m due to large stones or bedrock. Within WP2 comparison between sites for metre core data is done of cumulative soil mass thus avoiding issues related to short cores (see D2.2 and 2.3). Modellers in WP4 employ similar methods to adjust for cores under 1 m in length.

** Higher levels of variability are within ranges seen in sites across the UK within WP2, although are larger than other sites within the network. In addition, currently only 3 cores per site are taken therefore levels of variability across individual fields has not been fully assessed; it is therefore difficult to qualify “large” or “small” SD (see ELUM WP2 Reports PM04.2.2_Year 1 Chronosequence Report and recently submitted PM06.2.3_WP2 Year 2 Chronosequence Report for detailed discussion).

3.2 Quantify Plant Litter under Bioenergy Crops

The quantity of litter from each of the crops in each network site was determined through WP2 at the time of soil sampling using 0.25 m^2 quadrats. Table 5 gives an overview of the quantity of litter and coarse wood debris from each network site.

As the longest established site, Lincolnshire bioenergy crops show the highest levels of litter and woody debris compared to the other network sites. For sites with an arable to bioenergy transition (Lincolnshire and East Grange C and D), the arable has less litter debris and no coarse woody debris (as expected) compared to the bioenergy crops. For the three sites of grass to bioenergy conversion (Aberystwyth, West Sussex and East Grange A and B) the results are mixed: the grass at West Sussex had a lower amount of litter compared to the bioenergy crop whereas, at the other two sites, the grass had more litter. This is likely to be due to the difference in the age of the bioenergy crops and species differences. Site information can be found in the earlier ELUM Report (PM04.3.2_WP3 Year 1 Report).

Table 5: Mean (±SD, n=15) litter mass in each network site

		Litter (t dry mass ha^{-1})	
Network site / Sub site	**Date planted**	**Leaf/Undifferentiated**	**Coarse Woody**
Aberystwyth			
Miscanthus (A)	2012	0.17 (0.08)	0
Grass (B)	2006	0.25 (0.13)	0
East Grange			
SRF (A)	2009	0.37 (0.27)	0.16 (0.57)
Grass (B)		1.27 (3.46)	0
SRC Willow (C)	2009	0.82 (0.31)	0.14 (0.13)
Arable (D)	At least 10 years old	0.57 (0.53)	0
West Sussex			
SRC Willow (A)	2007	1.60 (0.70)	0.04 (0.07)
Grass (B)	2000	0.18 (0.11)	0
Lincolnshire			
Miscanthus (A)	2006	4.51 (2.98)	3.17 (2.02)
SRC Willow (B)	2000	3.36 (2.11)	2.30 (1.49)
Arable (C)	At least 20 years old	0.82 (0.36)	0

4. QUANTIFYING GHG EMISSIONS

4.1 Soil GHG Fluxes

Soil GHG fluxes were measured on a monthly basis from each of the network sites using the protocols outlined in Appendix 1 of the Year 1 report (ELUM Report - PM04.3.2_WP3 Year 1 Report). To summarise: soil CO_2 fluxes were measured close to the static chamber location using an infra-red gas analyser (IRGA) connected to an SRC-1 chamber. Measurements of soil CH_4 and N_2O fluxes were made using a static chamber method (approx 30 litres) with the addition of a vent to compensate for pressure changes within the chamber during times of sampling. Chambers were enclosed for approximately 50 minutes, with four measurements taken over this time. Gas samples from Lincolnshire, West Sussex and Aberystwyth (both experimental sub-sites) were analysed by gas chromatograph (GC) at CEH Lancaster; CEH Edinburgh and Forest Research analysed their own samples by GC from the East Grange sub-sites (Table 6, Figure 5, Figure 6, Figure 7). Ancillary data consists of measurements of volumetric soil moisture (Theta probe, 0-6 cm) and of air and soil temperature (Stab probe, 0-10 cm depth). The protocols for these measurements were reviewed but no justification for any changes was found. These measurements have been taken from all network sites at the time of sampling and the results are shown in Figure 8. Statistical differences between soil fluxes (CO_2, CH_4 and N_2O) and different land-use types were determined using linear mixed-effects models with ‘date’ and ‘field location’ (chamber) as random effects to account for repeated measures over time. Significant differences were accepted when $p<0.05$.

4.1.1 Arable vs. Bioenergy Fluxes

Two of the network sites - Lincolnshire and East Grange (C and D) - have an arable to bioenergy land-use change. The Lincolnshire site comprises of two transitions; arable to *Miscanthus* and arable to SRC willow, where the arable crop (wheat-oil seed rape rotation) represents the previous land use to bioenergy crops. The East Grange site has a transition from arable to SRC willow, where the arable field is a barley crop, again representing the previous land use.

The soil GHG emissions (CO_2, CH_4 and N_2O) from soils at both these sites were measured on a monthly basis (Figure 5) along with ancillary data (Figure 8a, b). For each month sampled, soil gas fluxes are presented as CO_2 equivalents (eq.) using the using global warming potentials (GWP) of 25 and 298 for CH_4 and N_2O respectively (IPCC, 2007). At both network sites, it is clear the soil CO_2 fluxes contribute the most to the overall GWP of the bioenergy crops, with only a very small contribution from CH_4 and N_2O fluxes. The soil CO_2 fluxes (from both sites) followed a seasonal pattern, with the highest fluxes found over the summer months. At Lincolnshire, in particular, soil moisture content was close to 50% in July 2012, which may have had a negative impact (reduced) soil CO_2 fluxes through reducing aeration to the roots, preventing respiration and restricting diffusion of CO_2 through the soil. This will become clearer with further analysis. In both the arable crops, soil N_2O emissions contributed more to the mean monthly flux than the bioenergy crops and this is especially evident at the East Grange site, where on two occasions, N_2O fluxes contributed more than half of the mean monthly GWP.

The soil CO_2 fluxes from both bioenergy crops at the Lincolnshire site were significantly different ($p<0.05$) to that of the arable control (Table 6). For *Miscanthus* and SRC willow, average annual fluxes were 49.5 and 77.2 mg CO_2-C m^{-2} h^{-1} respectively, compared to 66.9 mg CO_2-C m^{-2} h^{-1} from the arable control, making *Miscanthus* fluxes significant lower and SRC willow fluxes significantly higher than the arable control. This was different at the East Grange site, which showed no significant difference in soil CO_2 fluxes between the SRC willow and the arable control. This may be due to fewer measurements taken in the arable crop compared to the SRC willow due to limited access to the field during times of harvest and ploughing, breakdown of instruments and bad weather. At both network sites, average annual soil CH_4 fluxes from bioenergy crops were not significantly different ($p>0.05$) to that of the arable control and all (bioenergy and control crops) fluxes ranged from -4.7 to 0.8 µg CH_4-C m^{-2} h^{-1} (Table 6). Negative CH_4 fluxes indicate methane oxidation. CH_4 is used by certain soil organisms as a C source and in aerobic conditions is broken down into various end products. In this way soils can act as a sink for CH_4. The average annual soil N_2O fluxes from the arable crops at both sites were significantly larger ($p<0.05$) than those from the bioenergy crops, especially at the East Grange site, with an average annual flux of 79.1 compared to 0.6 µg N_2O-N m^{-2} h^{-1} from SRC willow (Table 6). This is likely to be as a result from fertiliser additions to the arable crops, since the bioenergy crops are not N fertilised.

The overall GWP suggest that *Miscanthus* has a significantly lower GWP ($p<0.01$) and SRC willow has a significantly higher GWP ($p<0.05$) than the arable control. However, at East Grange the GWP of SRC willow was significantly lower ($p<0.05$) than that of the arable crop. The difference between the SRC willow results may be linked to the timing of fertiliser addition and the proximity of measurements to fertiliser application. This will be investigated further when all site management details have been collected.

4.1.2 Grass vs. Bioenergy Fluxes

Three network sites compared grass to bioenergy crop transitions, where grass was the previous land use: West Sussex - grass to SRC willow; East Grange (A and B) - grass to SRF; and Aberystwyth - grass conversion to *Miscanthus*. Soil gas fluxes are presented as CO_2 eq. in Figure 6 and ancillary data (air temperature and soil moisture) is presented in Figure 8c,d,e.

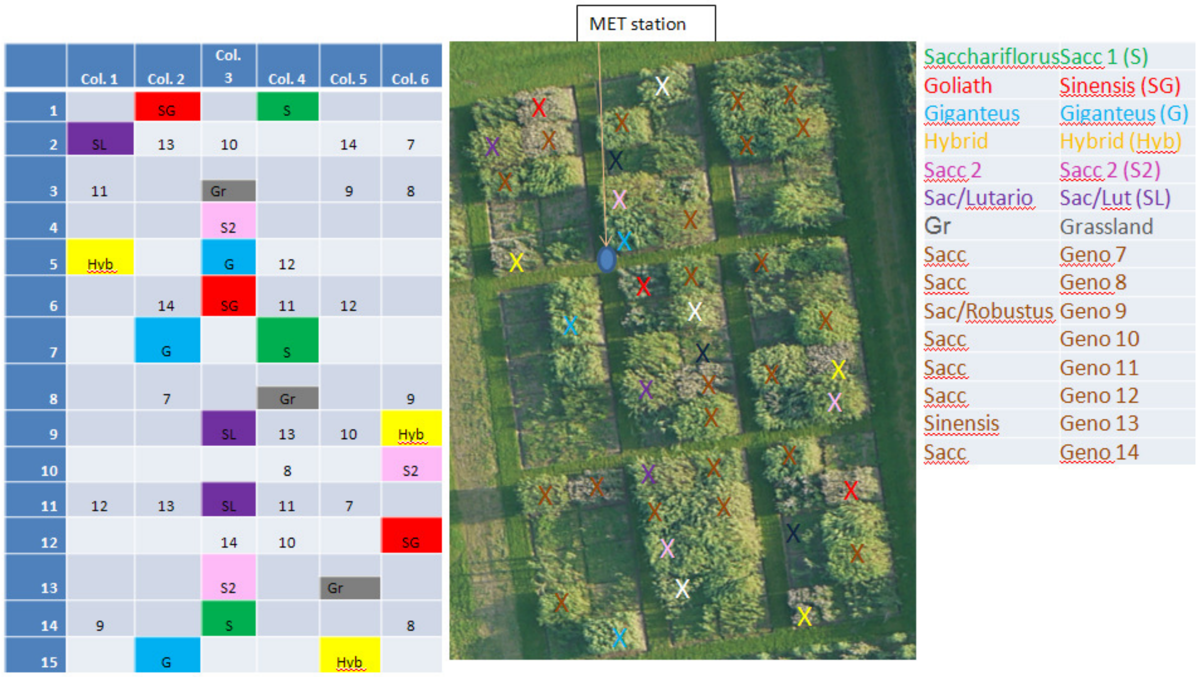
For transitions to SRF and SRC willow from grass, soil CO_2 fluxes were the main contributor to the monthly GWP, with N_2O and CH_4 contributing very little to the monthly GWP (Figure 6). The transition to *Miscanthus* showed the largest contribution to monthly GWP from N_2O shortly after planting and then soil CO_2 fluxes became the main contributor from Jul-12 onwards (Figure 6b). Soil CO_2 fluxes largely followed a seasonal pattern at all sites with fluxes generally increasing with increased air temperature. The main drivers of soil CO_2 flux will become clearer with the final analysis. Across all network sites, soil CH_4 fluxes contributed approximately 1% to the monthly GWP and on many occasions monthly fluxes were negative, indicating CH_4 oxidation in soils (Figure 6). For the SRF (East Grange) and SRC willow (West Sussex), soil N_2O emissions were minimal, and ranged from 0.24-3.69 and 0.53-7.63 mg CO_2 eq. m^{-2} h^{-1}, respectively (Figure 6). At all network sites, the grass control showed soil CO_2 flux to contribute the most to average monthly GWP. Soil CH_4 fluxes contributed less than 2% to the total monthly GWP at all network sites and was often negative, suggesting CH_4 oxidation in soils. N_2O emissions were highest from the grass at Aberystwyth and at times, contributed nearly 30% (Jan-12) to the total monthly GWP. At the other network sites, soil N_2O emissions contributed, on average, less than 2% to the monthly GWP.

At all three network sites, soil CO_2 fluxes from bioenergy crops were significantly different ($p<0.05$) to that of the grass control (Table 6). In all cases, annual soil CO_2 fluxes were less in the bioenergy crops compared to the control by 60.8, 11.9 and 93.9 mg CO_2-C m^{-2} h^{-1} for West Sussex, East Grange and Aberystwyth respectively. At West Sussex (SRC willow) and East Grange (SRC willow), soil CH_4 fluxes were significantly lower ($p<0.05$) than the control and in the case of West Sussex, soil CH_4 flux moved from a positive flux (production) in the grass, to a negative flux (oxidation) in SRC willow. There was no significant difference in annual average soil CH_4 flux ($p>0.05$) found between *Miscanthus* and grass control at Aberystwyth. There was no significant difference ($p>0.05$) in soil N_2O fluxes between bioenergy and control at West Sussex and East Grange but there was at Aberystwyth ($p<0.05$). The *Miscanthus* at Aberystwyth had an annual average soil N_2O flux of 147 compared to 37 µg N_2O-N m^{-2} h^{-1} of the control, and although this was an annual difference, this can largely be attributed to the large contribution of soil N_2O emissions to the monthly GWP in May-12 and Jun-12.

The overall GWP (CO_2 + CH_4 eq. + N_2O eq.) for grass to bioenergy conversions suggests that in all cases, bioenergy crops have a significantly lower ($p<0.01$) GWP than the grass control (Table 6). The largest difference in GWP between bioenergy crop and control was seen at Aberystwyth (301.4 mg CO_2 eq. M^{-2} h^{-1}), followed by West Sussex (224.4 mg CO_2 eq. m^{-2} h^{-1}) and East Grange (43.9 mg CO_2 eq. m^{-2} h^{-1}).

4.1.3 Genotype Plots

The genotype plots at Aberystwyth compare soil GHG emissions from four different genotypes of *Miscanthus* with a grass control (Figure 4).



	Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6
1		SG		S		
2	SL	13	10		14	7
3	11		Gr		9	8
4			S2			
5	Hyb		G	12		
6		14	SG	11	12	
7		G		S		
8		7		Gr		9
9			SL	13	10	Hyb
10				8		S2
11	12	13	SL	11	7	
12			14	10		SG
13			S2		Gr	
14	9		S			8
15		G			Hyb	

Sacchariflorus	Sacc 1 (S)
Goliath	Sinensis (SG)
Giganteus	Giganteus (G)
Hybrid	Hybrid (Hyb)
Sacc 2	Sacc 2 (S2)
Sac/Lutario	Sac/Lut (SL)
Gr	Grassland
Sacc	Geno 7
Sacc	Geno 8
Sac/Robustus	Geno 9
Sacc	Geno 10
Sacc	Geno 11
Sacc	Geno 12
Sinensis	Geno 13
Sacc	Geno 14

Figure 4: Photograph and location of all genotype plots. Genotypes used in experiment are: Sinensis (SG), Sacc 1 (S), Giganteus (G), Hybrid (Hyb) and grass (Gr)

Monthly gas fluxes are presented as CO_2 eq. for CH_4 and N_2O respectively (Figure 7) and monthly ancillary data is presented in Figure 8f. As yet, there are no clear differences emerging between the different genotypes (Figure 7) and no significant differences ($p>0.05$) were found between any of the genotypes and the control in CO_2, CH_4 and N_2O fluxes from soils (Table 6). It is evident that soil CO_2 emissions contributed the most to the average monthly GWP and showed a strong seasonal pattern, with higher fluxes over the summer and lower fluxes over the winter. The soil N_2O emissions were positive from all genotypes with all contributing about 3% to the annual average flux except Hybrid, which contributed about 5%, however, no significant differences ($p>0.05$) were found for any of the genotypes. All soil CH_4 fluxes were negative (oxidation), with Hybrid showing the highest rates of CH_4 oxidation but once again, no significant differences ($p>0.05$) were found between any genotypes and the control.

There was no significant difference ($p>0.05$) in total GWP of any genotype compared to the control (Table 6). This is not unexpected as the genotype plots were planted in 2010, which means that the plots are still in the establishment phase of *Miscanthus* growth (1-5 years; Lewandowski *et al.*, 2000). It will be interesting to see if next year's results (fourth growing season) reveal more differences between the genotypes and grass control.

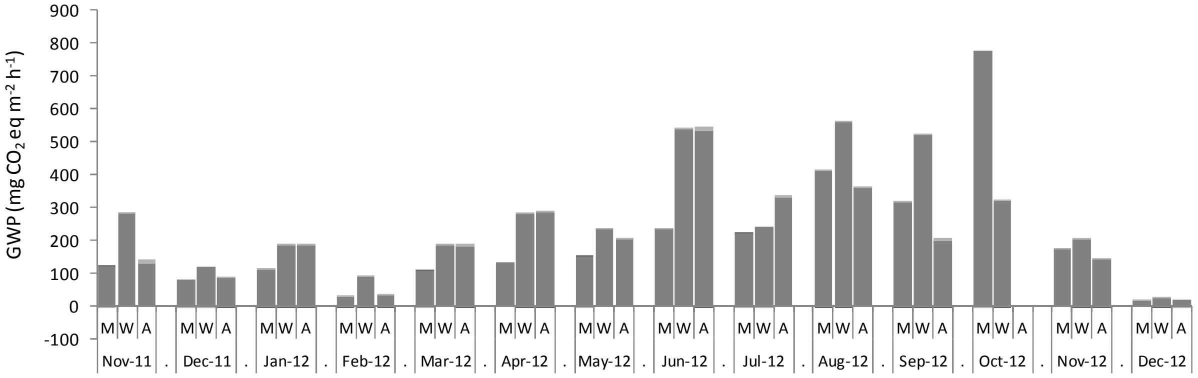
Table 6: A soil GHG summary for each crop at each network site from Jan-12 to Dec-12, comparing arable & bioenergy, grass & bioenergy and different Miscanthus genotypes. Fluxes of CO_2, CH_4 and N_2O are means over a measurement period from Jan-12 to Dec-12. CH_4 and N_2O fluxes were converted into CO_2 equivalents (CO_2 eq.) using global warming potentials (GWP) of 25 and 298 for CH_4 and N_2O respectively (IPCC, 2007). Significant differences between bioenergy and control crops, using linear mixed effects models were accepted when $p<0.05$.

Network Site	CO_2 Flux (mg CO_2-C m^{-2} h^{-1})	CH_4 Flux (µg CH_4-C m^{-2} h^{-1})	N_2O Flux (µg N_2O-N m^{-2} h^{-1})	CO_2 Flux (mg CO_2 m^{-2} h^{-1})	CH_4 Flux (mg CO_2 eq. m^{-2} h^{-1})	N_2O Flux (mg CO_2 eq. m^{-2} h^{-1})	n	**GWP TOTAL** (CO_2+CH_4 eq. + N_2O eq.) (mg CO_2 eq. m^{-2} h^{-1})
Arable vs Bioenergy								
Lincolnshire								
Miscanthus	49.5 *	0.79 ^{ns}	0.09 *	181.57	0.03	0.04	88, 88, 88	**181.64 ***
SRC willow	77.2 *	-2.52 ^{ns}	1.19 *	283.1	-0.10	0.56	95, 94, 96	**283.6 ***
Arable	66.9	-1.25	11.48	245.3	-0.05	5.43	77, 79, 76	**250.5**
E. Grange CEH								
SRC willow	31.8 ^{ns}	-4.70 ^{ns}	0.60 *	116.6	-0.18	0.28	86,110, 110	**116.7 ***
Arable	43.6	-0.66	79.10	159.9	-0.03	37.42	46, 79, 79	**197.4**
Grass vs Bioenergy								
West Sussex								
SRC willow	112.3 *	-3.69 *	4.91 ^{ns}	411.9	-0.14	2.32	88, 94, 94	**414.1 ***
Grass	173.1	9.80	7.02	634.7	0.38	3.32	88, 96, 95	**638.5**
E. Grange FR								
SRF	117.7 *	-2.58 *	1.98 ^{ns}	431.6	-0.10	0.94	88, 88, 87	**432.3 ***
Grass	129.6	-0.99	2.04	475.2	-0.04	0.97	88, 87, 87	**476.2**
Aberystwyth								
Miscanthus	124.9 *	-5.59 ^{ns}	147.00 *	458.0	-0.18	60.76	96, 78, 88	**517.8 ***
Grass	218.8	-5.32	36.63	802.3	-0.21	17.15	96, 85, 88	**819.2**

Genotype Plots								
Aberystwyth								
Sin	84.6 ^{ns}	-2.25 ^{ns}	6.10 ^{ns}	310.2	-0.09	2.89	35, 36, 36	**313.0 ^{ns}**
Sacc1	92.4 ^{ns}	-10.20 ^{ns}	6.55 ^{ns}	338.8	-0.39	3.10	41, 39, 39	**341.4 ^{ns}**
Giganteus	86.3 ^{ns}	-5.01 ^{ns}	5.94 ^{ns}	316.4	-0.19	2.81	42, 39, 39	**318.9 ^{ns}**
Hybrid	71.7 ^{ns}	-11.36 ^{ns}	8.06 ^{ns}	262.9	-0.44	3.81	42, 39, 39	**266.1 ^{ns}**
Grass	85.1	-8.10	5.86	312.0	-0.30	2.77	42, 38, 39	**314.4**

^{ns} = not significantly different to control, * = significantly different to control.

a) Lincolnshire



b) E.Grange (C and D)

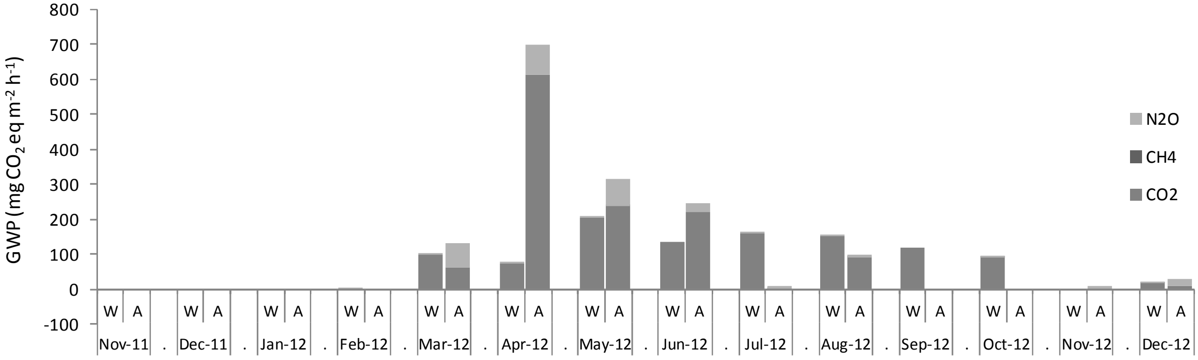
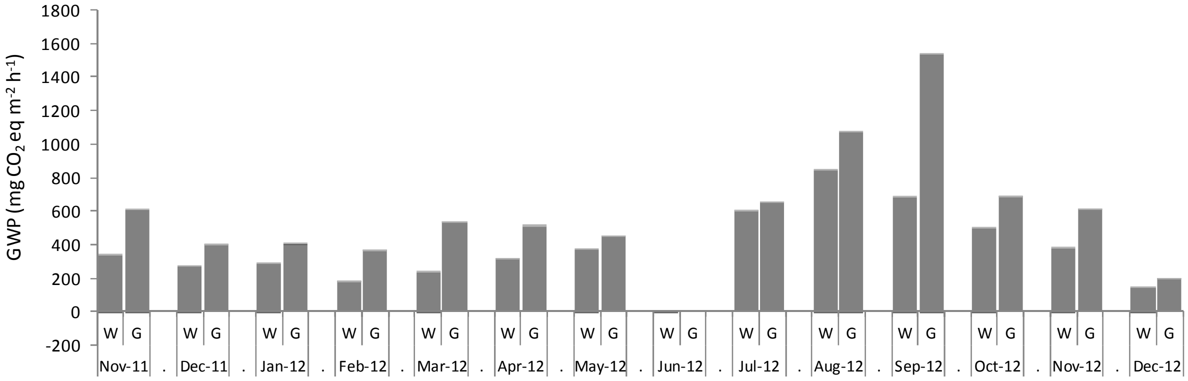
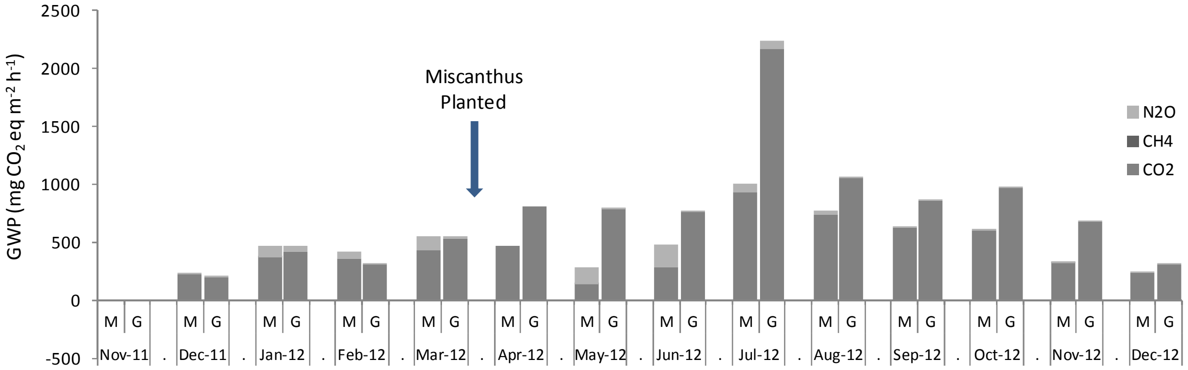


Figure 5: Mean fluxes of CO_2, CH_4 and N_2O (as CO_2 equivalents) for each month (Lincolnshire; n=8, East Grange; n=10) for Arable versus Bioenergy land-use change. W = SRC willow, M = Miscanthus, A = Arable.

a) West Sussex



b) Aberystwyth Miscanthus Conversion



c) E. Grange (A and B)

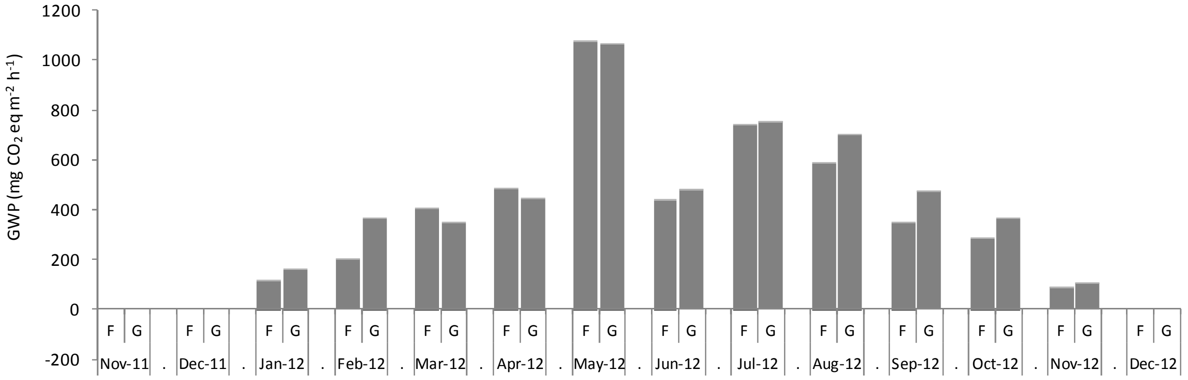


Figure 6: Mean fluxes of CO_2, CH_4 and N_2O (as CO_2 equivalents) for each month (n=8) for Grass versus Bioenergy land-use change. W = SRC willow, M = Miscanthus, F = SRF, G = Grass.

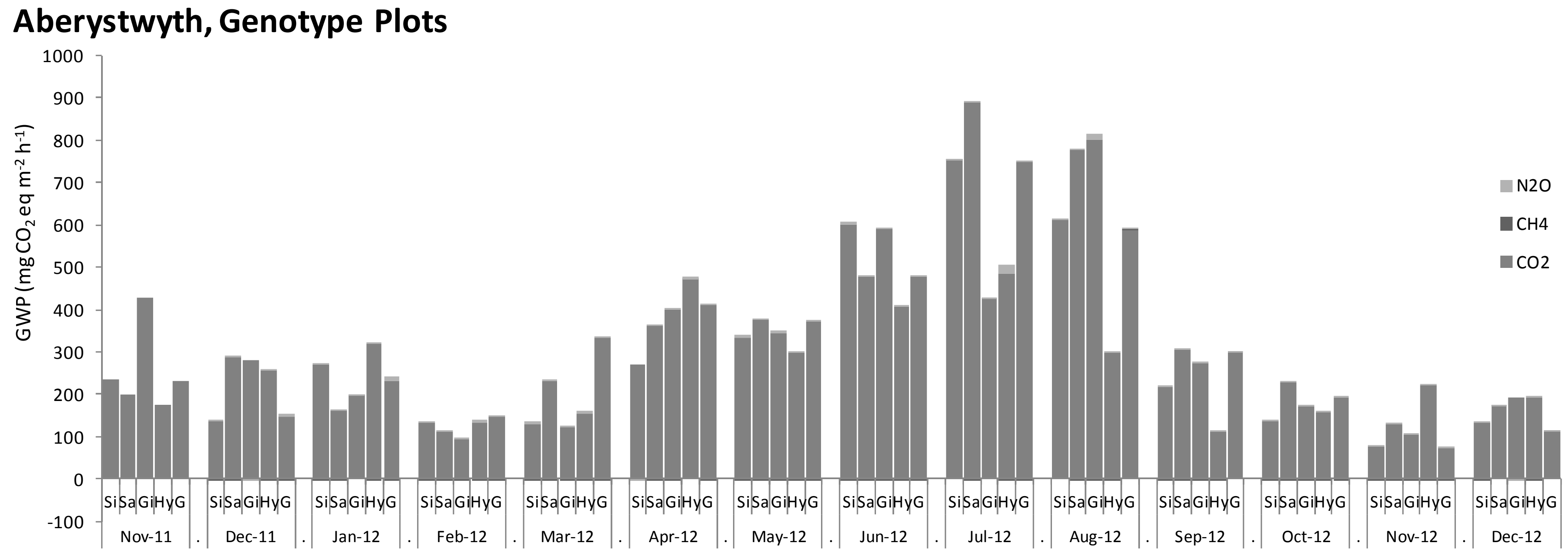


Figure 7: Mean fluxes of CO_2, CH_4 and N_2O (as CO_2 equivalents) for each month (n=3) for different genotypes of *Miscanthus* and a grass control. Si = Sinensis, Sa = Sacc 1, Gi = Giganteus, Hy = Hybrid, G = Grass.

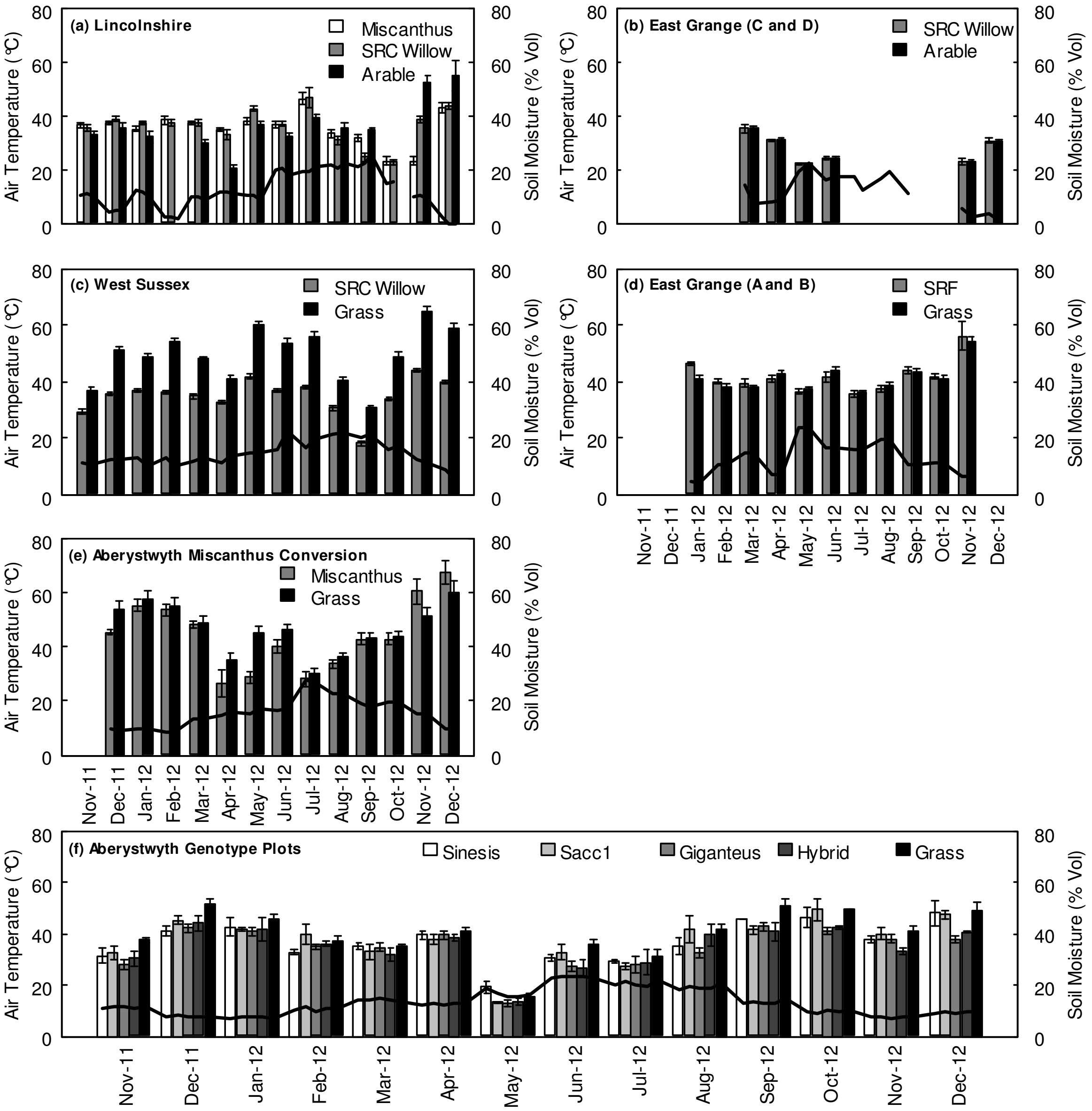


Figure 8: Average monthly soil moisture content (bars) and air temperature (black line) for all network sites; **a)** Lincolnshire (n=8 ± SE), **b)** East Grange CEH (n=10 ± SE), **c)** West Sussex (n=8 ± SE), **d)** East Grange FR (n=8 ± SE), **e)** Aberystwyth conversion (n=8 ± SE), and, **f)** Genotype Plots (n=3 ± SE)

4.2 Eddy Covariance – Whole System Balance

4.2.3 Site Instrumentation

A second EC system, identical to the first, was purchased and installed in the *Miscanthus* field at Aberystwyth (sub-site A). This was done in order to reduce the number of gaps in the time series of net ecosystem exchange (NEE) that will occur with a single EC system as a result of the geometry of the field, in that it is surrounded by woodlands and subject to the variability in wind direction associated with diurnal, coastal winds.

At East Grange, measurements have continued throughout 2012 at the SRF sub-site. The components necessary to complete a second EC system for the East Grange SRC willow sub-site were purchased, although it should be noted that this EC system is not part of the ELUM contract and is provided by CEH. The system has been assembled and tested and it is anticipated that it will be installed in July 2013. This delay in installing the EC system is due to the weather-related delay to harvesting; this would normally have been done in the autumn of 2012, but had to be delayed until mid-2013 because the very wet soils would not support machinery. However, Forest Research have temporarily loaned an EC system that is capable of being used at the height of the SRC willow, ca 4 m, from March 2013 until June 2013.

At the Lincolnshire SRC willow sub-site, measurements continued throughout 2012, the second year after harvest. At the *Miscanthus* sub-site, data was lost for the whole of February and March 2012. This was initially due to a power failure which resulted in data stored on the logger being lost; although this was promptly remedied, further data loss was incurred with the need to remove the EC system whilst the harvesting and baling of the crop took place. At the arable sub-site, the EC instruments were installed on 4th April 2012 and removed from the field on 7th August 2012 in anticipation of the harvest. However, the wet soil condition delayed the harvest for a month and it was not possible to get farm vehicles on to the field throughout the winter and not possible to re-install the EC system. It was therefore decided to re-install the system in a different arable field, adjacent to the SRC willow field, and this was accomplished in May 2013.

At the West Sussex SRC willow sub-site, an EC system was installed in the middle of 2012 and operational in August. A second, identical EC system was purchased, tested and installed at the grass sub-site; this became operational late in November 2012.

Eddy covariance measurements basically consist of measurements, at intervals of 0.05 secs., of the 3-D wind speed and the volumetric concentrations of water vapour and CO_2 - sometimes referred to as the “raw” data. These are processed to produce 30 minute average values of the H_2O (latent heat), sensible heat and CO_2 (NEE) fluxes. This processing applies a series of corrections to the measurements and also generates quality control flags (e.g. range exceedance) which allow a first level of QC and which identifies major measurement errors. The second stage is to carry out more sophisticated QC procedures which deal with other issues, such as: spikes, water on the IRGA lenses, meteorological conditions when the assumptions of eddy covariance theory are not met, etc. The third stage, which is not always necessary, is to carry out a foot-print analysis to identify when the land cover adjoining the land cover of interest is affecting the fluxes to an unacceptable degree. Finally, the time series is gap-filled to replace the periods when measurements were either not made or failed the QC procedures. When the use of the measurements is primarily to inform models, the use of the gap-filled data is limited as much as possible. In the case of the ELUM project, the models are run with a daily time-step and so the use of data when a few of the 30 minute values have been gap-filled is reasonable, whilst using a daily value that solely consists of gap-filled data is not.

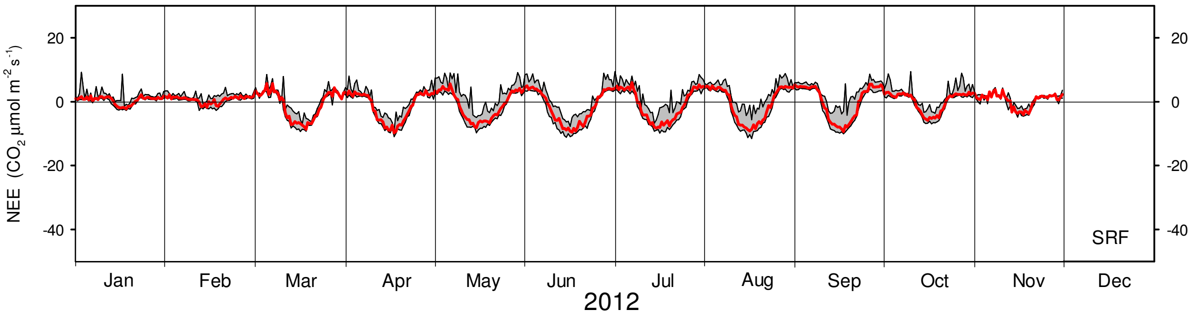
For this project, it is necessary to use the same data-handling procedures, as far as is practical, for all of the network sub-sites described above. It was agreed that the basis of this is to follow the CarboEurope procedures which are, in turn, based on the EUROFLUX procedures (Aubinet, 1999). Furthermore, the EddyPro software should be the basis for processing the raw data and all necessary staff have attended courses on the use of this software, given by LiCor – the software producer. A workshop, for project participants, was held, on 5-6th March 2013, with two objectives: to provide training in QC procedures and to promote discussion to agree the viability of using the same parameter values for the processing and QC at the different sites. Subsequently, it has been agreed that it is not viable to use common parameter values for the different sites.

The amount of data "lost" (i.e. not measured or failing the QC procedures) varies according to factors such as: the land cover type, the meteorological conditions, the type of instruments being used, etc. Data is not obtained when a crop is harvested and, in the case of the arable fields, the new crop drilled, and this can amount to about a month. Instrument problems, such as loss of power, drift in calibrations, damage due to birds, animals and humans etc. will also occur and can range from a few days to a couple of months in a year. Finally, data failing the QC procedures will also be significant, ranging from 10-40 % of the measurements collected. When the primary use of the data is to inform models then loss of data is less critical than when the measurements are primarily aimed at producing a continuous time-series of data. For models it is important to cover the full seasonal range and this is being achieved across the ELUM network sites. It is too early to have a full analysis but an example is available from the Lincolnshire network site where, for the SRC willow, 75% of the measurements are present within a three year period and, for the *Miscanthus*, 45% of the measurements are present for a 5 year period. These values are not untypical and are acceptable for the modelling work in WP4.

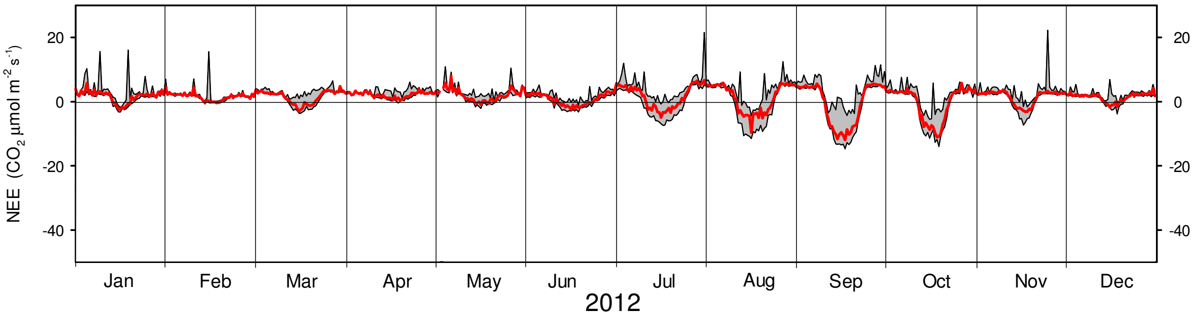
4.2.2 Results

Fully processed and QC data is not yet available from the sites, however all EC measurements have been part-processed allowing some general comments about these data to be made. Figure 9 shows, for each calendar month of 2012, the median diurnal cycles and inter-quartile ranges of the measured NEE. The strong seasonal cycle is clearly shown in these data with small fluxes in the winter months and large fluxes during the summer. Similarly, the strong diurnal cycle is clearly shown with positive values (respiration) at night and negative values (photosynthesis exceeding respiration) during the day, with the exception of the winter months. Differences between the land covers are also present, notably the differences in the time of year of the minimum values of NEE. The *Miscanthus* lags behind the other land covers because of its requirement for a higher temperature for growth. The measurements at the Lincolnshire site show clear differences between the arable crop (winter wheat) and the bioenergy crops for the period when the measurements from the arable crop are present. The night-time respiration rates are generally about twice as high and the minimum daytime rates are twice as low. In addition, the completion of senescence in August is demonstrated by dominantly positive values throughout the day.

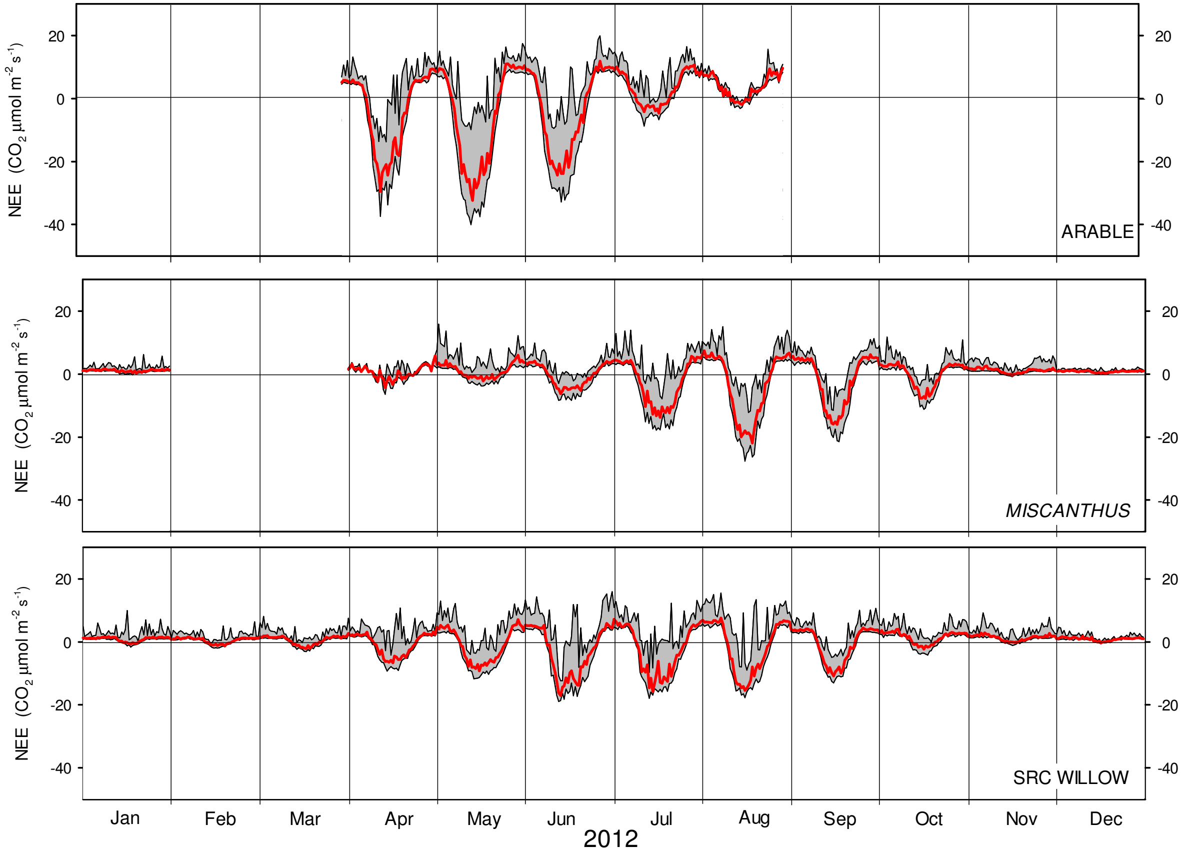
(b) East Grange



(a) Aberystwyth



(c) Lincolnshire



(d) West Sussex

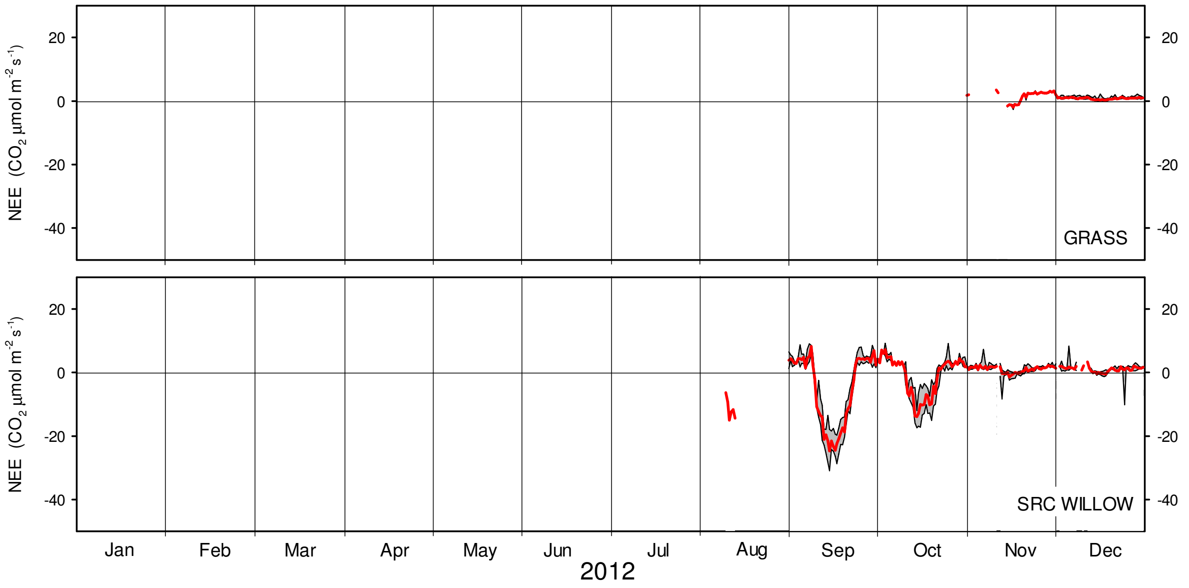


Figure 9: Monthly median diurnal cycles (red line) and inter-quartile ranges (shaded area) of the measured net ecosystem exchange (NEE) for each of the sub-sites

4.3 Novel GHG Technologies

4.3.1 Background

In order to assess the impacts of various land uses on GHG emissions it is vital that we are able to measure trace gas fluxes at high temporal and spatial resolution. This will allow an understanding of the factors controlling their production and consumption to be developed. In order to achieve this, a system for measuring trace gas fluxes across a large spatial scale, at high frequency and continuously is described below.

It is intended that this technique will measure fluxes at plot-scale resolution, thus allowing controlled, replicated manipulative experiments to be conducted to investigate their effect not just on soil respiration but on the net ecosystem exchange (NEE) of the gases of interest.

In addition to the development of this system, GHG fluxes were measured from two cropping systems at the Brattleby site using a combination of automated flux chambers and static chambers (coverboxes); here the hypothesis tested was that there is a significant difference between the GHG fluxes associated with the production of a bioenergy crop and those of a traditional arable system. It is expected that fluxes of N_2O will be greater in the arable system due to the history of nitrogen (N) fertiliser application; respiration rates are also likely to be higher from an arable system due to the increased carbon (C) inputs from decomposing roots post-harvest.

4.3.2 What we have done

An initial design for a gantry-mounted chamber was drawn up by the mechanical workshop at the department of Biology at the University of York (Figure 10) which consisted of two scaffold towers supporting a single 5 metre aluminium beam along which a motorised trolley would run. The trolley carries a winch to lower and raise a chamber which would be used to measure gas flux from a medium using the same principle other chamber systems, such as the Li-Cor LI-8100 system.

The electronic workshop at the department of Biology at the University of York developed a fully automated control system using a Li-Cor LI-8100 infrared gas analyser (IRGA). The IRGA communicates with the gantry system as though it were a standard Li-Cor chamber. This allows complete control over the length of time the chamber closes and the frequency of measurements; the pump in the IRGA is used to circulate the headspace gas and the IRGA calculates the flux of CO_2 using its internal software. The aim was to develop a fully automated system capable of taking continuous measurements of CO_2 flux. The umbilical lines for circulating gas to and from the chamber were kept to 10 m in length as per the Li-Cor design for their chambers.

Further development was undertaken to increase the height of the beam to enable a large chamber to move freely above a large crop such as those used for energy production, e.g. *Miscanthus*, which grows to a height of 3 m. The increased height was achieved through the use of taller, lightweight aluminium scaffolding towers. The span that the system covered was extended to 10 m by incorporating a longer beam with a perpendicular support beam and towers.

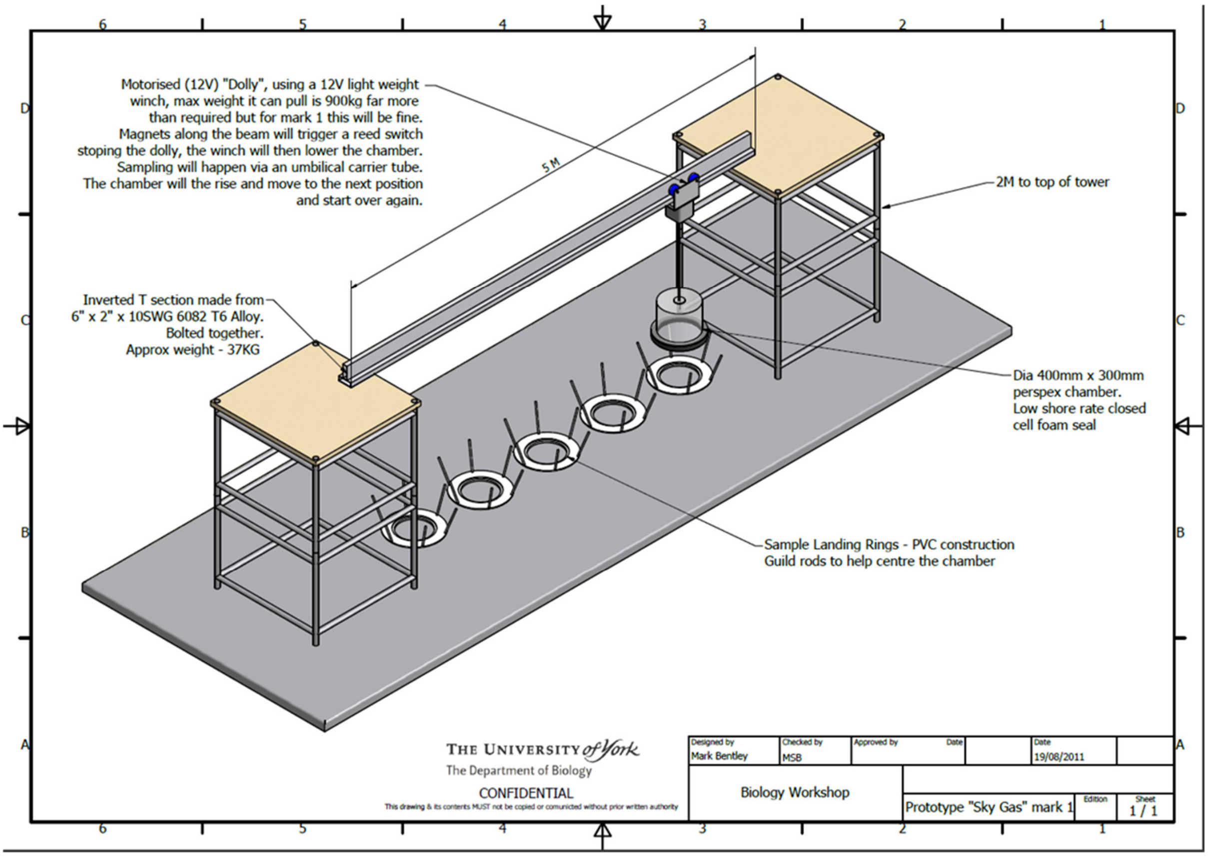


Figure 10: Original design for a chamber-mounted system for measuring trace gas fluxes

A chamber capable of measuring from over *Miscanthus* was built from a cage of aluminium with a circular perspex roof (diameter 1200 mm); the internal diameter of the chamber measured 1 m and the height 1.5 m; volume 1177.5 l). Holes were made in the roof of the chamber for the umbilical lines for gas circulation and a thermistor. A vent, following the design of Xu *et al.* (2006) was also included in the roof of the chamber to allow internal pressure to be equalised with ambient pressure. The material used for the walls of the chamber was a clear polythene sheet used for the construction of horticultural tunnels and designed to allow photosynthetically active radiation (PAR) to pass through it.

A landing base was designed to enable the chamber to make an airtight seal over the vegetation being measures, and to ensure that the same points were measured each time. The design was based on the circular cores used by many cover boxes and automated chambers. A cylindrical plastic base would sit on the surface of the ground, and this base had a perpendicular flange upon which the chamber sits (Figure 11). The seal is made with a rubber door seal around the base of the chamber.

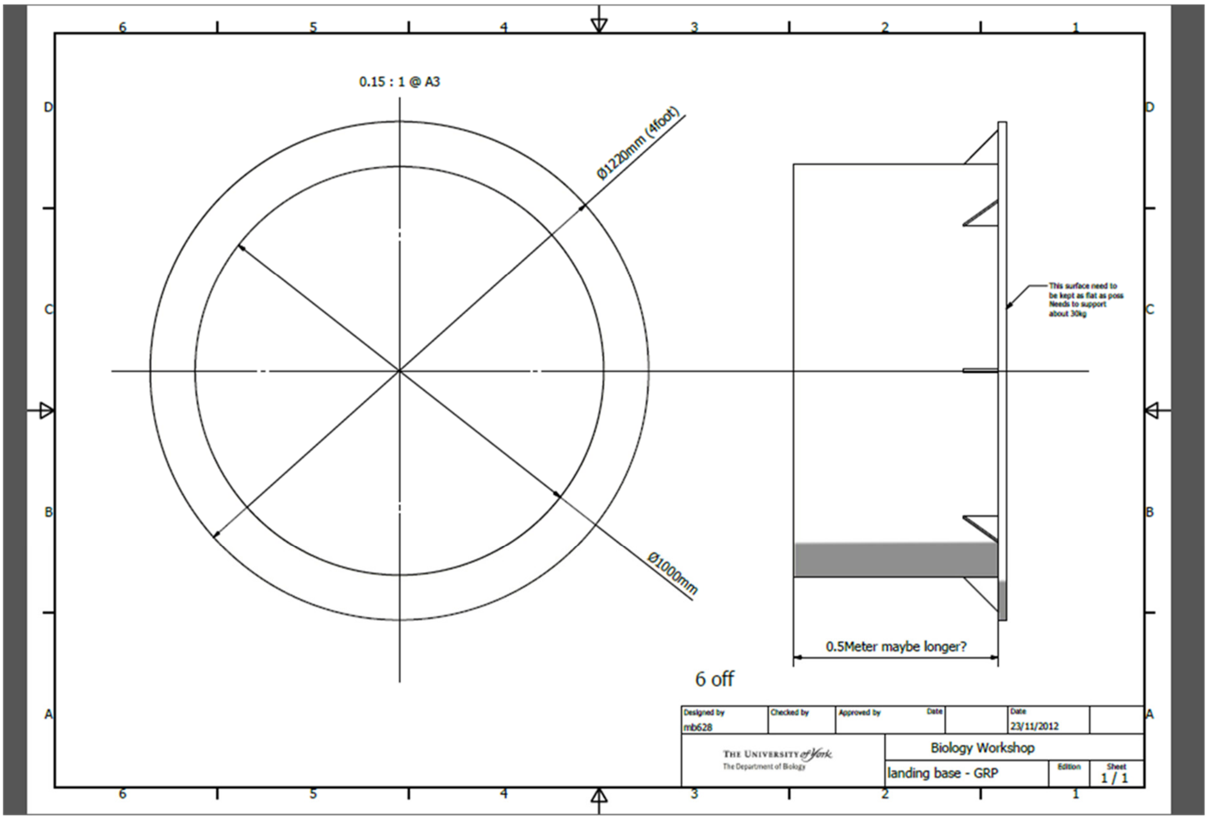


Figure 11: Design of the landing base for the gantry system

The redesigned gantry system was assembled on grass land at the University of York in December 2012 for testing. The hypothesis that there would be no significant difference between two measurement systems was tested with a paired design for comparing the fluxes measured from a 20 cm diameter Li-Cor automated chamber and those using the large gantry chamber at 6 points was carried out over short grass.

Automated chambers were closed for 2 minutes and the large chamber was closed for 10 minutes due to the larger volume. The same IRGA was used to measure from both chambers and the umbilical lines for each were kept to a similar length (under 10 m). The position of the core for the Li-Cor chamber measurements was randomly assigned to the north or south side of the large chamber's position (Figure 12). The large chamber's landing position was restricted to one plane as it is suspended from a rigid beam. The order in which measurements were made was randomised, i.e. whether the gantry system or the Li-Cor measured first. The raw data were used to plot a linear regression of concentration CO_2 over time, from which the flux was calculated. Analyses were carried out using SAS 9.3 (SAS Institute), and a Wilcoxon signed ranks test was performed on the flux data.

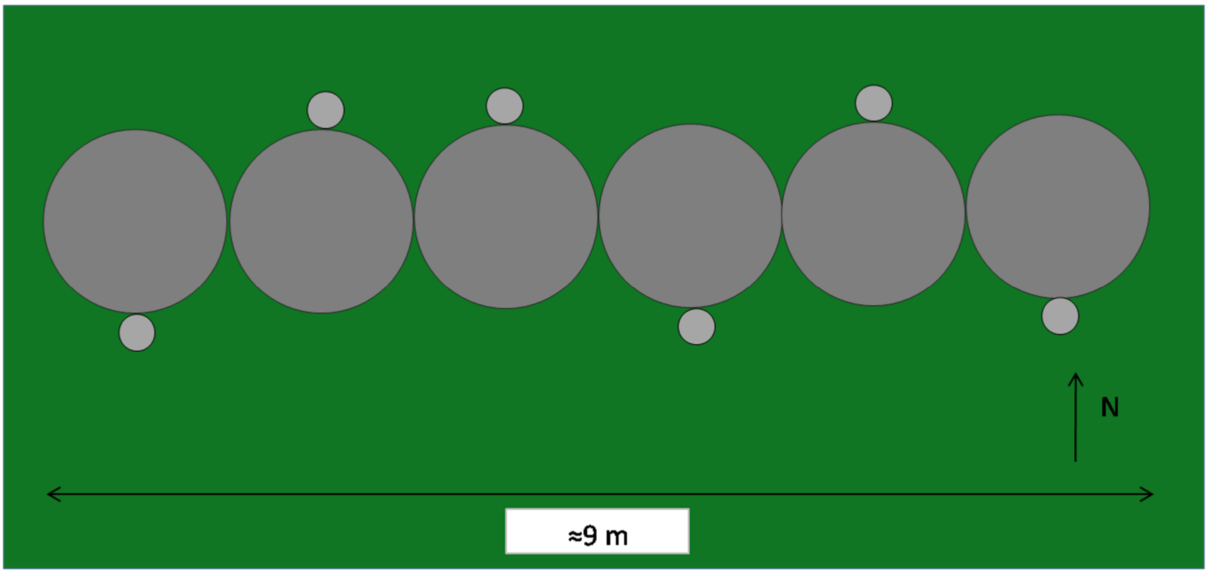


Figure 12: The paired design of the experiment to compare the fluxes measured from the gantry system (large circles) and the Li-Cor system (small circles)

Measurements of PAR, soil temperature were made. In addition to the measurements of CO_2 flux, measurements of CH_4 and N_2O were made using Los Gatos analysers (Los Gatos Research, CA, USA). The headspace gas from each chamber was cycled to the IRGA, the exhaust from the IRGA was routed to the inlet of the CH_4 analyser, and the same principle used to carry the exhaust from the CH_4 analyser through the N_2O analyser, before the exhaust was returned to the chamber. To avoid pressure issues involved with sequential pumps from the analysers, a shunt to allow excess pressure to bypass the analysers downstream of the IRGA was included in the system.

Upon completion of the testing undertaken at the University of York campus, the gantry system was deployed to the Lincolnshire network site to take measurements from over the *Miscanthus* crop. The system was deployed in February 2013 with a view to collecting a month's data from the crop before harvest at the end of March. However, due to an early harvest, the equipment had to be dismantled in the second week of March, and will be used to follow the next growing season. Redeployment of the apparatus started at the end of May 2013 and data collection resumed in the third week of June.

A gantry with a 5 m beam was assembled over the crop, with towers 6.4 m in height (Figure 13). This configuration allowed for three replicate landing sites to be positioned under the gantry. Measurements were made from the same *Miscanthus* field discussed in section 2, in which continuous measurements of CO_2 flux were being made using Li-Cor automated chambers, and periodic measurements of trace gas fluxes (CH_4 and N_2O) were being taken using cover boxes.

Figure 13: Gantry deployed over Miscanthus. The towers are 6.4 m high with a 5 m beam between (left). The 5 m span allowed for 3 replicate sampling sites over the vegetation

Measurements of CO_2 began using a Li-Cor IRGA in late February 2013. Chamber measurements were taken using a 10 minute closure period. In order to accommodate the height of the crop the landing bases had an extension added to them, bringing them to 1.2 m high. With the chamber height of 1.5 m, the total volume enclosing the crop is 2119 l. Fluxes were calculated using the internal Li-Cor software on the LI-8100 IRGA.

Flux measurements were taken from two adjacent (on a north-south orientation) fields under different cropping strategies to assess the different trace gas fluxes associated with arable and *Miscanthus* production. The arable field had produced wheat the previous growing season, and had been due to be sown with wheat again in the autumn for the 2012-13 growing season. However, due to the above-average levels of rainfall during 2012, the ground was deemed too wet to be able to support the agricultural vehicles required for the operation and the ground was left fallow with a view to sowing spring wheat early in 2013.

Continuous measurements of CO_2 flux were made using a multiplexed system of 8 automated static chambers attached to an LI-8100 infrared gas analyser (IRGA) (Li-Cor, Lincoln NE, USA). The multiplexer was made by the electronics workshop in the Department of Biology, University of York, UK. Measurements began in July 2012, with 20 cm cores being driven into the ground to a depth of 2-3 cm. The chambers closed for a period of 3 minutes and the linear regression function in the Li-Cor software was used to calculate the flux.

Further measurements of trace gas fluxes were taken at approximately monthly intervals starting in September 2012 using manually sampled static chambers (cover boxes) for CO_2, CH_4 and N_2O, and additional measurements of CO_2 were taken using a Li-Cor 20 cm survey chamber attached to a LI-8100 IRGA. Survey chamber measurements were taken from the same cores as used for the cover boxes, and measurements were made immediately prior to cover box closure. The survey chamber was closed for 2 minutes and a linear regression for flux calculation fitted using the Li-Cor software.

Each cover box was closed for two hours, with samples being taken at 0, 30, 60, 90 and 120 minutes. A total of 12 cover boxes were used in the arable field and 8 in the *Miscanthus* field. The cores used as the base of the cover boxes in the *Miscanthus* were the same as those used for the automated chambers; permanent cores were not established in the arable field due to expected vehicular activity.

All statistics were performed using SAS and graphs were plotted using Sigmaplot (Systat Software Inc, California, USA). Fluxes between measurement points were calculated as the mean of the consecutive fluxes multiplied by the time interval, and cumulative fluxes as the addition of these values.

4.3.3 Results

Fluxes measured in the comparison test between the Li-Cor system and the gantry were both positive. Although measurements were taken over green plant species, it was December and PAR measurements were low, (mean 1.52 µmol.m^{-2}.s^{-1}, range 0.6-2.7 µmol.m^{-2}.s^{-1}), so CO_2 fluxes were dominated by respiration.

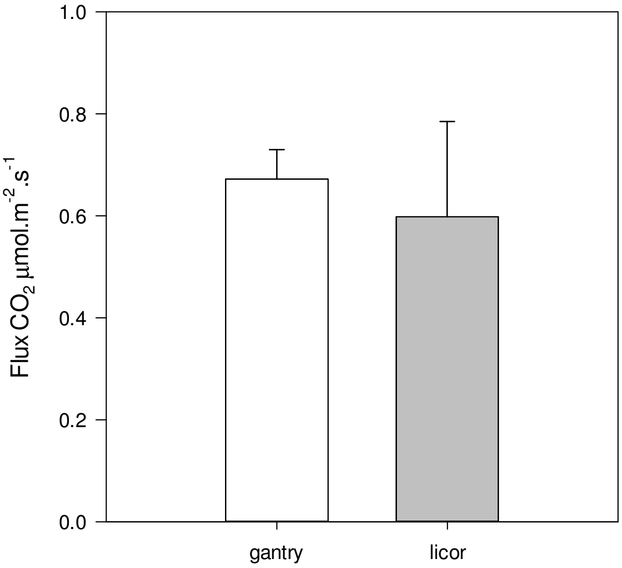


Figure 14: Flux CO_2 measured using a Li-Cor system (grey bar) and the gantry system (white) in a paired test over short vegetation at the University of York in December 2012. Error bars represent +- 1 SE of the mean of 6 replicate measurements

There was no difference in the fluxes measured using the two different chamber systems, Wilcoxon S- = -9, n=6, p>0.05 (Figure 14). The null hypothesis that there would be no difference between the systems of measuring fluxes was therefore not rejected. Data from the N_2O and CH_4 analysers has yet to undergo complete analysis and is not presented here, but will be reported in the complete review of novel GHG measurement systems in May 2014.

Fluxes of CO_2 measured from over *Miscanthus* during February and March were also positive, indicating that photosynthesis is very slow at this time of year (Figure 15). Although the data sets are limited to 1-2 days in length each, a diurnal trend in CO_2 efflux can be seen. However, peaks in respiration occurred at around 2 am on the 21st and 22nd of February, and midnight on the 28th February. The lowest fluxes were seen at 6 pm on the 21st, 1 pm on the 22nd and 6 am on the 6th March. Gaps in the dataset were caused due to mechanical failure of the trolley during sub-zero temperatures when ice built up on the top of the beam. Total flux measured using the gantry system will be calculated from the equipment during the next growing season allowing a comparison to be made between data derived from the different systems used. Environmental and meteorological variables continue to be measured that should enable explanation of the variation in the fluxes measured during this time.

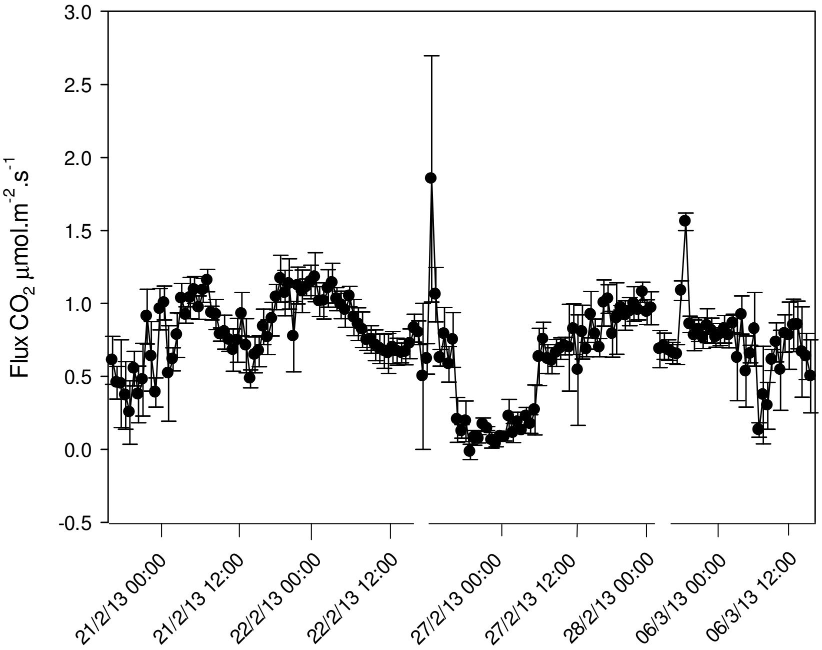


Figure 15: CO_2 fluxes from over *Miscanthus*, measured using the gantry system. Note the broken scale on the x axis. Data were collected from 3 discreet time periods, not continuously. Error bars represent +- 1SE, n=3.

Fluxes of CO_2 measured with the cover boxes were positive on all occasions (Figure 16, top panel) reflecting the fact that opaque chambers are useful in picking up soil respiration, but halt any vegetation from photosynthesising. Fluxes were consistently higher in the arable field than in the *Miscanthus*, decreasing from approximately 25 $mg.m^{-2}.hr^{-1}$ in October through the winter months before rising to a peak of 27.5 $mg.m^{-2}.hr^{-1}$ in March. Respiration in the *Miscanthus* also peaked in March, reaching 12 $mg.m^{-2}.hr^{-1}$. The difference in CO_2 flux between the *Miscanthus* and arable were significant, repeated measures ANOVA, $F_{[1,18]}$= 12.37, p=0.0025. Differences were not seen until December, but then were consistent from then until March (Figure 16).

Fluxes of N_2O in both crops were close to zero for all months, with the exception of a large peak (25.4 $mg.m^{-2}.hr^{-1}$) in emissions from the arable in January (Figure 16, middle panel). There were no differences between the two cropping systems until this peak, and the difference remained evident in March. As seen with CO_2 flux, the increase in efflux in the first months of 2013 is the cause of the significantly higher flux from the arable cropping system, repeated measures ANOVA $F_{[1,18]}$= 8.16, p=0.0105. Higher N_2O emissions are to be expected from a field that has a history of nitrogenous (N) fertiliser application, and are likely to be driven by increased soil moisture levels at that date, as there was a covering of snow of approximately 10 cm on the occasion the largest flux was seen in January.

Methane fluxes appeared positive in the *Miscanthus* field in October, following a downward trend towards zero, with a negative flux measured in December. Fluxes were also negative in the arable field in October, December and March, though the range of fluxes in both cropping systems was -8.8 - +9.6 µg.m^{-2}.hr^{-1}. The fluxes measured were very small and there were no significant differences between the fluxes from both systems at any time-point.

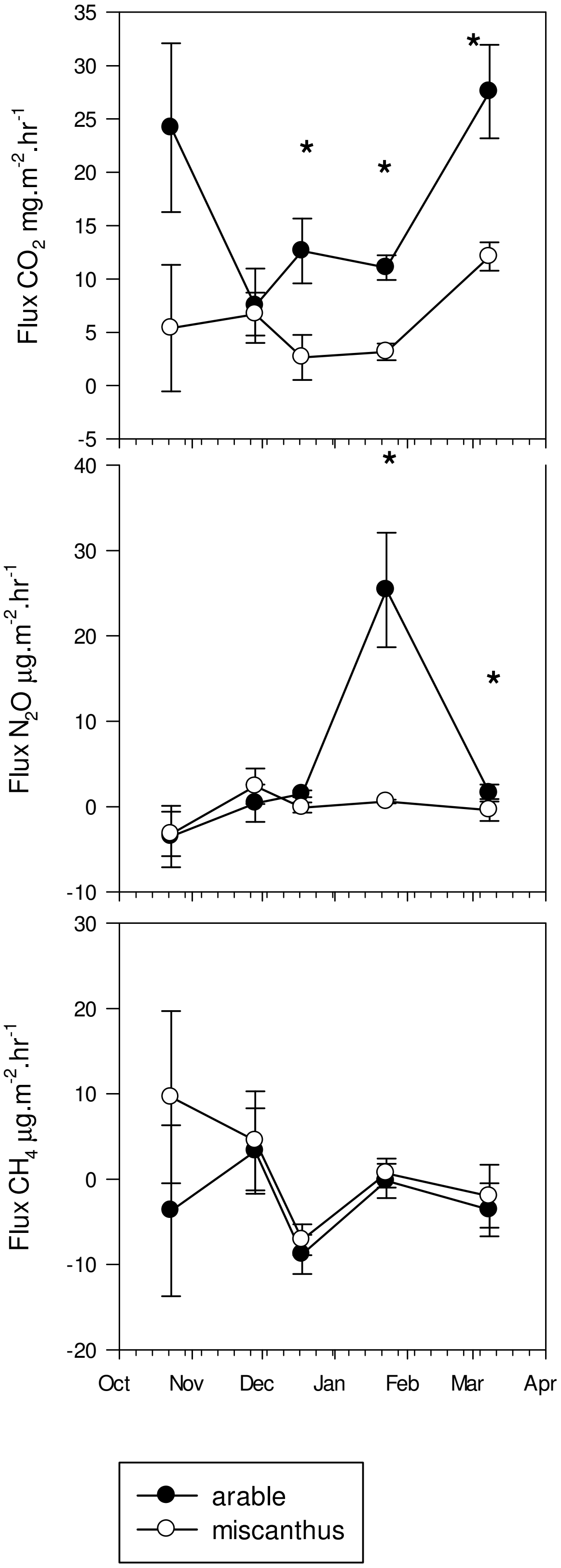


Figure 16: Fluxes of three trace gases, (CO_2, CH_4 and N_2O) from two crop systems, measured using static chambers during 2012-13. Filled circles are measurements from an arable system, unfilled from *Miscanthus*. Error bars represent ± 1 SE, significant differences are denoted with '*'.

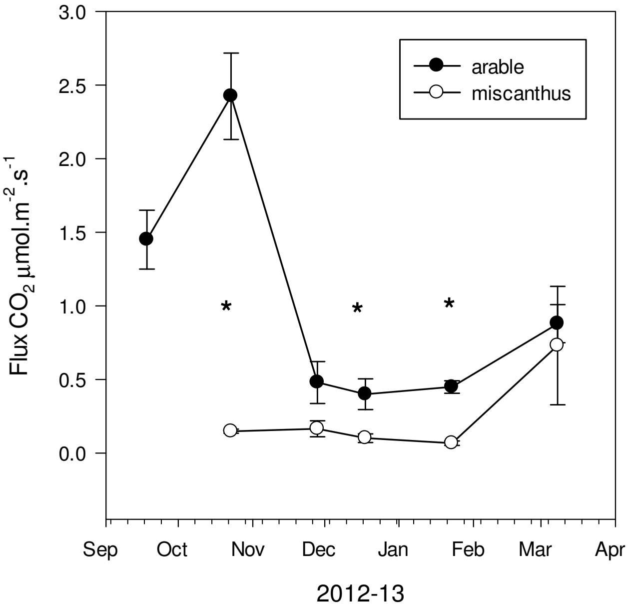


Figure 17: CO_2 flux measured from two cropping systems using Li-Cor survey chamber and IRGA. Error bars represent ± 1SE, significant differences are denoted with '*'

Fluxes of CO_2 measured using the survey chamber reflected the pattern shown from the cover box data, with the lowest fluxes shown from November to January. The highest flux in the *Miscanthus* occurred during March (Figure 17), whereas the peak efflux from the arable occurred in October, though the flux was increasing again by March. As with the measurements from the static chambers, fluxes were always positive, and were consistently higher in the arable system than the *Miscanthus*, repeated measures ANOVA $F_{[1,18]}$= 17.82, p=0.0005.

The cumulative flux of methane (Figure 18) was negative in both the arable, -1323 mg.m$^{-2,}$ and *Miscanthus*, -44 mg.m^{-2}, (Figure 18, right panel), but there was no difference between the two cropping systems. The cumulative values are the result of many small fluxes close to zero, suggesting that the conditions are not suitable for CH_4 production.

Cumulative fluxes of N_2O differed greatly between the two systems, with total emission from the arable field (1770 mg.m$^{-2)}$ much higher than that from the *Miscanthus* (17.48 mg.m$^{-2,}$ Figure 18 left panel), $t_{[18]}$= 2.91, p=0.0093. N_2O emissions are most likely driven by the history of mineral N addition in the form of fertiliser to the arable system.

Fluxes measured from the automated Li-Cor chambers situated in the *Miscanthus* show a peak in soil respiration in August at nearly 4 µmol.m^{-2}.s^{-1} (Figure 19).

Fluxes declined throughout the year and approached zero in December. High resolution data of methane fluxes from the same chambers are yet to be processed. Comparisons of the fluxes calculated by the different methods employed here, namely automated chambers (measuring approximately hourly), survey chambers (monthly) and static chambers (monthly) will be made

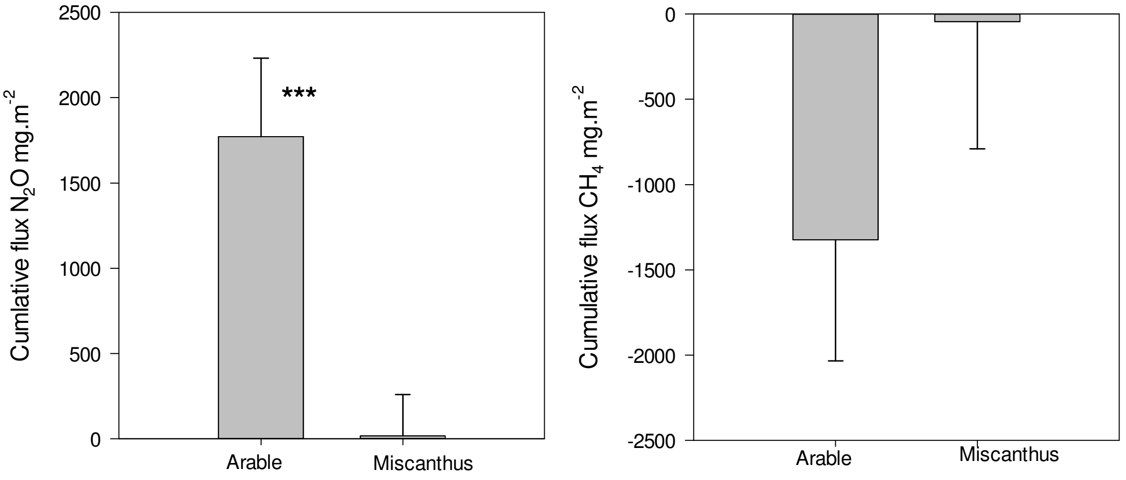


Figure 18: Cumulative fluxes from N_2O (left panel) and CH_4 (right panel) measured from two cropping systems from October 2012 to March 2013. The net flux of methane was negative in both systems. Error bars represent ± 1SE, *** denotes significant differences p<0.001

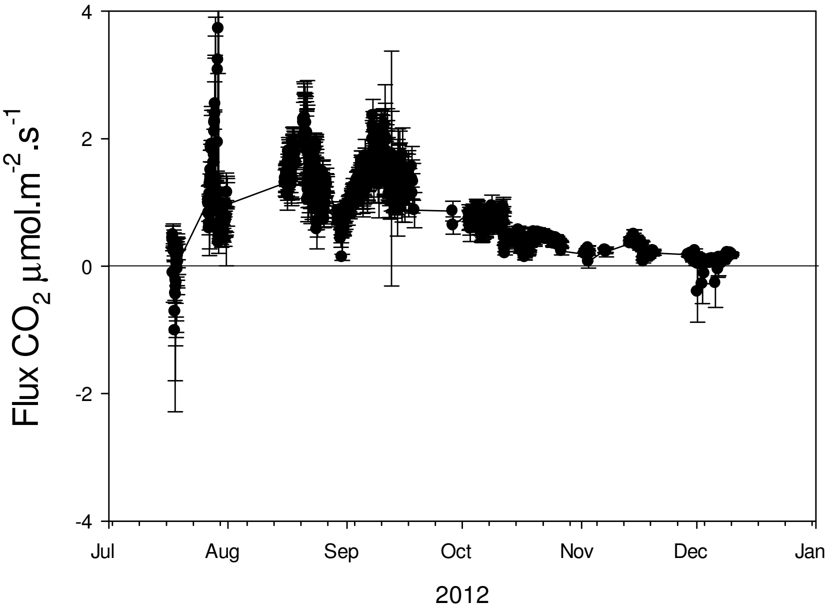


Figure 19: Automated Li-Cor chambers provide high resolution measurements of CO_2 flux from the *Miscanthus* crop in Brattleby, Lincolnshire. Each data point represents the mean of 8 independent chamber measurements taken approximately every hour, in contrast to the monthly measurements from coverboxes; error bars represent ± 1SE.

4.3.4 Lessons Learned

Results from the initial comparison test between the Li-Cor chamber and the gantry system demonstrated that a chamber in excess of 2000 l was capable of detecting fluxes of CO_2. It was a concern that the analyser would not be accurate enough to detect small changes in concentration in a volume of such magnitude. Individual regressions however, from chamber closures of 10 minutes frequently return an r^2 of ~ 0.9, which in addition to the comparison with the Li-Cor-derived fluxes has been taken to indicate that the flux calculations are reliable. This conclusion comes with the caveat that testing is still at an early stage, and a rigorous period of measurements during which time the protocol for collecting data from the apparatus will be refined must be undertaken once the equipment is reassembled. This period of testing will take place following the recommencement of data collection in June 2013.

A characteristic of the CO_2 data collected in this comparison test that is worth commenting on is the difference in variance of the fluxes from the two systems. The Li-Cor chambers, measuring form a smaller area (317 cm^2 compared with 7850 cm^2), had a much larger standard error. This can be taken to demonstrate the spatial variability in sources of trace gas fluxes across even a fairly homogeneous substrate. By increasing the area over which measurements are taken, the variation in measured values decreases and therefore the confidence one is able to put into any extrapolation of values to a landscape scale will increase. If *in situ* data are to be used for developing models, then this is a very attractive proposition.

The preliminary data from the field site, gathered between 21st February and 8th March 2013 showed the apparatus was capable of picking up diurnal variation in CO_2 flux. This may have particular value since data collection from manual chambers tends to be strongly biased towards daytime values, and nocturnal eddy covariance data is often discarded due to boundary layer conditions being unsuitable during this time. Of particular interest is the appearance of peaks in CO_2 efflux during the small hours of the morning. As expected, the flux of CO_2 was positive, reflecting the lack of chlorophyll in the senesced *Miscanthus* (Figure 19), indicating that the flux was dominated by respiration. Deploying this equipment in tandem with automated soil flux chambers will allow the opportunity to partition the vegetation and soil only components of net ecosystem exchange of trace gases at high temporal resolution.

The tendency of the trolley on the gantry system to slip and cause the system to halt measurements has been addressed. A non-slip paint has been applied to the beam; in addition the firmware has been modified to restart periodically after halting to avoid gaps in the data set.

4.4 Pulse labelling experiment

4.4.1 Background

Short term *in-situ* experiments concerning the fate of recently assimilated C to the belowground components of root, soil and microbial pools can yield valuable data required for predicting ecosystem respiration fluxes. Under land-use change these pools are not at equilibrium and an important experimental challenge therein is to quantify the residence and trajectory of C in these pools. Many C allocation studies that have focused on land-use change and management have therefore taken advantage of ^{13}C pulse chase studies (Ostle *et al.*, 2000; Högberg *et al.*, 2008; Subke *et al.,* 2009; Biasi *et al.*, 2012). The short-term ^{13}C tracer approach does not override the utility of using long-term monitoring networks or space-for-time experiments (i.e. chronosequences); rather, it provides a new level of process understanding. The ^{13}C pulse chase approach provides valuable data for C allocation to belowground ecosystem components; the contribution of photosynthate to heterotrophic and autotrophic fluxes; time lags between assimilation and soil respiration and the transfer of C to microbial and fungal pathways.

The most common field approach is through the exposure of plants to isotopically enriched ^{13}C in CO_2 at ambient (Ostle *et al.*, 2000) or above ambient concentrations (Högberg *et al.*, 2008) for several hours in clear chambers or tents. The photo-assimilation of $^{13}CO_2$ during this pulse labelling is then tracked through soil and plant materials and into respiratory fluxes during the following days to months. The technique is referred to as the "$^{13}CO_2$ pulse chase" approach due to the highly intensive nature of the field sampling that follows the isotope addition. This ^{13}C approach has generally been used for grass and peatland ecosystems with shorter vegetation (Ostle *et al.*, 2000 and citations of). However, recent ^{13}C pulse chase experiments on whole tree (Högberg *et al.*, 2008; Subke *et al.*, 2009) and large energy crop grass (Biasi *et al.*, 2012) have demonstrated the potential for this technique at a larger scale. The objective for this work here was to compare the rate and fate of recently fixed CO_2 under co-located *Miscanthus* and Willow fields in Lincolnshire.

4.4.2 ^{13}C Pulse Labelling

Our chamber design and ^{13}C pulse approach was similar to Högberg *et al.* (2008); Subke *et al.* (2009) and Biasi *et al.* (2012) but on an area basis was the world's largest ^{13}C pulse. Each (4 willow, 4 *Miscanthus*) rectangular pulse tent (to encapsulate a willow row) was 6m *l*, 2.5m *w*, 3m *h* resulting in a chamber of 45 m^3 (Figure 20). Aluminium poles were used to support a plastic film which comprised the tent structure. The plastic film allowed 90% of photosynthetically active radiation to enter the tent. During the ^{13}C pulse the tent was sealed at the base using a continuous line of sandbags (*ca.* 400 kg sand per tent). Air inside the chamber was cooled using 7.3 kW water-cooled split air conditioner capable of air movement of 1,450 m^3/hr. Additional air movement was facilitated by two tripod fans. 8 individual diesel or petrol generators were used to provide power to each tent. During the ^{13}C pulse, air temperatures were recorded every 3 minutes inside and outside the tent so as to quantify the degree of cooling that was achieved.

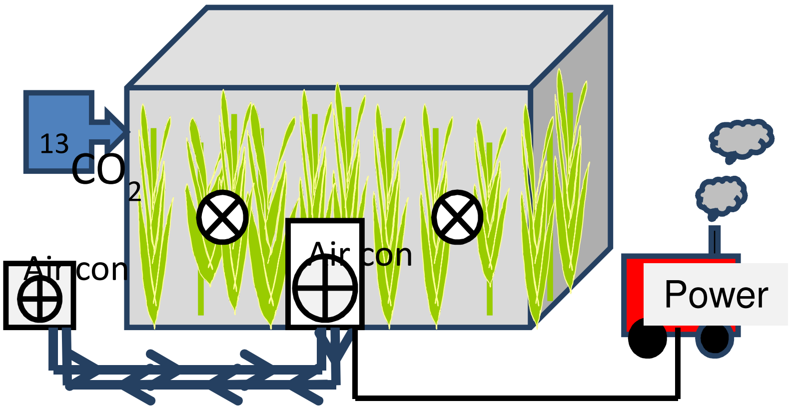


Figure 20: Diagram of the ^{13}C pulse tent. 4 tents were randomly placed in Willow and Miscanthus plots in Lincolnshire

The isotopic pulse labelling was carried out on 23 August 2012 at *ca.* 08:20 hrs by introducing *ca.* 17 l of 99% ^{13}C-atom enriched pure CO_2 shortly after sealing the tent (Figure 21). During the ^{13}C pulse, the ^{13}C isotope delta value and the total CO_2 concentration was monitored in each tent using the Picarro multiplex system. All 8 tents and two air reference lines could be analysed in approximately 30 minutes cycles. Samples were delivered to the Picarro in a flow-through system which comprised PTFE sampling lines, flow controllers and flow monitors which all lead to the Picarro system. An additional generator was used to power the Picarro and flow-through system. After the tent sealing, and prior to the ^{13}C pulse, we observed a rise in CO_2 concentrations (*ca* twice ambient) at approximately 1 hour after sealing the tent. Then CO_2 concentrations dropped as photosynthesis outstripped ecosystem respiration. At this time the $^{13}CO_2$ was then introduced in sequential batches over 4 hours to ensure that the pure CO_2 additions did not exceed ambient CO_2 levels.

Figure 21: Four ^{13}C pulse tents at the Lincolnshire site installed in *Miscanthus*.

4.4.3 Post-pulse sampling

Post-pulse sampling for soil and gas samples has taken place after 4, 24 and 48 hours and then at days 7, 14, 21, 28, 42, 76, 104 and 196 days. Soil CO_2 samples were taken using the same static chamber method used for our routine WP3 GHG measurements (PM04.3.2_WP3 Year 1 Report, p16). At each gas sampling event, bulk/solid samples (rhizome, root, stem, leaf) were also taken and frozen at 23°C or air dried, depending on requirements. Four soil samples were taken at each sampling point to 30 cm and separated in the field to 0-10; 10-20; 20-30 cm depths. To date over 1000 samples each have been collected for both gas and bulk (soils and plant) ^{13}C analyses. To date all gas samples have been analysed except day 196, and bulk samples will be analysed from late May 2013. Gas analyses have been analysed using cavity ring-down spectroscopy (CRDS) using a Picarro system. Bulk/solid samples will be analysed using a Costech Elemental Analyser coupled to the Picarro system (see Section 4.4.6).

4.4.4 Calculating pulse derived ^{13}C in soil respiration

Isotopic mass balance equations were used to calculate the amount of elevated ^{13}C in soil respiration from the pulse. Outputs from the Picarro $^{13}CO_2$ analyser were in standard delta (δ) value notation. $\delta^{13}C$ is an isotopic signature, a measure of the ratio of ^{13}C and ^{12}C, reported in parts per thousand (‰). First these δ values were converted to Atom% values (APC ^{13}C) using the equation:

$$\text{APC } ^{13}C = (100 \times R13) / (1+R13)$$

Where $R13 = (\delta/1000 + 1)\ R1$

R13 is the absolute ratio of a sample = $((\delta^{13}C/1000)+1) \times R1$. R1 being the international standard value for the 13/12 C ratio and =0.0112372.

Gas concentrations from the start and end of chamber closure (45 minutes) were then partitioned in to their ^{12}C and ^{13}C components using the above equation. From this a ^{12}C and ^{13}C gas flux rate could be calculated using standard WP3 flux calculations. The ^{13}C fluxes from the ^{13}C pulsed plots are a combination of pre-existing natural abundance ^{13}C (all environmental samples have background ^{13}C) and elevated pulse-derived ^{13}C. To correct for the new and old ^{13}C, the amount of ^{13}C in soil respiration in the absence of the pulse was calculated using chamber data from outside the ^{13}C pulsed plots. This was the Natural Abundance flux. The excess ^{13}C flux from the ^{13}C pulse was then calculated by:

Pulse Labelled ^{13}C flux – Natural Abundance ^{13}C flux = Excess ^{13}C Flux ($\mu g\ m^{-2}\ hr^{-1}$)

4.4.5 Respiration results

Soil respiration values for the Willow and *Miscanthus* steadily declined in line with environmental conditions. Willow respiration rates ranged from 122 to 5 mg CO_2-C $m^{-2}\ hr^{-1}$ and *Miscanthus* rates ranged from 101 to 7 mg CO_2-C $m^{-2}\ hr^{-1}$ (Figure 22). A preliminary statistical assessment indicates that total soil respiration was significantly higher for Willow compared to *Miscanthus* ($F_{[1,11]}$ = 12.27, p=0.0049). Statistical differences were calculated using mixed effects models with time as random factor to account for repeated measures over time.

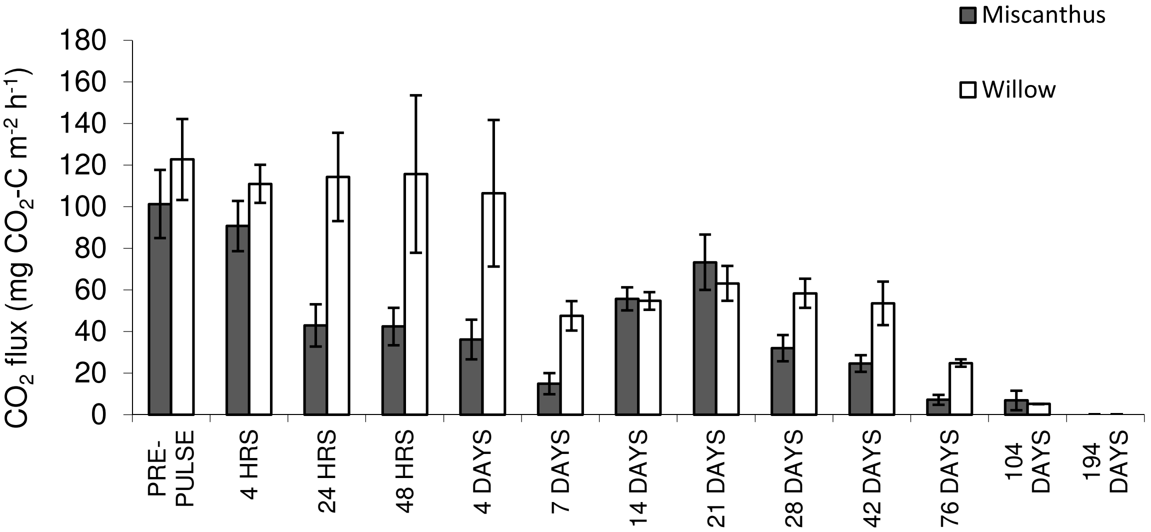


Figure 22: Soil respiration rates based on chamber data from the ^{13}C pulsed plots. These data represent to the total C flux from the soils. Error bars are standard errors of the mean ± 1SE.

$\delta^{13}C$ values measured from chambers in the ^{13}C pulsed plots were elevated above background levels in Willow and *Miscanthus* with the former showing the greatest enrichment (Figure 23). The highest ^{13}C enrichments were observed during the first week following the ^{13}C pulse. Figure 23 shows this dynamic. As the $\delta^{13}C$ values in respiration do not account for the quantity of carbon (i.e. a flux) only its ^{12}C:^{13}C ratio of the C being emitted; isotope mass balance equations we made to quantify the ^{13}C excess flux in respiration which was derived from the pulse (Section 4.4.4). Results mirror the ^{12}C:^{13}C ratio data with greater pulse-derived ^{13}C flux from under the Willow plots compared to the *Miscanthus* (Figure 24). A preliminary statistical assessment indicates that ^{13}C excess in respiration was significantly higher for Willow compared to *Miscanthus* ($F_{[1,11]}$ = 6.70, p=0.0230). Statistical differences were calculated using mixed effects models with time as random factor to account for repeated measures over time.

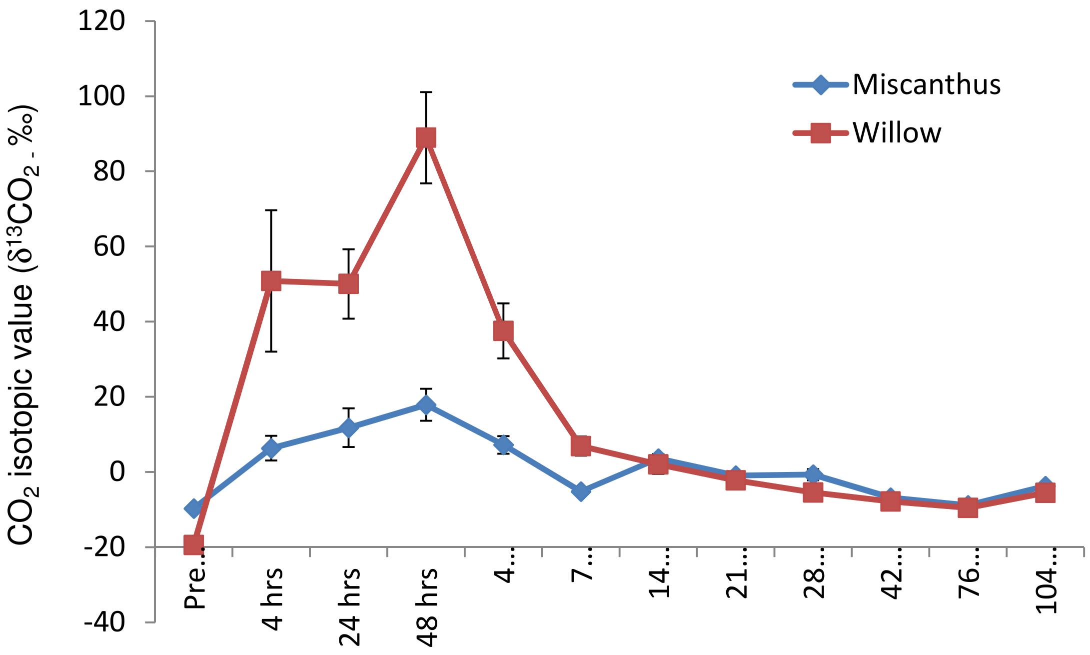


Figure 23: The δ13C of soil respiration collected in chambers from the ^{13}C pulsed plots. These data represent the isotopic value of the headspace chamber value after 45 minutes enclosure. Error bars are standard errors of the mean ± 1SE

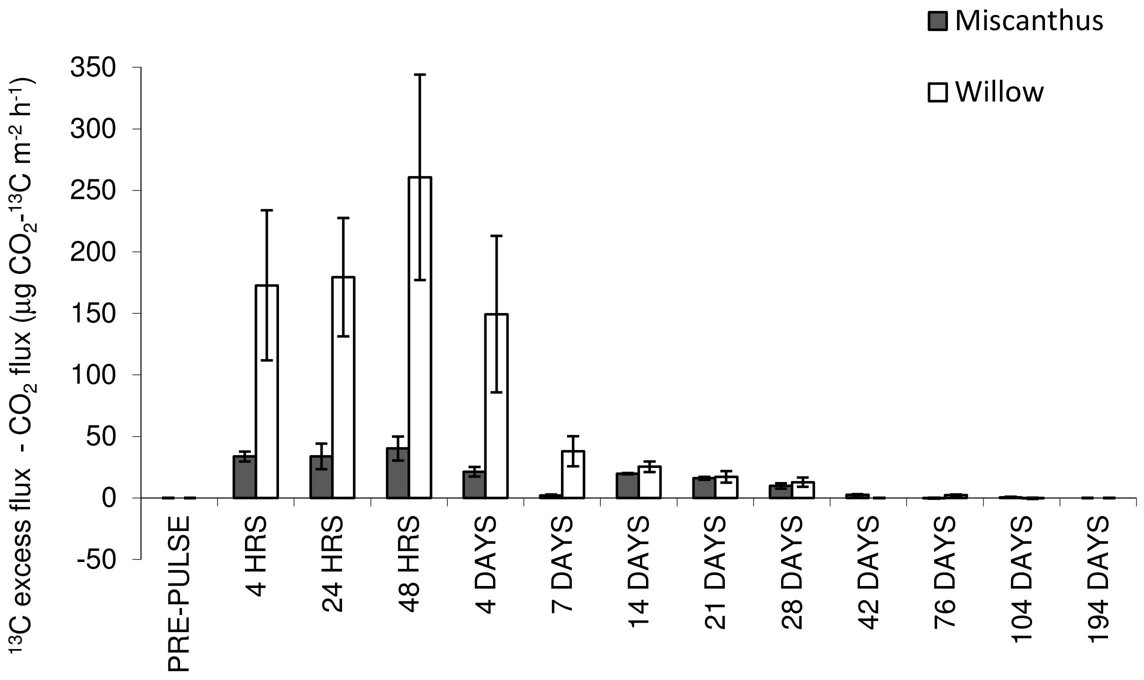


Figure 24: ^{13}C fluxes in excess of the background flux from Willow and *Miscanthus*. These data represent C flux that has arisen from the recently fixed $^{13}CO_2$. Error bars are standard errors of the mean ± 1SE

4.4.6 Bulk samples

Bulk samples including soil, leaves, roots and rhizomes will be analysed from the end of May 2013. Until all the higher priority gas samples were analysed, limited development time has been available to link our Costech ECS Carbon Analyser to the Picarro Trace Gas Analyser. The combination of the two is a world first and despite some technical issues, our validation with certified standards is showing promising results (Table 7).

Table 7: Analyses of two sugar standards using the Costech ECS linked to the Picarro CRDS. The sugar beet standard is -26.03‰ and the cane sugar is -11.64‰

Sample	Wt (mg)	Measured δ^{13}C (‰)	Sample	Wt (mg)	Measured δδ^{13}C (‰)
Beet sugar	2.47	-26.508	Cane sugar	1.95	-11.264
Beet sugar	3.33	-26.531	Cane sugar	1.98	-11.531
Beet sugar	1.88	-26.394	Cane sugar	2.33	-11.222
Beet sugar	2.88	-26.670	Cane sugar	2.75	-11.287
Beet sugar	2.32	-26.726	Cane sugar	3.59	-11.173

4.4.7 Discussion

This pulse labelling has been a technical challenge in terms of the sheer scale of the field event and with respect to laboratory developments regarding isotopic analysis of samples. Results so far are intriguing as *Miscanthus* appears to lock up more of the fixed C compared to the adjacent Willow plots. The difference between these two crops is striking. Our understanding of where this fixed C is going requires ^{13}C analysis of bulk samples of soil and plant material which is imminent. It is important to highlight that a component of the elevated ^{13}C respired from the soils during the first week could come from the introduced ^{13}C tracer itself (residual tracer) as opposed to being fixed C that is being cycled back through the plant soil system as ecosystem respiration. However, the amount of ^{13}C returned follows the total rates of soil respiration strongly suggesting that this is biotic response (compare Figure 22 and Figure 24). A further consideration is that this comparison does not account for the fact that the two crops are at slightly different growth cycles. The *Miscanthus* was still in an active growth phase while peak growth for Willow has occurred earlier. This and the fact that *Miscanthus* has a C4 photosynthetic pathway provides the likely explanation for the different C fixation rates observed. A consideration or lesson learned for such comparisons is that multiple ^{13}C pulses would generate a greater understanding of seasonal and growth stage impacts on C fixation into soils. Such work would, however, extend beyond the life of ELUM.

5. COLLATION OF DATABASE

Work on the database, in collaboration with WP4 (Aberdeen University) is at an early stage because the emphasis so far in WP3 has been on defining what is to be measured, establishing the protocols required to achieve that, installing the measurements systems and to begin making measurements. A start has been made in designing the appropriate structures to best capture data for subsequent modelling analysis. The prototype spreadsheets for the soil GHG fluxes and ancillary data have been reviewed, modified as necessary and finalised. These have been used for the accompanying data file, which comprises part of this deliverable. A prototype spreadsheet has been developed for the meteorological data and will be finalised by the end of June 2013. These will be refined in the light of ongoing experience and with the further input of the WP4 modelling team at Aberdeen.

6. CONCLUSIONS

All the project Year 2 objectives for this work package have been achieved. All objectives are ongoing and will continue through Year 3, as shown below in Table 8.

Table 8: Status of Year 2 WP3 Objectives

Objective	**Status**
To complete the installation of any instrumentation required at the sites	Completed
To make measurements of soil GHG and ancillary data at monthly intervals	Ongoing
To make eddy covariance (EC) and meteorological measurements	Ongoing
To deliver a ^{13}C pulse labelling experiment in Lincolnshire	Ongoing
To collate appropriate site details required for WP4 modelling	Ongoing
To summarise the results and highlight lessons learnt to be applied to subsequent measurements to improve their quality	Ongoing

At the two sites with arable to bioenergy crop transitions, the global warming potential (GWP) of the soil GHG emissions from the bioenergy crops is dominantly due to CO_2 emissions, with small contributions from CH_4 and N_2O. For the arable crops, N_2O is important, although CO_2 emissions are still dominant. At the Lincolnshire site, the CO_2 emissions were lowest from the *Miscanthus*, highest from the SRC willow and mid-range from the arable crop. However, at the East Grange site there was no significant difference between the CO_2 emissions of the different bioenergy crops. A full analysis will be carried out at the end of 2013, along with the data from WP2, in order to understand these differences.

For transitions from grass to woody bioenergy crops, CO_2 fluxes were the main contributor to the GWP. The *Miscanthus* was planted during the year which probably explains why N_2O emissions made the largest contribution to the GWP shortly after planting but the CO_2 fluxes dominated the second half of the year. At all three sites the CO_2 fluxes from the bioenergy crops were less than those from grass.

The processing, QC and filling of gaps is not yet complete for the eddy covariance data acquired in 2012. However, the quality of the data is good and general seasonal and diurnal patterns are recognizable in the data. This data will be fed forward to the WP4 modelling team once all data have been fully worked-up.

Year 2 activities have met all expectations and so there are no recommendations for significant changes to the plans for Year 3.

7. PLANS FOR YEAR 3

Year 2 has met all expectations and so there are no recommendations for significant changes to the plans for Year 3.

7.1 The Sites

All instruments at the sites have now been installed. It will be necessary to remove and re-install some of the EC instruments to deal with land management considerations, notably at the *Miscanthus* sub-sites and the Lincolnshire arable sub-site, where harvesting will take place.

Ongoing land management activities, for example fertiliser applications and harvests, will be quantified and documented.

Meteorological and hydrological measurements will continue. They will be quality controlled and added to the database.

7.2 Estimating the Soil Carbon Stock and Dynamic

Sampling and analysis at all the sites was completed in Year 2. In Year 3 an analysis of the results will be completed through WP2.

7.3 Quantifying GHG Emissions

Monthly measurements and analysis of soil GHG fluxes will continue. A more detailed analysis of the results will be carried out towards the end of Year 3 in conjunction with the WP4 modelling team.

EC measurements will continue with the nine systems. A meeting to finalise agreement on the parameters to be used for processing, QC and gap-filling will be held the day before the ELUM Annual Meeting (June 2013). If it is appropriate to use the same parameters for the data from all the sub-sites will then be used to produce the datasets required by WP4. A detailed analysis of the dataset will be carried out towards the end of Year 3 and it has been agreed that deliver of data taken before 1 December 2013 will be delivered to WP4 by the end of the 2013.

Ancillary data (soil water content and temperature and air temperature) will continue to be collected, at the same time as the soil GHG fluxes are measured, and will be analysed.

Over the coming year, the gantry system of the novel GHG technology will continue to be developed. The system was deployed before the protocol for measurement from the apparatus had been refined. Similarly, not all the data from the initial testing, when methane and nitrous oxide analysers were used has been analysed. It is intended that these analysers will be deployed to measure the fluxes of CH_4 and N_2O from over *Miscanthus* at high temporal resolution in a campaign structure throughout the coming growing season. In order to achieve this, a protocol must be in place that produces results that are reliable. This begins with analysis of existing data and further experimentation. Further considerations regarding future plans for novel GHGs are detailed in Appendix I.

7.4 ^{13}C Pulse Labelling of Genotypes

A ^{13}C pulse labelling experiment is planned for the replicated *Miscanthus* genotype experiment in Aberystwyth near the end of July 2013 (Figure 25). The aim here is to supplement the WP3 existing GHG work with further insight into below ground C cycling for three genotypes. We choose *Miscanthus Giganteus* which is the main commercial variety as well as *Sinensis* and *Sacc/Lut* varieties. *Sinensis* is also commercially available but is predominantly used as an ornamental plant rather than as an energy crop. However, research has shown that that it is not as vulnerable as *Giganteus*, with regards to late spring frosts and has a higher combustion quality than *Giganteus*. The *Sacc/Lut* cross was chosen as *Sacchariflorus* has demonstrated the ability to produce high yields during field trials, while at the same time showing considerable variation in the response of yield to different site conditions. Although it is very early days and still much belowground work to be carried out, currently this genotype looks to have the tallest canopy, the biggest CO_2 flux and has the highest soil C content.

Figure 25: Arrangement of the *Miscanthus* genotype trials. In all there are 27 different genotypes in the experiment replicated in 3 experimental blocks.

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APPENDIX I – FURTHER CONSIDERATIONS FOR NOVEL GHG EXPERIMENTS

As seen in the data generated from cover boxes, the prolonged closure time required to etect fluxes of CH_4 and N_2O may affect the flux of CO_2. The effect of chamber closure time on the fluxes measured with the gantry system needs to be investigated. It is proposed that this is done in a controlled experiment, where fluxes from the same positions are measured for varying lengths of time with the gantry chamber.

Whilst developing the measurement protocol, the method of sealing the chamber requires refinement. At present the trolley from which the chamber is suspended will stop accurately at the prescribed position due the presence of magnets placed at intervals on the beam. The issue of landing accurately and consistently is harder to resolve, as wind causes the chamber to sway. Guides for aiding chamber location are being developed. Additionally the chamber, and crucially the seal the landing base makes with the soil surface must be checked for leaks. The principle on which flux chamber measurements are founded is that the change in concentration from a known volume is measured. This requires the system to be well sealed; the method used thus far for preventing leakage from under the landing base has been to pack sand around the soil-base interface. The effectiveness of this will be investigated by injecting a tracer such as N_2O or SF_6 into the chamber and observing the concentration over time. An alternative to using sand to form the seal is to drive the base into the soil, but even doing so to a shallow depth can have an effect on fluxes (Heinemeyer *et al.* 2011) and so a surface-sitting base is preferable.

Another question that must be answered is whether the gas within the closed chamber is sufficiently well mixed to allow an accurate flux measurement to be made. This may be addressed by the addition of a fan to stimulate mixing. The counter argument to this is that it may create an artificial level of turbulence within the chamber. Another controlled experiment where the treatment is in the presence (or not) of a fan within the chamber should be conducted to deduce the effect it has on measured fluxes. Related to the mixing of the headspace gas within the chamber is the point from which the gas is sampled. In the study presented here the pipe drawing gas from the chamber was positioned at the top of the chamber (2.7 m above the soil surface in this instance) and the return pipe outlet was positioned at the bottom of the chamber (when the height of the landing base is accounted for, this is still 1.2 m above the soil surface; this will alter when measuring early in the growing season since the landing base extension will not be required and the chamber will in effect be much smaller). Nottingham *et al.* (2012) showed that by altering the position that gas is returned to a Li-Cor chamber the flux measured was significantly altered. This is another factor therefore, that must be investigated.

A manipulation experiment will be carried out through the 2013 growing season with this apparatus and it is proposed that this will be a nitrogen (N) addition experiment. The application of N fertiliser to arable crops is the largest driver of N_2O emissions, and one of the purported benefits of *Miscanthus* is its low requirement for N; the *Miscanthus* at the field site does not receive N fertiliser. However, guidelines for farmers recommend the addition of between 50 and 100 kg N ha^{-1} yr^{-1} (DEFRA 2011, Thelen *et al.,* 2009, Teagasc & AFBI 2010). Cadoux *et al.* (2012) report that on average 75 kg N ha^{-1} is removed from land in the form of harvested *Miscanthus*. Whilst annual N deposition from the atmosphere may keep up with this removal, Christian *et al.* (2008) found that, although yields may not decline, N application will be required to prevent soils becoming N depleted through long term (10 years) cultivation of *Miscanthus*. Taking this into consideration, it is important to know what effect on trace gas fluxes N addition to *Miscanthus* will have, since this will have a strong influence on the life-cycle analysis of energy production from the crop.

In addition to this, automated chambers will be redeployed within the *Miscanthus* to measure soil respiration, and similar chambers will be used in the adjacent arable field. Measurements with coverboxes will continue, and the addition on CH_4 and N_2O analysers to the gantry system will also be completed.