Quantifying the effects of no till vegetable farming and organic mulch on greenhouse gas emissions and soil carbon

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AHR Environmental Pty Ltd

Project Number: VG09138

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This report is published by Horticulture Australia Ltd to pass on information concerning horticultural research and development undertaken for the vegetables industry.

The research contained in this report was funded by Horticulture Australia Ltd with the financial support of Applied Horticultural Research P/L.

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ISBN 0 7341 3016 3

Published and distributed by:
Horticulture Australia Ltd
Level 7
179 Elizabeth Street
Sydney NSW 2000
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Fax: (02) 8295 2399

HAL

Horticulture Australia

***HAL Project Number**:* VG09138

(Completed March 2012)

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AHR Environmental

Horticulture Australia
Project Number: VG09138

March 2012

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Funding

This project has been funded by HAL using voluntary contributions from industry and matched funds from the Australian Government.

The broad objective of this project was to assess the potential of sustainable vegetable farming systems, developed by AHR and others, to reduce CO_2 and N_2O emissions and to sequester carbon in soils. It also measured productivity of these alternative crop production systems.

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Media Summary

The broad objective of this project was to assess the potential of sustainable vegetable farming systems, developed by AHR and others, to reduce carbon dioxide (CO_2) and nitrous oxide (N_2O) emissions. This was achieved by first measuring greenhouse gas emissions and soil carbon (C) levels on common vegetable crops (processing potatoes, lettuce, broccoli and cabbage) grown using sprinkler irrigation and conventional nutrition and cultivation practices. Subsequently, no-tillage permanent beds, cover crops and organic mulches were established and the measurements repeated.

Baseline N_2O emissions were in the range of 15-25 mg N_2O h^{-1} m^{-2}, and spikes in N_2O emissions were caused by nitrogen fertilizer applications and rainfall events. Methane (CH_4) emissions were about 300 mg CH_4 h^{-1} m^{-2}, and were affected by rainfall events. CO_2 emissions were highest for lucerne and annual rye cover crops, with emissions in the order of 400 g CO_2 h^{-1} m^{-2}. Organic mulch, chicken manure and inorganic fertilizer treatments resulted in lower CO_2 emissions of about 250-300 g CO_2 h^{-1} m^{-2}. Organic mulch resulted in the greatest accumulation of soil C over time.

The data collected is a valuable contribution to that currently available on greenhouse gas emissions and soil C for the Australian vegetable industry. Soil C levels and CO_2 emissions were modelled using the RothC model and predictions made for 100 years, for various land use scenarios.

Organic mulch and annual rye cover crops resulted in the highest level of CO_2 emissions and also the highest level of C sequestration in the soil. Inorganic fertilizer resulted in the lowest C emissions and sequestration.

The work will be published in a recognised international scientific journal, as it represents some of the first baseline vegetable soil greenhouse gas emissions data available for the Australian vegetable industry.

Technical Summary

The broad objective of this project was to assess the potential of sustainable vegetable farming systems, developed by AHR and others, to reduce CO_2 and N_2O emissions. This was achieved by first measuring greenhouse gas emissions and soil C levels on common vegetable crops (processing potatoes, lettuce, broccoli and cabbage) grown using sprinkler irrigation and conventional nutrition and cultivation practices. Subsequently, no-tillage permanent beds, cover crops and organic mulches were established and the measurements repeated. The data collected is a valuable contribution to the scant data currently available on greenhouse gas emissions and soil C form the Australian vegetable industry.

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The prediction of CO_2 lost to the atmosphere under different land management practices followed a similar relationship with the amount of plant residue applied to or incorporated into soil, i.e. the more plant residue applied the greater the amount of CO_2 released to the atmosphere. In the case of organic mulch the CO_2 loss would occur regardless, as this plant residue is sourced from council green waste. The comparison between land use patterns therefore becomes somewhat arbitrary, but still clearly shows the relationship between higher levels of plant residue and higher accumulated loss of CO_2 from cropping systems.

Soil C storage was higher for land management practices such as organic mulch, where a large volume of green waste was added to supply enough nitrogen (N) for efficient crop growth. Very little C was stored from conventional synthetic fertiliser applications, as almost no additional C was added for this cropping system. The release of CO_2 and storage of C in the soil is strongly related to the amount of organic matter grown on the land or incorporated from elsewhere. Additional storage of C in the soil will help offset higher CO_2 loss, particularly considering that this loss will occur regardless, as in the case of council green waste.

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The work will be published in a recognised international scientific journal, as it represents some of the first baseline vegetable soil greenhouse gas emissions data available for the Australian vegetable industry.

The mulch and no-till systems need to be established for a longer period than was possible with this relatively short-term experiment. The data clearly shows there is great potential in cover crops, mulch and compost treatments for building soil C levels, and there is potential for greenhouse gas emissions to stabilise over time. Data needs to be collected from 5-year experiments to confirm these trends. The other area of

great potential is in managing the inter-row area in perennial tree crops, where soil disturbance is minimal and long-term C sequestration is feasible. Data should be collected on these systems.

As rainfall and fertilizer events clearly influence N_2O and CH_4 emissions from soils, these events need to be taken into consideration when interpreting greenhouse gas emission data.

For static chambers, there should be a standardised chamber size and sampling time so that data collected can be compared between research groups. There is also a need to calibrate the static systems by comparing them alongside automatic systems for a period of time. Initial data suggests manual static chambers that have an internal volume of 6,300 cm^3 should be closed for 15 minutes before gas samples are taken.

Introduction

Climate change research has focused largely on predicting the magnitude and consequences of the climatic disturbances that greenhouse emissions will cause, and the case is compelling. The next research priorities are to develop ways for agriculture to adapt to the consequences of changing weather patterns and, more importantly, to develop techniques that mitigate against greenhouse gas emissions (Howden, 2009).

There has been significant research into developing adaptations to deal with the climate changes caused by greenhouse gases. But such adaptations will provide only short-term relief; there remains an urgent need to develop mitigation techniques and quantify impacts on greenhouse gas emissions and soil carbon.

Agriculture has been identified as a major polluter responsible for 16% of total greenhouse gas emissions (Garnaut 2008; Greenhouse 2009: Climate Change and Resources conference in Perth 23-26th March 2009).

While most emission estimates relate to broadacre cropping and livestock systems, open-field vegetable production systems can also release significant quantities of greenhouse gases. High nutrient input, irrigation and cultivation can cause rapid oxidation of stable soil C and N, which leads to elevated CO_2 and N_2O emissions. N_2O emissions in Australian arable cropping systems are also high, varying from 0.02 – 15.4% of N fertiliser applied (Dalal et al. 2003). The impact of N_2O as a greenhouse gas is 300 times greater than that of CO_2 (Forster et al. 2007; van Groenigen et al. 2011).

The Australian vegetable industry produces $3.2 billion worth of produce each year on 103,000 ha of irrigated soils (AusVeg 2008). A typical, intensively-managed vegetable crop releases up to 2.3–3.6 t CO_2-eq ha^{-1} to the atmosphere (Neufeldt and Schafer 2008). Based on this estimate, vegetable soils in Australia release from 236,900 to 370,800 t of C per year.

As in life, when seemingly unrelated skills can sometimes converge into useful synergies, the research AHR has completed on developing sustainable no-till vegetable cropping systems may have potential for producing vegetable crops with minimal or even negative CO_2 emissions. If the techniques of minimum-tillage organic cover crops are combined with the use of legumes to fix nitrogen, it may be possible to significantly reduce N_2O emissions from vegetable cropping soils.

Management practices such as no-tillage and residue mulching help sequester C in the soil by increasing soil organic matter levels and reducing the rate of C breakdown (Rogers et al. 2004; Kumar et al. 2005; Wang et al. 2005; Carrera et al. 2007; Stirling 2008), hence improving the sustainability of vegetable systems. The amount of C that potentially can be sequestered is significant, e.g. if soil organic C in the top 10 cm can be increased by 1%, this translates to the sequestration of 37 t ha^{-1} C. A 12-year study of no-till vegetable cropping in Michigan USA showed that C was sequestered at a rate of 0.26 t ha^{-1} $year^{-1}$ in the 0-5 cm soil layer; this represents 0.9 t of sequestered C per ha per year or 10.8 t ha^{-1} of C over the 12-year period (Grandy et al. 2006).

The effects of these practices on N_2O emissions in intensive vegetable systems are less understood (Grandy et al. 2006). Vegetable crops grown under high nutrient and water regimes commonly leave significant amounts of residual N, which is then either

leached or lost as N_2O through denitrification. For example, crop residues of a spinach crop can leave up to 200 kg ha^{-1} of N in the soil after harvest (Guler 2005). In addition, crop residues on the soil surface after harvest can contain large amounts of N, e.g. cauliflower leaves; 20–80 kg ha^{-1} of N, spinach and celery; 25–60 kg ha^{-1} of N, white cabbage and Brussels sprouts 150–250 kg ha^{-1} of N (Neeteson et al. 1999).

AHR conducted two Horticulture Australia Limited (HAL) funded projects (VG98050; VX10133) and one Natural Heritage Trust funded project (NHT 982032), ostensibly on commercial farms in the major production areas in Australia, resulting in a great deal of long-term data being collected on the effects of no-till on soil microbial biomass (SMB) and organic matter levels (Rogers 2002; Rogers 2002; Rogers et al. 2004; Rogers et al. 2007). A key feature of this research was the use of cover crops, which were killed and used as in-situ organic mulch. The substitution of organic mulch for plastic mulch alone represents a saving in CO_2 emissions of about 0.5 t ha^{-1}, based on the amount of C in plastic mulch.

A separate HAL project (VG09142) has produced a carbon foot-printing tool (***Carbon Vegetable Calculator***) to quantify the effects of vegetable farming practices on the evolution or sequestration of greenhouse gases (http://www.vegiecarbontool.com.au).

The broad objective of this project was to assess the potential of sustainable vegetable farming systems, developed by AHR and others, to reduce CO_2 and N_2O emissions. This was achieved by first measuring greenhouse gas emissions and soil C levels on common vegetable crops (processing potatoes, lettuce, broccoli and cabbage) grown using sprinkler irrigation and conventional nutrition and cultivation practices. Subsequently, no-tillage permanent beds, cover crops and organic mulches were established and the measurements repeated. The data collected will be a valuable contribution to the scant data currently available on greenhouse gas emissions and soil C for the Australian vegetable industry.

It will also provide the C vegetable calculator project with data that quantifies the effects of no-till vegetable farming and organic mulches on the net soil CO_2 and N_2O emissions or sequestration, which can then be incorporated into the carbon foot-printing tool.

Review of two previous AHR/HAL projects aimed at developing sustainable permanent bedding systems for vegetables and their effects on soil carbon

The following HAL projects were reviewed:

> *VG98050 – Development of a sustainable integrated permanent bed system for vegetable crop production including sub-surface irrigation extension*
>
> *VX01033 – Establishment of no-till permanent bed vegetable production systems in the major vegetable growing regions in Australia*

These projects aimed to address production aspects of permanent-bed vegetable agronomy, in particular: relative yield and quality of different crops compared with conventional plastic mulch systems; water use; nutritional requirements; determining most suitable cover crops; and methods for growing and mulching them. There was no particular objective to capture changes in soil C, particularly in VX01033, which was aimed at testing and extending the findings from VG98050 in other major vegetable production areas with a particular emphasis on grower extension.

The key findings from VG98050 of relevance to the current project were:

Soil Organic Carbon

Soil organic C levels in tomato trials at Bowen, North Qld were maintained using *Centrosema* sp. mulch but have declined under plastic mulch over 2 years.

Table 1: Changes in Organic Carbon over two years (Figure 4.2, VG98050)

Soil organic matter (% - Walkley Black)

Treatment	1997	1998	1999
Organic mulch *(Centrosema sp.)*	1.5	1.20	1.45
Organic mulch (Bluegrass cv. Hatch)	1.5	1.39	1.20
Organic mulch (Bluegrass cv. Keppel)	1.5	1.12	1.06
Plastic mulch	1.5	1.20	1.00
Inter-row area	1.5	1.09	-

Dry Matter Production

In addition to C sequestered in the top 30 cm of soil, the following dry matter yields were obtained from different cover crops. The cover crops were sprayed with herbicide, rolled and then left on the soil surface. Dry matter measurements were taken once the cover crops were dead, but prior to planting vegetable crops through the residue. Figure 1 refers to the Northern Queensland trials and Figure 2 refers to trials at Richmond in NSW. The units in Figure 1 are t ha^{-1}; and in Figure 2 are g m^{-2}.

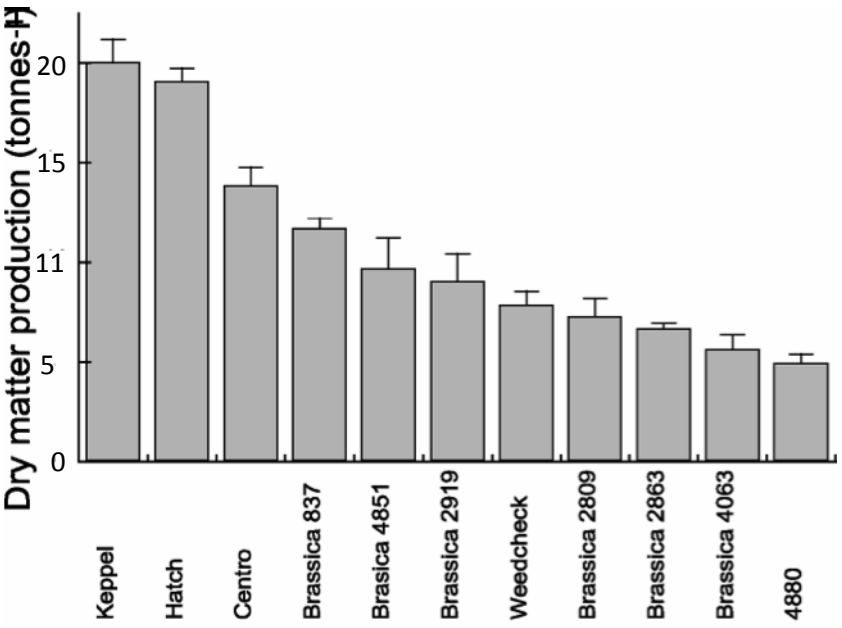

Figure 1: Dry Matter Production of cover crops at Bowen, Qld, in t ha^{-1} (Figure 1.3, VG98050).

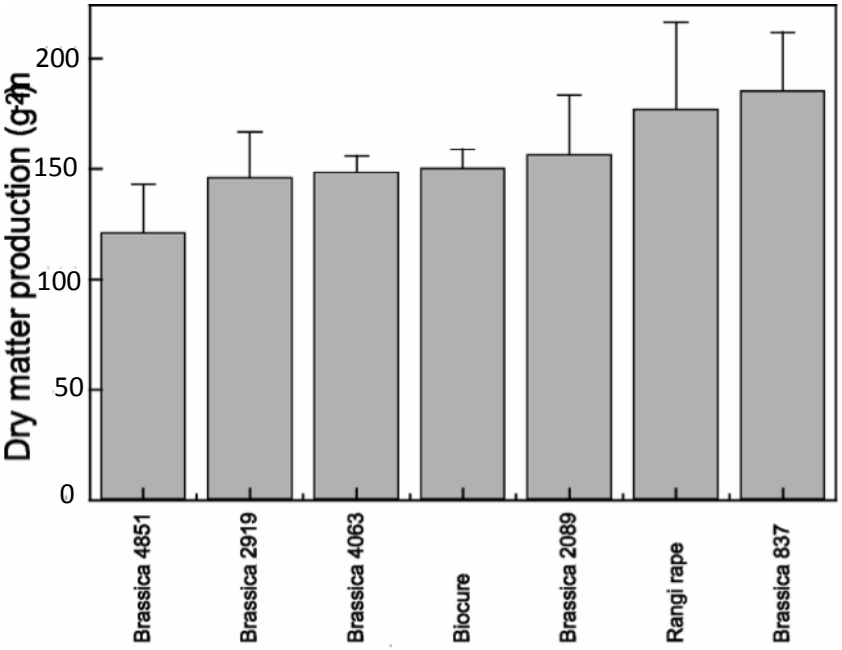

Figure 2: Dry Matter Production of Brassica cover crops at Richmond, NSW, in g m^{-2} (Figure 2.1.1, VG98050).

Soil Microflora and Fauna Carbon

The data below show soil microbial levels in soil samples taken from permanent beds under cover crop residues, or beneath plastic mulch at the beginning of a tomato crop and during the fruiting stage of production (Tables 2 & 3; Tables 4.4 & 4.5, VG98050).

Table 2: Pre-Planting Soil Samples

	Permanent beds		**Cultivated beds**	
Culturable micro-organisms (log cfu/g soil)	**10 cm**	**20 cm**	**10 cm**	**20 cm**
Total bacteria	7.24	7.81	7.39	6.93
Gram positive bacteria	6.93	6.67	6.39	6.39
Fluorescent pseudomonads	5.60	4.81	3.81	4.2
Actinomycetes	6.85	5.93	7.43	6.54
Total fungi	5.39	4.85	4.86	4.20
Microbial activity (µg FDA hydrolysed/g/min)	0.348	0.253	0.193	0.3 12
Free-living nematodes (numbers/200 ml soil)				
Fungal feeding nematodes	940	840	550	846
Bacterial feeding nematodes	1340	2040	550	1800
Omnivorous nematodes	88	20	0	9

Table 3: Plant Fruiting Stage Soil Samples

	Permanent beds		**Cultivated beds**	
Culturable micro-organisms (log cfu/g soil)	**10 cm**	**20 cm**	**10 cm**	**20 cm**
Total bacteria	8.30	7.39	7.39	7.22
Gram positive bacteria	7.30	5.93	6.74	7.22
Fluorescent pseudomonads	5.30	5.08	4.93	4.85
Actinomycetes	6.39	6.59	6.39	6.74
Total fungi	5.22	5.53	5.36	5.04
Microbial activity (µg FDA hydrolysed/g/min)	0.339	0.268	0.276	0.259
Free-living nematodes (numbers/200 ml soil)				
Fungal feeding nematodes	200	150	160	240
Bacterial feeding nematodes	860	760	400	450
Omnivorous nematodes	7	2	6	0

The pre-plant soil samples showed that biological activity in the upper 10 cm of soil was higher in the permanent bed / mulched soil compared to cultivated beds. Permanent beds and organic mulch resulted in a higher microbial activity, more free-living nematodes and higher populations of fluorescent pseudomonads. These effects are likely due to the use of plastic mulch and detrimental effects of cultivation when the field was prepared for planting. The low numbers of omnivorous nematodes in the standard block may also be due to cultivation. These large nematodes are usually killed when soil is cultivated (Table 3).

Samples taken from the upper 10 cm of the permanent bed when the crop was 3 months old showed that there were more gram-positive bacteria, total bacteria, fluorescent pseudomonads and bacterial-feeding nematodes, and greater microbial activity compared to the cultivated soil. These differences in soil microflora were not apparent at a depth of 20 cm.

Overall, these results suggest that the soil in the permanent bed has a better microbial status than the standard block, particularly in the upper 10 cm of soil.

The Bowen work (Figure 4.1, VG98050) also showed worm populations increased to as much as 8000 m^{-3} under a Centro cover crop, compared with none under plastic and less than 500 m^{-3} in native uncultivated soil.

Conclusions

Permanent-bed vegetable cropping has shown up to 50% better retention of soil organic C than conventional plastic mulch systems over two years when the most suitable cover crops are selected. This was due to retention of pre-trial soil C levels, not due to net gain over the measurement period of 2 years.

If mulches are considered to be part of the C sequestered, then certain cover crops, particularly in the tropics, have the potential to produce as much as 20 tonnes of dry matter per ha. Clearly much of the C in this dry matter will be returned to the atmosphere once the organic matter is decomposed, but the potential exists for some of this C to be sequestered in soils in the longer term.

Under permanent beds, soil organisms and microorganisms also increase the live C fraction of the soil in the top 30 cm.

Literature review of greenhouse gas emissions from sustainable cropping systems of relevance to vegetable production

The impacts on greenhouse gas emissions of conventional and sustainable agronomic practices have been extensively researched and reviewed in broadacre agriculture. However, there have been few similar studies in horticulture.

Horticultural production in Australia occupies about one million hectares, and due to the high level of inputs such as irrigation water, nutrients and cultivation, it is likely to be responsible for much higher greenhouse gas emissions per unit area than broadacre agricultural cropping or grazing.

Soil organic carbon (SOC) is a large potential sink for sequestering C on a global scale (Komatsuzaki & Ohta 2007). The C sink capacity of the world's agricultural and degraded soils is 50-66% of the historic C loss or 42-72 Pg (1 Pg=10^{15} g). Apart from its C sequestering potential, SOC helps to sustain fertility and conserve soil water quality. And organic C compounds play a vital role in the nutrient, water and biological cycles.

The significance of this terrestrial C sink in agriculture is well recognised, and was a major focus of recent Australian Department of Agriculture, Fisheries and Forestry *Action on the ground* and *Filling the research gaps* initiatives.

No-tillage practices, cover crop management and manure applications all have potential to enhance SOC as well as contribute to sustainable food production and soil quality. The added benefit of sequestering carbon as a SOC is the associated improvements in soil health and consequently crop productivity. A potential negative aspect of building SOC levels is that this can be at the expense of increasing emissions of non-CO_2 greenhouse gases (Komatsuzaki & Ohta, 2007). In horticulture, soil C sequestration and greenhouse gas emissions can be strongly influenced by the modifying the impact of irrigation (Grace, 2008).

Minimum tillage and soil carbon

In Australian dry land agriculture, reduced tillage is aimed primarily at improving soil moisture retention. The practice has been widely adopted and uptake has continued to increase over the last 20 years. While there is now data to also support the use of minimum tillage for C sequestration in soils, this can be difficult to achieve due to the impact of high temperatures and variable rainfall.

Conservation tillage systems, including no-till, leaves more organic residue on the soil surface because the soil is not turned over (Komatsuzaki & Ohta, 2007). The organic matter is retained in stratified soil layers, with highest concentrations nearer to the surface due to the lack of soil disturbance. Stratification of layers can be reduced in no-till situations by selecting crops with deeper roots.

Crop trash retention alone does not necessarily result in improved SOC. A long-term (60-year) study from a wheat soil in Oregon, USA, showed how soil C could be maintained when stubble was retained and cultivated in with 111 kg ha^{-1} $year^{-1}$ of N supplied as organic

manure. This contrasted with a steady decline in SOC when the residue was burned, cultivated in with no added N or cultivated in with the addition of 90 kg ha^{-1} $year^{-1}$ of inorganic N. The critical factor was the gradual mineralisation of organic N, and therefore the greatly reduced losses of N through leaching of NO_3. Furthermore, higher C:N ratios in soils with higher SOC reduced the availability of N, only gradually making it available (Komatsuzaki & Ohta, (2007). Another example is: after 12 years of no-tillage under a maize-soybean rotation in southern Illinois, the top 75 cm of soil showed that a no-till system sequestered 0.71 Mt ha^{-1} $year^{-1}$ more SOC than by mouldboard ploughing and 0.46 Mt ha^{-1} $year^{-1}$ more SOC than by chisel ploughing (Olson *et al*, 2005).

There are also limits to the amount of SOC that can be retained. Soils lose SOC more readily as the SOC content increases (Komatsuzaki & Ohta, 2007). In a Japanese soya sweet-corn rotation, a variety of steady-state systems produced a balance between C input and mineralisation within five years.

Yan *et al* (2007) showed that practising no-tillage on 50% of China's arable land and returning 50% of the crop residue to the soil would lead to an annual soil sequestration of 32.5 Tg of C, or about 4% of China's annual emissions for that year. This effect was expected to persist for 20-80 years. Metay *et al* (2007) found that in *Cerrado* soils in Brazil, in the top 10 cm of soil, no-tillage resulted in a net benefit of 350 kg of C sequestered per year compared with conventional tillage (offset discs to 15 cm).

Minimum tillage and greenhouse gas emissions

Manipulating tillage systems has great potential for reducing CO_2 emissions in agricultural cropping (Govaerts *et al*, 2009). Cultivation causes increased fluxes of CO_2 by increasing soil aeration and microbial activity that converts SOC into CO_2 (Komatsuzaki & Ohta, 2007). The highest fluxes of CO_2 occur in moist soils immediately after tillage. While individual experimental results vary, it is widely accepted that CO_2 emissions from cultivated soils are greater than those from uncultivated soils. Models have been developed to describe short-term soil C losses after tillage.

Six *et al* (2004), found that greenhouse gas mitigation through adoption of minimum tillage is complex and significant benefits are likely to occur in the long term. The importance of N_2O was much greater than previously thought and a better understanding of the role of N management was required before any definitive answers could be given on the net benefit of no-tillage.

N_2O emissions under conservation tillage are also influenced by the form of nitrogenous fertilizer applied. Venterea *et al* (2005) found a significant reduction in N_2O emissions after broadcasting urea or applying anhydrous ammonia to a minimum tillage but little difference in emissions between cultivation methods when N was applied as urea or ammonium nitrate.

In a corn-soybean rotation in Midwest USA, in the short-term (2 years), no tillage resulted in lower emissions of CO_2 than conventional methods involving heavy cultivation (mouldboard or chisel ploughing). Nearby, in a similar study, Ussiri & Lal (2009) found the trend was still the same after 43 years, with about 70% less SOC remaining after mouldboard or chisel

plough cultivation and approximately 24% higher average daily CO_2 emissions compared with no tillage.

In Denmark, in loamy sand planted to spring barley, Chatskikh and Olesen (2007) found during a 113-day trial, that no-tillage reduced emissions of both CO_2 (about 25%) and N_2O (about 50%), compared with full conventional tillage.

Liu *et al* (2007) analysed soil cores in a laboratory and found higher fluxes of N_2 + N_2O, N_2O and CO_2 from the no-till soil than from conventional tillage. Ammonium N increased emissions of N_2 and N_2O compared with nitrate N, when soil moisture exceeded 60% water-filled pore space. N emissions continued to increase as soil moisture increased, presumably under anaerobic denitrification.

The finding by Lui *et al* (2007) supports the idea that when uncultivated soils become poorly aerated, anaerobic soil microbial activity is promoted and can lead to a reduced rate of oxidation of SOC to CO_2. Anaerobic soil conditions favour denitrification and the production of N_2O. Anaerobic conditions can also favour the production of CH_4 and means that reduced tillage aimed at increasing SOC levels risks causing greater fluxes of N_2O and CH_4 from the soil if anaerobic conditions are created (Komatsuzaki & Ohta, 2007).

Depth of fertiliser placement can also be a factor in greenhouse gas emissions. In a three-year wheat-corn-soybean field study in Canada, Drury *et al* (2006) found N_2O emissions were lower when the N fertilizer was placed deeper in the soil. This finding was supported by long-term results of a similar study by Liu *et al* (2006) under continuous maize cropping on a Colorado clay soil which showed lower nitrogen oxide (NO) and N_2O emissions at 10-15 cm compared to very shallow placement at 0-5 cm. CO_2 and CH_4 emissions were not affected by the depth of nitrogen placement.

Soil organic matter content may also modify greenhouse gas emissions. In soil with very high organic matter content, cultivation had no effect on CO_2 or CH_4 emissions while N_2O emissions were greater in cultivated soils, all at the same moisture content (Elder & Lal, 2008).

Studies into the impact of cultivation on CH_4 emissions have found either no effect of cultivation on CH_4 emissions, or no-till causing an increase in emissions (Omonode *et al*, 2007). The determining factor is most likely the impact on soil aeration since anaerobic soil conditions favour CH_4 formation.

Modelling of carbon sequestration and greenhouse gas emissions

The CENTURY model can be used to model soil C, N, S and P dynamics, and it has been used more recently to estimate C sequestration under full-tillage and no-tillage situations. This model shows a good correlation between observed and predicted SOC sequestration (R^2=0.83), and that a reduction in tillage intensity results in greater C sequestration in a Mediterranean semi-arid agro ecosystems (Alvaro-Fuentes *et al*, 2009).

The DAYCENT model is a daily version of the CENTURY. It was developed more recently and is being used by the intergovernmental panel on climate change (IPCC) to estimate direct and indirect N_2O emissions for major cropping systems in the USA. It can be used to

model fluxes of all three major greenhouse gases. Del Grosso *et al* (2005) used the DAYCENT model to evaluate major cropping across the USA and, including machinery emissions, the study found that conversion to no-tillage would lower the US national agricultural emissions by 20%.
La Scala Jr *et al* (2008) developed a first-order decay model that uses the decay rate of C in cultivated and uncultivated soil, together with the amount of labile C added, to predict CO_2 fluxes to a high degree of accuracy (R^2=0.97).

Clay mineralogy in those soils with a significant clay component appears to play a key role in determining the extent to which SOC can be sequestered under conservation tillage (Denef *et al*, 2004). In fact, the Rothamsted soil C model uses the clay fraction of soils to estimate changes in soil C. Therefore soils that have higher clay content also have a higher propensity to store C.

Impact of machinery emissions

Very few studies appear to incorporate emissions from machinery in CO_2 calculations. A Croatian study looking at wheat, soybeans, barley and maize compared conventional full tillage with no-till and found that across all crops total CO_2 emissions, including those from machinery, were reduced by around 88% for no-tillage systems (Filipovic *et al* 2006). This indicates that although CO_2 emissions can sometimes be higher under no-tillage, when emissions from machinery are taken into account, overall CO_2 emissions are higher for tillage cropping systems.

Organic mulches and manures

Adding manure to soils can lead to increased CH_4 and N_2O emissions (Yagi, 2002). Good management, such as avoiding excessive manure application and optimizing the application timing to synchronize with crop uptake, can reduce this negative impact on greenhouse gas emissions and maximise the positive effects of manure addition on SOC storage (Johnson *et al,* 2005).

Cover crops

Cover crops are a critical tool for sustainable soil management because they can scavenge soil residual N and help to establish an optimal N cycle (Komatsuzaki & Ohta, 2007). Grain cover crop residues have high C:N ratios and yield large amounts of litter, which can increase the soil organic matter content. Leguminous crops also produce considerable litter, but their residues have lower C:N ratios. Brassica crops produce small amounts of litter and the C:N ratio of their residues is low. These low C:N residue-producing crops result in quick decomposition of residues in the soil (Komatsuzaki, 1999). This supports the idea that intensive vegetable-producing soils have a greater capacity to sequester SOC than most field crops, despite the relatively small production area compared to broadacre crops.

The effect of cover crops on N_2O emissions depends more on the N application rate than form or timing. (Jarecki *et al*, 2009). High-yielding vegetable crops usually require more

nutrients to be present in the soil than can be absorbed. Even where only organic manures are used to produce a high-yielding crop, nutrients are usually provided in excess of requirement. This leads to excessive nutrient leaching, particularly of $NO_{3,}$ and potential N_2O production. In such situations as this, the use of cover crops becomes an even more attractive alternative, since they can prevent N leaching or emission by accumulating excess soil N (Wagger and Mengel 1988, Gu *et al*, 2004).

Leguminous cover crops are potentially very useful because they have the potential to fix atmospheric N, thereby reducing or eliminating the need to supply N. This reduces the demand for synthetic nitrogenous fertilizers that are manufactured using fossil fuels and therefore reduces CO_2 emissions associated with fertilizer manufacture.

Materials and Methods

Experiment 1: Collection of baseline data using automated gas flux chambers

Location of experiments

Experiments were conducted on a commercial farm located near Theresa Park, NSW (Grech Farms). The soil type was a sandy loam with irrigation provided from the Nepean River by a lateral move irrigation system. Plants were grown on standard 1.2 m wide raised beds on 1.8 m centres. The crops were managed as per commercial practice at this farm; no treatment effect was imposed. This was a commercial crop where gas emissions from soil were measured.

Experimental design

Three chambers were each placed in commercial crops of lettuce, cabbage and broccoli. The edge of the chamber was pushed 5 cm into the soil. Chambers were mostly open and were only closed for 20 min every 3 h, to allow for gas sampling. The system was not designed to be gas-tight during sampling; rather it was designed as a “leaky system”.

Lettuce: Plants were grown in 3 rows with 30 cm spacing between plants. The crop was approximately 5 weeks from harvest when gas sampling commenced. Chambers were positioned so that one lettuce head was fully contained in the chamber. Image 1 illustrates the placement of one of the chambers in the lettuce crop.

Image 1: Example of a gas-sampling chamber placed in a lettuce crop at Grech Farms. Note the doors are normally open, and close briefly to collect gas samples.

Broccoli: Plants were grown in 3 rows with 40 cm spacing between plants. The stage of development for plants was at the 9th true leaf. Chambers were positioned so that one broccoli plant was fully contained in the chamber.

Cabbage: Plants were grown in 2 rows with 50 cm spacing between plants. The developmental stage of plants was at the 14th true leaf. Chambers were positioned between plants, enabling emissions from the inter-row area to be measured. This placement of chambers differs from that of lettuce and broccoli.

Gas chambers were installed in respective crops on the 8th June 2010. Measurements were taken every three hours until the 22nd July 2010, which was when the lettuce crop reached commercial maturity. The sampling period was therefore 44 days.

Gas sampling

Gas samples were taken and measured in situ using The University of Sydney's field-deployable gas-measuring system. This system is comprised of 9 automated chambers capable of measuring CH_4 and N_2O using a gas chromatograph (GC), and CO_2 using an infrared gas analyser (IRGA). The system also measures soil moisture, soil temperature, rainfall and internal chamber temperature. All data is logged to a laptop that also controls the parameters of the system. It is capable of operating unattended for up to 7 days in remote locations, Image 2.

Image 2: Vehicle and trailer, which house the monitoring equipment.

The greenhouse gas emissions from each crop were monitored using three portable chambers. Gas samples were measured in situ. The system accumulates gases for 20 min and then measures the concentration while the next chamber is accumulating gases. Gases were sampled and then immediately measured using IRGA and GC instruments, Image 3.

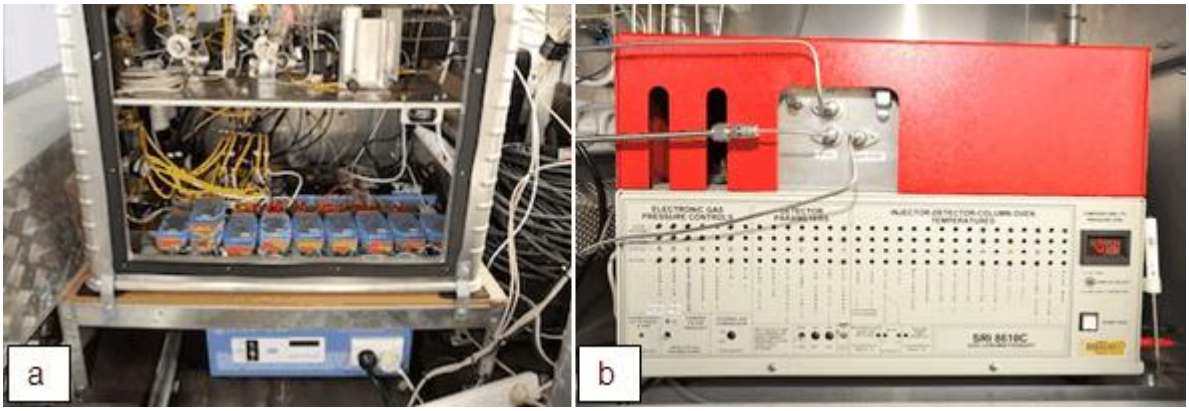

Image 3: (a) Sampling equipment and infrared gas analyser used to measure CO_2 emissions; (b) gas chromatograph instrument used to measure CH_4 and N_2O emissions.

Soil samples

Soil samples were taken from 0-10 cm and 10-20 cm at the end of the sampling period. These samples were taken at each monitoring site from within the sampling plot and analysed separately, giving 3 replicates per crop.

Leaf samples from crops were also taken at the end of the experiment. Ten whole heads of lettuce were sampled at maturity. For cabbage and broccoli, 20 of the youngest fully expanded leaves were sampled. Cabbage plants were sampled at the half-head developmental stage and broccoli at the 4-6 cm head stage.

Experiment 2: Baseline data for potatoes and calibration of static chambers

Location of experiments

Experiments were conducted on a commercial farm located near Theresa Park, NSW (Grech Farms). Irrigation was provided by a lateral move irrigation system. Potato plants were grown on standard 0.9 m row width, with 30 cm spacing between plants. The crop was managed as per commercial practice at this farm; no treatments were imposed. This was a commercial crop and gas emissions from soil were measured.

Experimental design

Four static chambers were placed in a commercial potato crop. The edge of the chamber was pushed 6 cm into the soil. Gas samples were taken during December 2010 and January 2011. The chambers were randomly placed in the crop, between plants. The lids of chambers were closed with samples taken after 15, 30, 45, 60 and 120 min. The chambers are designed as a “leaky system”, with a 2 mm ventilation tube near ground level.

Image 4: Illustration of a manual static gas chamber in a potato crop at Grech Farms, Theresa Park. Note the septum on the lid and thermometer used to measure internal chamber temperature.

Gas sampling

The chambers had an approximate air volume of 6,300 cm^3 and were located in the centre of a row over bare soil (Image 4). The lid and rubber seal were placed on chambers, after which samples were taken at different time intervals. Gas samples were taken in the morning and afternoon, starting at 1000 and 1400 hrs, respectively. Gas samples were taken on 17th and 21st December 2010; and 12th, 16th and 19th January 2011. At each sampling event a 25 ml gas sample was taken and transferred into evacuated 10 ml Exetainer® glass vial (Labco Ltd, United Kingdom). The air temperature was recorded when the sample was taken, as temperature influences the density and hence concentration of gases. A small amount of blue-tack was then placed over the rubber septum of the Exetainer® to ensure a good seal. Samples were stored at ambient temperature until they were analysed.

Analysis of gases

Approximately half of the samples were sent to The University of Melbourne for analysis. Technical staff there determined the concentration of N_2O, CH_4 and CO_2 using gas chromatography (GC). In brief: samples were split into two poropak-q columns (80/140, 6 ft x 1/8 in. X 2.1 mm, Sigma-Aldrich), one going to an electron-capture detector (ECD) for N_2O, and the other via a methaniser to a flame ionisation detector (FID) for CH_4 and CO_2. The column was maintained at 40 °C, with a carrier gas flow rate of 25 ml min^{-1}. The remainder of samples were measured using a GC system set up by AHR specifically to measure greenhouse gas emissions from soil. Full details of analytical conditions are described below in experiment 3.

Statistical analysis

The data were analyzed using GenStat® 13th ed. (Hemel Hempstead, United Kingdom). Restricted maximum likelihood (REML) was used to analyse gas data, with minutes and time of day analysed as factors. Differences between means were determined using least significant difference (5%).

Experiment 3: Impact of cover crops and no-till

Location of experiments

Experiments were conducted on a commercial farm located near Theresa Park, NSW. Irrigation was provided by fixed sprinkler systems and was supplied as required by the farm manager. Irrigation was not supplied to crops on the morning of gas sampling. Crops were grown on standard 1.2 m wide raised beds. Weeds were controlled during the experiment using a combination of herbicide, mechanical and hand-tillage.

Experimental design

Experiments were arranged in a completely randomised block design with five treatments and four blocks. Treatments used represented different land use practices including: Treatment 1 - inorganic nutrient supply and cultivation (referred to as the *calcium nitrate*); Treatment - 2 organic mulch; Treatment – 3 chicken manure; Treatment - 4 lucerne cover

crop and Treatment 5 - annual rye grass cover crop. These land use patterns were examined for their effect on greenhouse gas emissions, SMB and soil C and N%.

Cover crops

Lucerne and annual rye grass cover crops were sown on the 24th February 2011 at commercial densities of 4 and 20 kg ha^{-1}, respectively. Cover crops were grown for approximately 5 months, after which they were killed using glyphosate herbicide on the 11th July 2011 (Image 5). The fresh and dry biomass produced by the cover crops was measured by using a quadrant.

Image 5: View of the trial site before crops were transplanted. Note the size of plots and the placement of static manual gas chambers.

Nitrogen supply

Initial soil samples were taken after cover crops were sprayed with herbicide to determine the fertiliser requirement. All soil macronutrients, with the exception of N, were supplied at non-limiting levels, and then 150 kg ha^{-1} of N was supplied to soil on 21st July 2011. The N content of different sources and the amount applied to plots is described below in Table 4.

Table 4: The percentage nitrogen content of different amendments and the total applied to different treatment plots.

Treatment	N%	Amendment/plot* kg
Calcium nitrate	15.5	1.0
Organic mulch^	0.9	13.0
Chicken manure^	4.6	3.3
Lucerne cover crop	15.5	1.0
Annual rye cover crop	15.5	1.0

*Note: plot area was 15 m^2. ^Moisture content of organic mulch and chicken manure was taken into consideration when rates were determined.

The treatments calcium nitrate, lucerne and annual rye grass cover crops received 150 kg ha^{-1} of N from calcium nitrate. The organic mulch treatment received 150 kg ha^{-1} of N from green compost. The chicken manure treatment received 150 kg ha^{-1} of N from chicken manure. A side application of 50 kg ha^{-1} of N was applied to cover crop treatments on 16th September 2011 (56 days after transplanting).

Organic mulch was sourced from M. Collins & Sons of Milperra, Sydney. The product used was called Collins rich earth compost, which is manufactured to AS4454-2003. The chicken manure was sourced from the farmer and was taken from the composted pile which was ready for application. The composting process involved the periodic turn of manure until it is dry enough to spread evenly.

Transplanting

Commercial seedlings of head lettuce and cabbage were acquired from Choice Seedlings Pty. Ltd., Theresa Park. The choice of varieties was based on recommendations made for the period of growth for respective crops. The lettuce variety used was Patagonia (Rijk Zwaan), and the cabbage variety was Green Coronet (Terranova Seeds). Seedlings were transplanted by hand on the 22 July 2011. They were planted in two rows per bed with 33 cm spacing between lettuce plants and 60 cm for cabbage.

Gas sampling

Chambers were placed in the inter-row area approximately in the centre of each plot. Samples were taken using the same method described in experiment 2. Gas samples were taken from the 29th July 2011 on a weekly basis starting at 1000 hrs and finishing at about 1200 hrs. Irrigation was not provided to plots on the morning of gas sampling, this ensured that irrigation events did not influence the level of gas emissions from soil. Samples were collected for 17 weeks for lettuce and 19 weeks for cabbage, which corresponded to the length of time required to reach maturity. The chamber lid was closed for 15 min before samples were taken. Chambers remained in the same location throughout the experiment (Image 6).

Image 6: Example of the placement of gas sampling chambers in the inter-row area of crops.

Gas measurement methodology

Nitrous oxide

The concentration of N_2O in samples was determined using, an 8A-Shimadzu (Kyoto, Japan) GC fitted with ECD (Image 7a). A Porapak Q (80/100, 6 ft x 1/8 in. X 2.1 mm, Sigma-Aldrich) column was used to separate gases. Column temperature was 70 °C and injection temperature 80 °C. Helium was used as the carrier gas with a pressure of 2 kg cm^{-2}. A 0.5 ml gas sample was injected into the ECD with a run-time of 5 min. N_2O in air was used to calibrate the instrument at the beginning of each day.

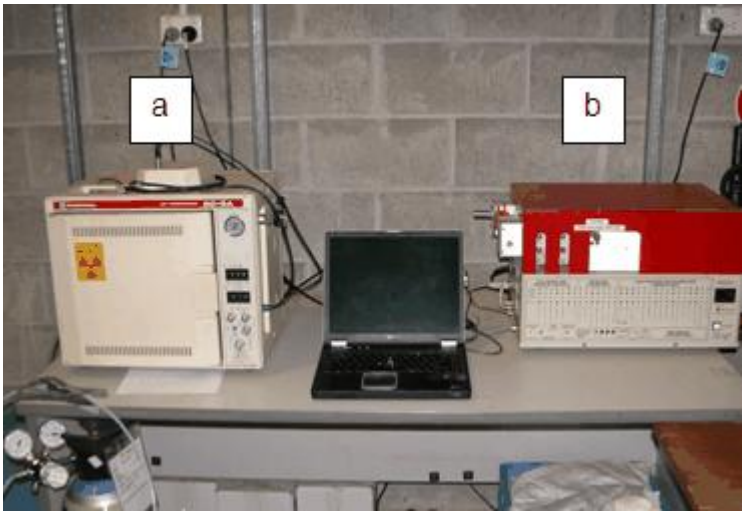

Image 7: Gas chromatography instruments set up for measuring N_2O (a), CH_4 and CO_2 (b) emissions from soil.

Carbon dioxide and methane

An SRI instruments (California, United States) GC with a thermal conductivity detector (TCD) to measure CH_4, and a FID to measure CO_2 were used to determine the concentration of gases emitted from soil (Image 7b). The TCD was operated at 130 °C, and FID 180 °C. Air pressure was 0.56 kg cm^{-2}, hydrogen pressure 0.84 kg cm^{-2} and helium pressure 0.63 kg cm^{-2}. Oven temperature was 35 °C with an injection volume of 3 ml. Samples had a run-time of 3.5 min. The sample was separated using a Porapak Q (80/100, 6 ft x 1/8 in. X 2.1 mm, Sigma-Aldrich) column. Samples were first passed through the TCD and then the FID, as the FID is destructive. CH_4 and CO_2 in air were used to calibrate the instrument at the beginning of each day.

Soil samples

Soil samples were taken pre-transplant to determine the amount of N fertilizer required. Bulk samples were taken from 0-15 cm and sent to Phosyn Analytical (QLD) for analysis. Soil macronutrient concentrations are summarised in Table 5.

Table 5: Concentration (as $mg \cdot kg^{-1}$) of soil macronutrients before nitrogen application.

Treatment	pH	NO_3^-	P	K	Ca	Mg	S
Control	6.6	10.0	119.0	160.0	1984.0	174.0	48.0
Lucerne	6.6	0.0	110.0	164.0	1976.0	160.0	33.0
Annual rye grass	6.6	0.0	115.0	160.0	2086.0	194.0	21.0

Soil microbial biomass

Soil samples were taken pre-transplant and postharvest at depths of 0-15 cm and 15-30 cm and stored at 5 °C until extraction. Soil microbial biomass C and N was determined by the fumigation-extraction technique (Horwath & Paul, 1994; Michelsen *et al,* 2004; Ohlinger, 1995).

In brief: soils were sieved to 2 mm, triplicate sub-samples of 4 g dry weight were weighed with control and fumigation samples. Control samples were extracted with 40 ml 0.05 M K_2SO_4 and shaken for 1 h at 200 rpm. Extracts were then filtered using Whatman no. 42 filter papers. Fumigated samples were placed in a pressurised desiccator for 48 h with chloroform and anti-bumping granules. The desiccator was kept moist and in the dark during fumigation of soil. After fumigation soil extraction was the same as described above. Samples extracts were stored at -20 °C until analysis.

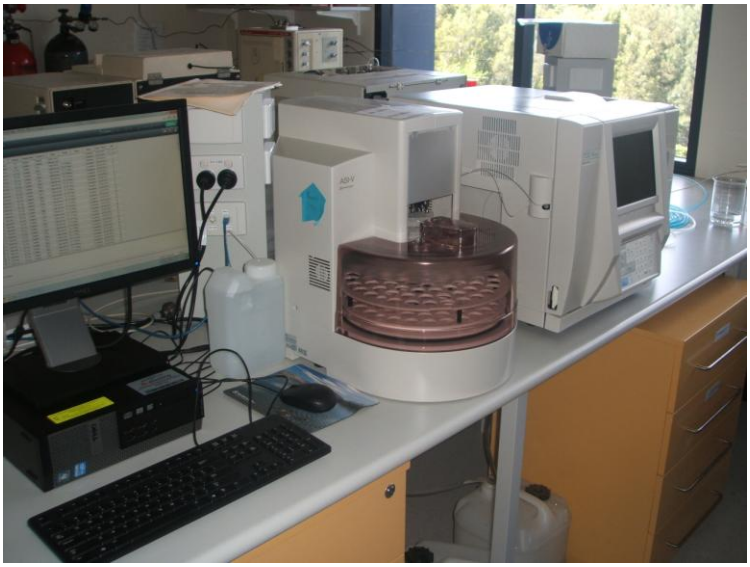

Image 8: Shimadzu total organic carbon analyser and total nitrogen measuring unit used to determine soil microbial carbon and nitrogen.

Total C and N in soil extracts were determined using a total organic carbon (TOC) analyser, fitted with a total nitrogen measuring unit (TNM-1), Shimadzu (Kyoto, Japan), image 8. Concentrations were determined in 50 µl of extract, with 3 to 4 injections per sample.

Potassium hydrogen phthalate ($C_8H_5KO_4$) was used as a standard for C calibration, and Potassium nitrate (KNO_3) for N calibration. The instrument was calibrated daily before samples were measured.

Calculations of SMB were as follows:

Carbon

$V = FW – DW + EV$

Where:
V = volume of solution in extracted soil (ml)
FW = fresh weigh of soil (g)
DW = dry weight of soil (g)
EV = extracted volume (ml)

$C_F = EC_f \times V/DW$
$Cc = EC_c \times V/DW$
Where:
C_F = extractable C in fumigated sample in µg/g soil
EC_f= extractable C in fumigated sample in µg/ml
Cc = extractable C in control sample in µg/g soil
EC_c= extractable C in control sample in µg/ml

Microbial biomass carbon (MBC)

$MBC = (C_F\text{-}C_C)/k_{EC}$

k_{EC}= extraction coefficient for extractable C = 0.35

Nitrogen

$N_F = EN_f \times V/DW$
$Nc = EN_c \times V/DW$

Where:
N_F = extractable N in fumigated sample in µg/g soil
EN_f= extractable N in fumigated sample in µg/ml
Nc = extractable N in control sample in µg/g soil
EN_c= extractable N in control sample in µg/ml
Microbial biomass nitrogen (MBN)

$MBN = (N_F\text{-}N_C)/k_{EC}$

k_{EC}= extraction coefficient for extractable C = 0.35

Soil carbon and nitrogen percentage

Soil samples were further sieved to 50 µm with total C and N determined in 1 g of dried soil using an Elementar vario Max CNS macro analyzer (Hanau, Germany), Image 9. Combustion and post-combustion tubes were operated at 900 °C, and the reduction tube operated at 830 °C. Gas pressures were 3.9 kg cm^{-2} for helium and 2.6 kg cm^{-2} for oxygen. The standard glutamic acid was used for calibration.

Image 9: Elementar carbon and nitrogen analyser used to determine total soil carbon and nitrogen.

Harvesting

Basic yield data was measured for crops when they reached commercial maturity. Head weight, trimmed weight, core diameter and dry weight were measured for both crops. In addition, core length and tip burn were measured for lettuce and head diameter for cabbage. A total of 10 plants were harvested from respective plots. Weights were measured using an electronic balance and lengths using a ruler.

Carbon modelling

The Rothamsted C model was used to predict soil C changes based on land management practices. The model allows for the prediction of soil organic C in topsoils over a specified period, which can range from years to centuries. The model requires various input factors including: climatic averages, soil type, plant cover and quantity of organic matter added to the system. The main principle of the model is that C and its behaviour in the soil is strongly correlated with the soil clay fraction. Therefore soil C is modelled based on the clay fraction of a given soil, combined with environmental factors.

RothC model parameters

Weather data

All weather data was acquired from the Bureau of Meteorology (BOM) website, climate and past weather tab (www.bom.gov.au/climate/). Camden weather station #68007 was used for historical monthly temperature and rainfall averages; while Prospect Dam weather station #67019 was used for monthly evaporation averages (Table 6).

Table 6: Weather averages used in the RothC model.

Month	Temperature °C	Rainfall mm	Evaporation mm
January	23.1	85.4	170.5
February	22.7	86.2	131.6
March	20.9	80.9	120.9
April	17.4	62.9	90.0
May	13.8	56.8	62.0
June	11.1	59.8	48.0
July	10.1	44.2	55.8
August	11.5	39.9	80.6
September	14.4	39.6	108
October	17.0	57.2	136.4
November	19.5	65.9	150.0
December	21.8	67.5	176.7

Land management data

Land management source files were used to model the effects of management practices on soil C and accumulated losses of CO_2 to the atmosphere. Three variables were required to model land use patterns: plant resides, farmyard manure (FYM) and soil coverage. Plant residue values were determined by the quantity of organic mulch supplied to the system or the amount of C provided by cover crops. The only land management file that had values for FYM was the organic mulch/chicken manure scenario. Information for the different land management source files are detailed in Tables 7-11 below.

Table 7: Treatment 1 - calcium nitrate

Month	Plant residues (t C ha^{-1})	FYM (t C ha^{-1})	Soil cover
January	0.1	0	covered
February	0.0	0	covered
March	0.0	0	covered
April	0.0	0	covered
May	0.1	0	covered
June	0.0	0	covered
July	0.0	0	covered
August	0.0	0	covered
September	0.1	0	covered
October	0.0	0	covered
November	0.0	0	covered
December	0.0	0	covered

Table 8: Treatment 2 - organic mulch

Month	Plant residues (t C ha^{-1})	FYM (t C ha^{-1})	Soil cover
January	3.6	0	covered
February	0.0	0	covered
March	0.0	0	covered
April	0.0	0	covered
May	3.6	0	covered
June	0.0	0	covered
July	0.0	0	covered
August	0.0	0	covered
September	3.6	0	covered
October	0.0	0	covered
November	0.0	0	covered
December	0.0	0	covered

Table 9: Treatment 3 - chicken manure

Month	Plant residues (t C ha^{-1})	FYM (t C ha^{-1})	Soil cover
January	0.1	0.5	covered
February	0.0	0.0	covered
March	0.0	0.0	covered
April	0.0	0.0	covered
May	0.1	0.5	covered
June	0.0	0.0	covered
July	0.0	0.0	covered
August	0.0	0.0	covered
September	0.1	0.5	covered
October	0.0	0.0	covered
November	0.0	0.0	covered
December	0.0	0.0	covered

Table 10: Treatment 4 - lucerne cover crop

Month	Plant residues (t C ha^{-1})	FYM (t C ha^{-1})	Soil cover
January	1.6	0.0	covered
February	0.0	0.0	covered
March	0.0	0.0	covered
April	0.0	0.0	covered
May	1.6	0.0	covered
June	0.0	0.0	covered
July	0.0	0.0	covered
August	0.0	0.0	covered
September	1.6	0.0	covered
October	0.0	0.0	covered
November	0.0	0.0	covered
December	0.0	0.0	covered

Table 11: Treatment 5 - annual rye grass cover crop

Month	Plant residues (t C ha^{-1})	FYM (t C ha^{-1})	Soil cover
January	2.3	0.0	covered
February	0.0	0.0	covered
March	0.0	0.0	covered
April	0.0	0.0	covered
May	2.3	0.0	covered
June	0.0	0.0	covered
July	0.0	0.0	covered
August	0.0	0.0	covered
September	2.3	0.0	covered
October	0.0	0.0	covered
November	0.0	0.0	covered
December	0.0	0.0	covered

Conversion of soil C% to t C ha^{-1}

The model requires that input variables including soil C be in the unit t ha^{-1}. As a result, soil C% values measured in experiment 3 were converted to a t C ha^{-1} basis using the following formula:

t C ha^{-1} = soil C% × bulk density × soil depth

where:
soil C%, is mg of C in 1g of soil
bulk density, is 1.4
soil depth, is 30 cm

The starting point of 80 t C ha^{-1} was used for modelling and represents the average C levels in soil at Grech Farms (Theresa Park).

Modelling of scenarios

Land management source files were used to predict changes in soil C and the amount CO_2 lost at different time intervals of: 1, 2, 3, 4, 5, 10, 15, 20, 50 and 100 years. Comparisons between these factors across land management scenarios were made at these time intervals.

In addition, five management scenarios were examined with combinations of different land management practices; one longer term (100 years), one mid-term (20 years) and three shorter term (10 years) scenarios were modelled. Scenario 1 - examined the effects of 20 years of organic mulch amendments followed by 80 years of chicken manure amendments. Scenario 2 - examine the effects of adopting an annual rye grass cover cropping system for 5 years, followed by 10 years of reverting back to synthetic fertiliser amendments, and then again adoption a cover cropping system for another 5 years. Scenario 3 - examined the effect of 5 years organic mulch followed by 5 years chicken manure. Scenario 4 - examined the effects of organic mulch amendments for 5 years and then reverting back to synthetic

fertilizer for another 5 years. Scenario 5 - examined the effects of 5 years of synthetic fertilizer amendments followed by 5 years of lucerne cover cropping. Constant land use patterns and combinations were plotted in respective scenarios allowing for comparisons to be made.

Statistical analysis

The data were analyzed using GenStat® 13th ed. (Hemel Hempstead, United Kingdom). General analysis of variance (ANOVA) was used to analyze soil and yield data, while REML was used to analyse gas data. Differences between means were determined using least significant difference (5%) or least squares means analysis. Responses of crops were not directly compared, as they have different physiological and growth characteristics.

Results

Experiment 1: Collection of baseline data using automatic chambers

The chambers were removed from the field on the 27th July 2010 when the lettuce crops were mature and ready for harvest. Cabbage crops were at the heading stage, they were healthy with no obvious signs of pests or diseases. Broccoli crops were in the early heading stage, with heads 4-6 cm in diameter. Plants were generally healthy, but there was a small amount of the bacterial disease (Black Rot) present in the crop which was of minor significance and would not have affected the results. There were no significant weed infestations in any of the crops.

The soil and leaf test results are shown in Table 12 and 13, respectively. The soil results indicate high NO_3 and NH_4 levels, particularly for the lettuce crop at a depth of 0-10 cm (Table 12). In addition, high NO_3 levels were measured in lettuce tissue (Table 13). This is consistent with the finding that N_2O emissions were higher in lettuce compared to the other two crops (Table 14).

Analysis of repeated measures

To eliminate split runs, daily averages were computed for each individual chamber. A repeated measurements generalised linear model (GLM) was run for the 27 time points for each of the three gases. This enabled daily averages and minimum and maximum emission levels to be calculated.

Sphericity can be assumed for the CO_2 daily average dataset (df=350, Mauchley's W<0.001). Fluxes of CO_2 vary significantly over time (df=26, P<0.001). Fluxes of CO_2 vary significantly between vegetation types over time (df=52, P<0.001). After factoring in the effect of time, crop type has a significant effect on rates of CO_2 evolution (df=2, P<0.001).

Sphericity can be assumed for the CH_4 daily average dataset (df=350, Mauchley's W<0.001). Fluxes of CH_4 do not vary significantly over time. There is, however, significant variation in each crop type over time (df=52, P<0.001). Fluxes of CH_4 vary significantly between crop type (df=2, P=0.013).

Sphericity can be assumed for the N_2O daily average dataset (df=350, Mauchley's W<0.001). Fluxes of N_2O do not vary significantly over time. There is, however, significant variation in a specific crop type over time (df=52, P=0.018). There is no significant difference in rates of N_2O flux between crop types after factoring in the effect of time.

Table 12: Soil test results for the broccoli, cabbage and lettuce monitoring sites.

Crop	Depth (cm)	NO_3-N (mg/kg)	se	NH_4-N (mg/kg)	se	Soil P (mg/kg)	se	Organic carbon (%)	se	Soil CEC	se	Soil pH (H_2O)	se	Soil EC (mS/cm)	se
Broccoli	0-10	7.17	1.22	2.00	0.36	106.00	4.16	1.71	0.07	11.89	0.22	7.13	0.03	0.11	0.01
	10-20	11.07	6.07	1.77	0.18	114.33	1.45	1.80	0.03	11.42	0.35	7.17	0.03	0.11	0.02
Cabbage	0-10	17.47	5.71	1.90	0.15	114.00	2.31	1.69	0.06	12.88	0.10	7.17	0.07	0.14	0.02
	10-20	10.20	2.70	1.80	0.35	114.33	1.45	1.71	0.08	12.81	0.82	7.23	0.03	0.14	0.04
Lettuce	0-10	22.60	3.65	2.47	0.72	97.67	3.18	1.30	0.04	10.85	0.20	6.93	0.03	0.14	0.01
	10-20	9.87	2.32	1.83	0.03	99.67	4.84	1.32	0.05	10.50	0.06	6.97	0.03	0.11	0.01

Note: full soil test data is available, however only N, P and organic matter data is presented in this report.

Table 13: Leaf tissue nutrient results

Crop	Nitrogen (%)	NO_3 (mg/kg)	P (%)	K (%)	S (%)	Ca (%)
Broccoli	5.43	3190	0.43	2.52	1.05	1.98
Cabbage	3.41	3216	0.23	1.43	0.61	1.13
Lettuce	5.08	4545	0.43	4.53	0.33	0.89

Note: full tissue nutrient data is available however only NPK, NO_3, S and Ca is presented here.

Analysis of total mass flux

All flux rates were converted to mass-based equivalents using the 0.25 m^{-2} chamber area and 0.8 h run-time. Values were summed for the duration of the deployment for each chamber. Means and errors calculated for each cropping type are summaries below in Table 14.

Table 14: Total gas fluxes for lettuce, cabbage and broccoli.

	g CO_2		mg CH_4		mg N_2O	
	Mean	SE	Mean	SE	Mean	SE
Lettuce	51.3	1.4^{b}	-1.1	1.1^{b}	56.9	15.3^{a}
Cabbage	50.9	6.5^{b}	-4.6	0.7^{a}	16.9	2.5^{a}
Broccoli	84.2	1.5^{a}	-2.3	0.7^{b}	19.8	8.3^{a}

The total mass of effluxed CO_2 was greater for the broccoli crop, which respired significantly greater quantities of CO_2 than either lettuce or cabbage. The cabbage crop oxidized the greatest mass of CH_4 from the atmosphere when compared to the other crops. There were no significant differences between the total quantity of N_2O lost. This is despite the graphic divergence of emissions from the lettuce crop, which appears to release far greater quantities of N_2O. Variation between the three lettuce chambers in quantities of N_2O released and the associated error is likely to have reduced the statistical significance.

Mean daily CO_2 flux equivalent

The emission of CO_2 from soil for different crops over time was significantly different (Figure 3). Higher CO_2 emissions were recorded from broccoli when compared to the other crops, and a peak in emissions occurred on 24th June and 6th of July 2010. These peaks in CO_2 emissions corresponded with prolonged rainfall events, where from the 23rd to the 26th of June Theresa Park received 7 mm and 3.6 mm from 6th to 9th July (BOM, weather station #68007).

The emission of CH_4 from soil was constant throughout the measuring period (Figure 3). There were some significant differences in emissions between crops but no clear trend was observed.

Emission of N_2O from soil was different for crops but not over time (Figure 3). The lettuce crop generally had higher emissions, particularly from 23 to 26 June and 7 July onwards, which correspond to rainfall events.

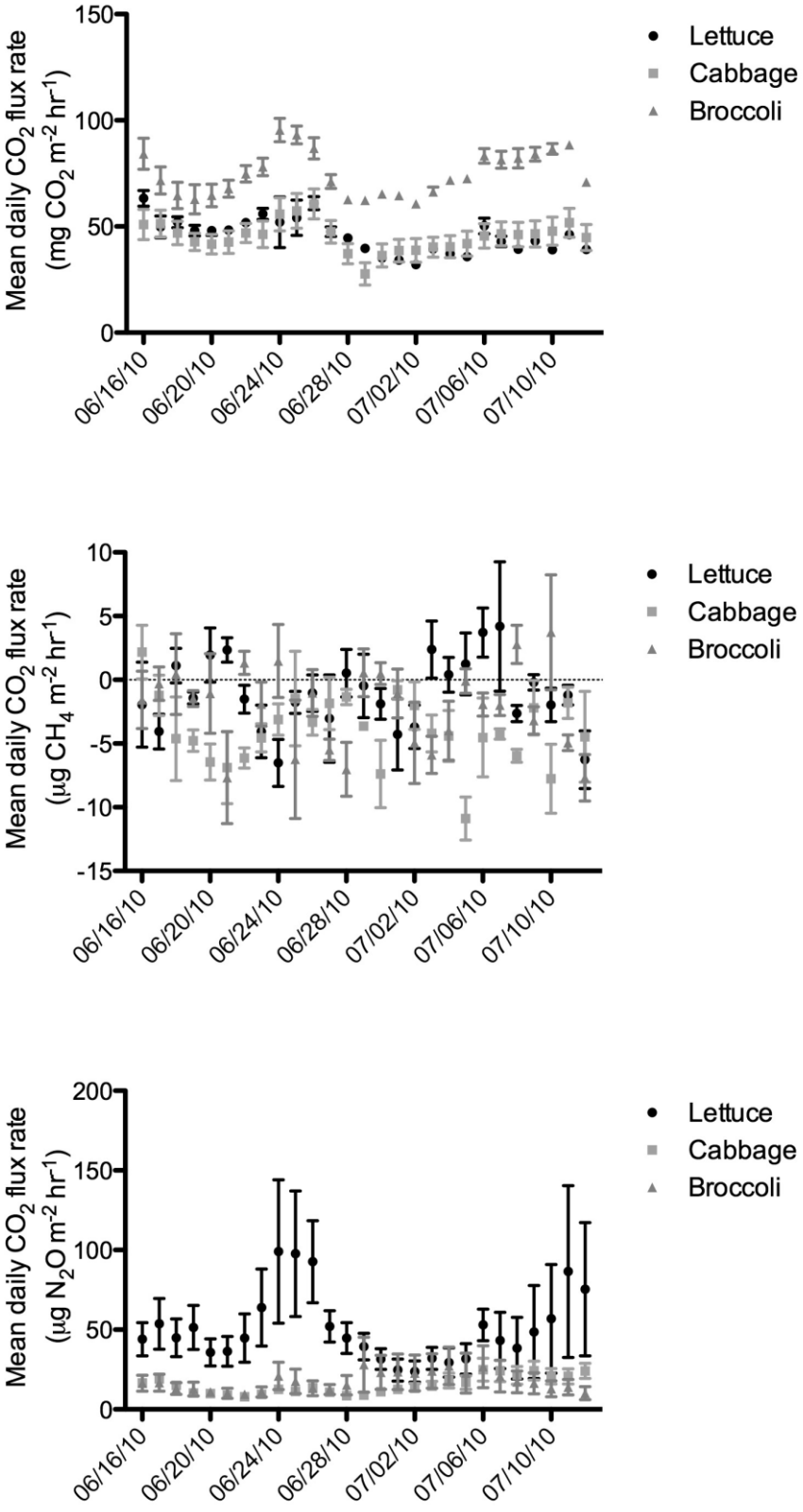

Figure 3: Mean daily CO_2, CH_4 and N_2O emissions over the monitoring period for lettuce, cabbage and broccoli.

Concentration of emission on a time area basis

When concentrations of gases were converted to an emissions rate per time area basis, the relationship between crops and time was the same as the CO_2 flux equivalent (Figure 4). This is essentially another way of presenting the same data.

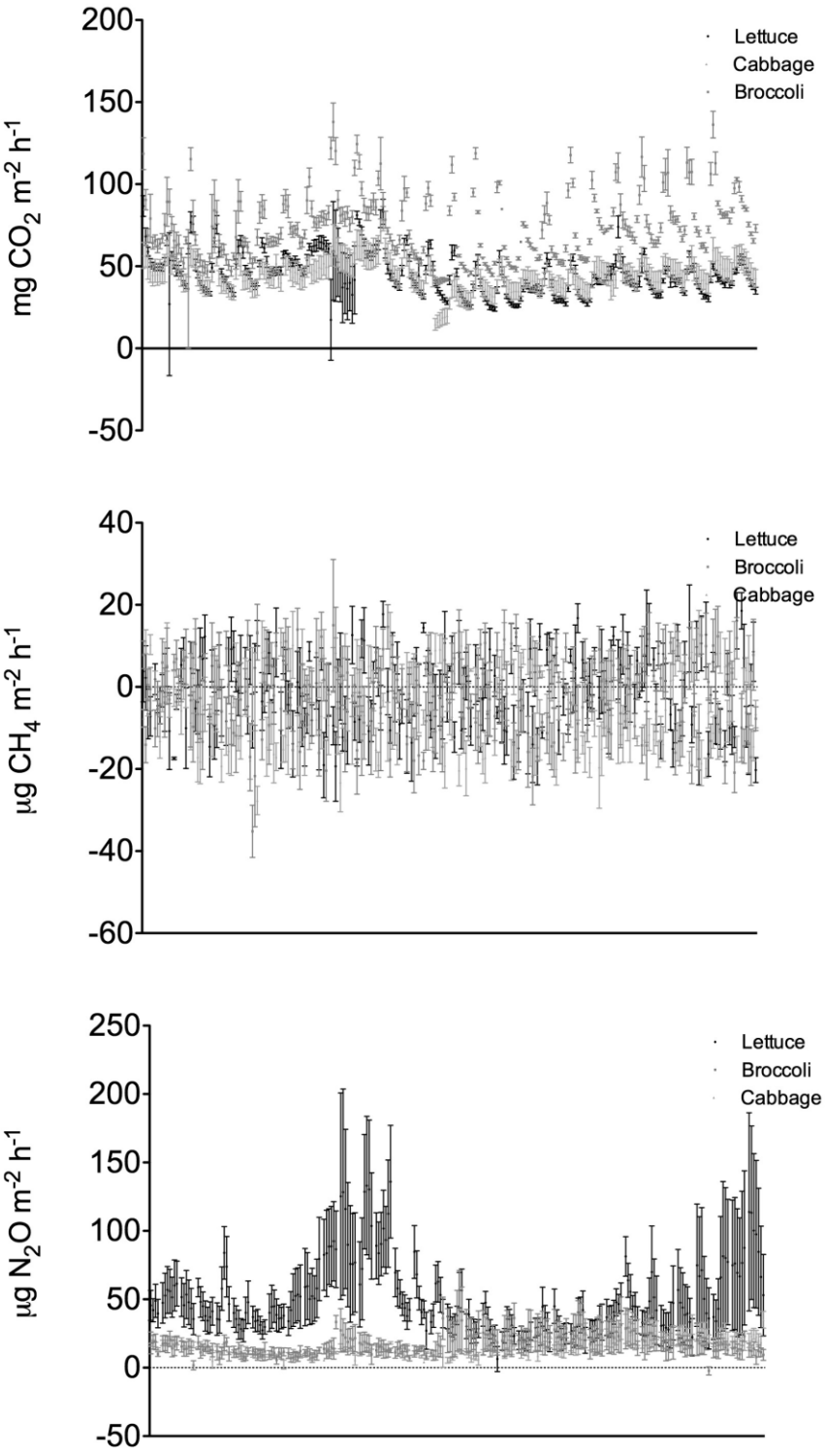

Figure 4: Time series of CO_2, CH_4 and N_2O fluxes at Grech Farms for lettuce, broccoli and cabbage.

Experiment 2: Baseline data for potatoes and calibration of static chambers

The concentration of greenhouse gases at different time-intervals after chambers were closed and at different times of the day varied greatly. This means that the behaviour of gas emissions from soil is different between these gases.

The concentration of CH_4 was not affected by the time that chambers were closed, but N_2O and CO_2 concentrations were affected by this factor (Table 15). In comparison, the concentrations of all gases were influenced by the time of day, but not the interaction between these factors (Table 15).

Table 15: REML table of the effect of minutes that chambers are closed for and the time of day on concentrations of gases and their interaction.

Factor	N_2O	CH_4	CO_2
	Concentration		
Minutes (M)	0.004	ns	0.001
Time of day (T)	0.001	0.039	0.026
Interactions			
T × M	ns	ns	ns
	Concentration on a time area basis		
Minutes (M)	0.001	0.001	0.001
Time of day (T)	0.003	ns	0.006
Interactions			
M × T	ns	ns	ns

ns, non-significant, ANOVA.

A similar response between these factors was shown when emissions were converted to a time area basis; this being the most common way of presenting greenhouse gas emissions. However, the response to these factors is significantly different to that of the absolute concentration. This is an important finding and illustrates the importance of a unified sampling method across studies.

The increase in concentration of N_2O and CO_2 followed a linear relationship with time (Figure 5 and 6).

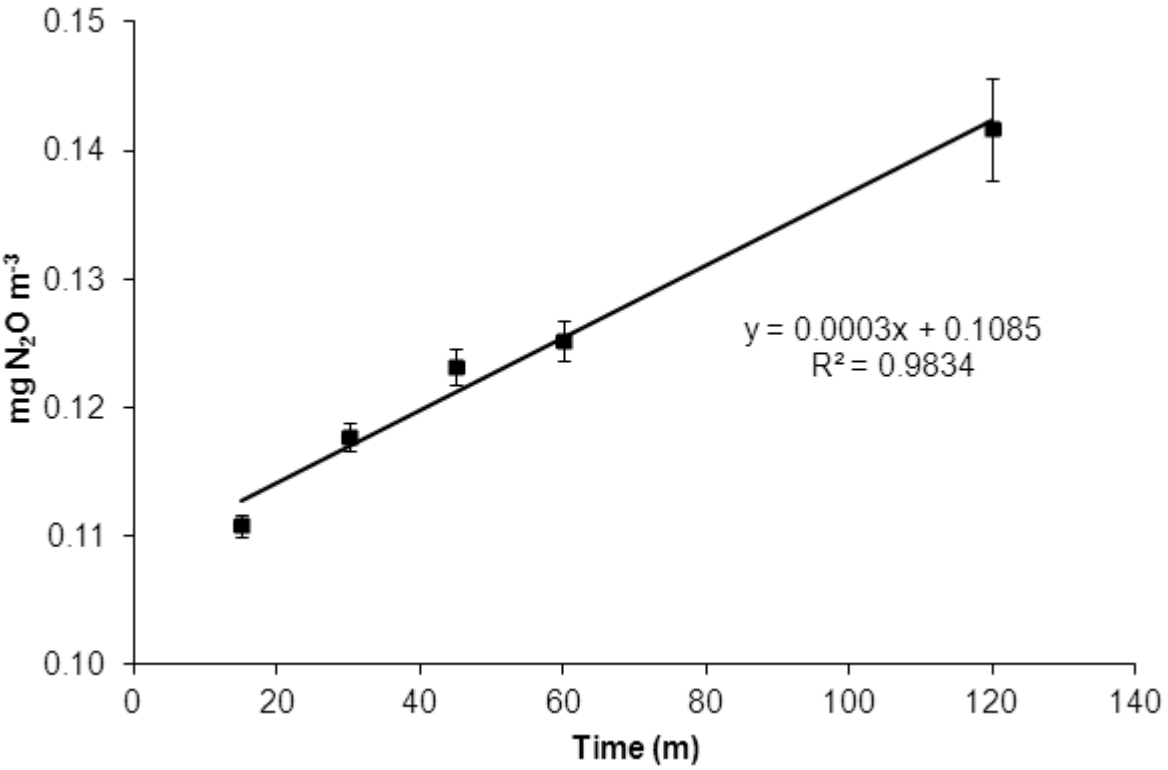

Figure 5: Concentration of N_2O inside a manual static gas chamber over time after the lid was closed**.**

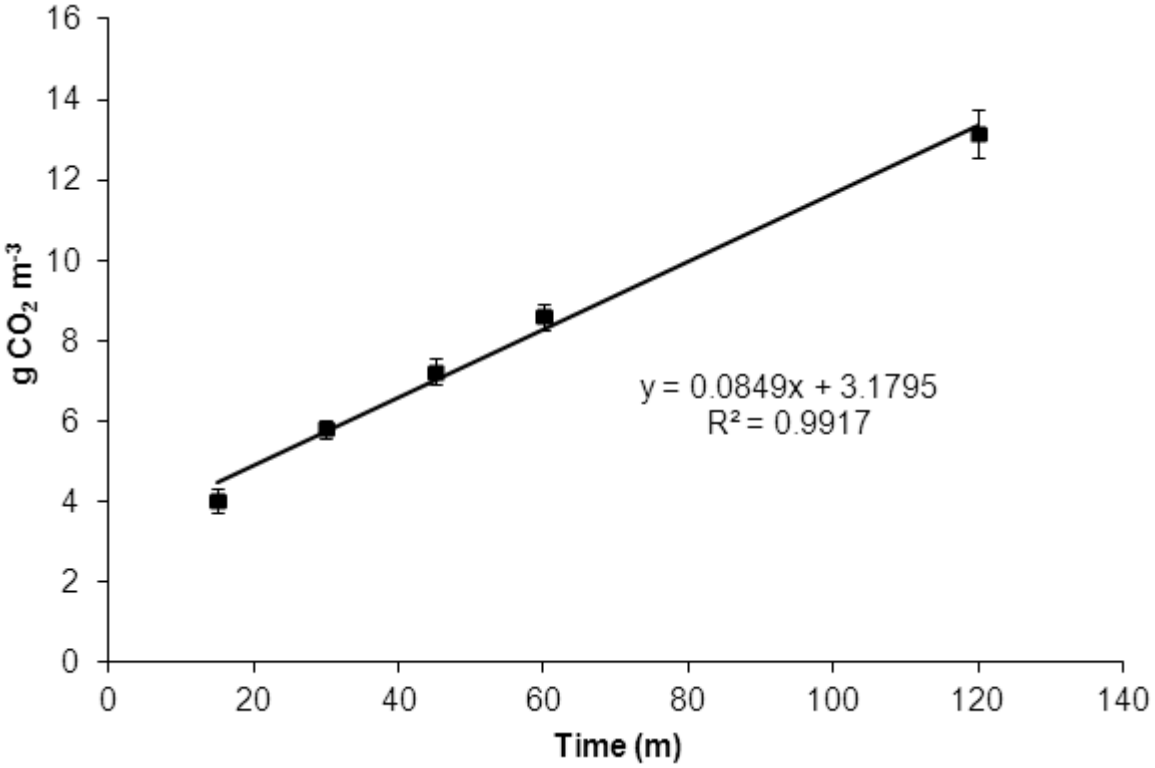

Figure 6: Concentration of CO_2 inside a manual static gas chamber over time after the lid was closed.

The time of day when gas samples were taken influenced the concentration of all three gases (Table 16). Emissions of N_2O and CO_2 were higher in the afternoon than in the morning, while CH_4 emissions were higher in the morning than the afternoon.

Table 16: The change in concentration of gases depending on the time of day samples are collected.

Time of day	mg N_2O m^{-3}	mg CH_4 m^{-3}	g CO_2 m^{-3}
Morning	0.11 b	3.92 a	7.45 b
Afternoon	0.13 a	3.77 b	8.07 a

When the concentration of greenhouse gas emissions were converted to a time per unit area basis, all three gases showed a similar response curve to time of sampling after chambers were closed (Figure 7 to 9). Concentrations on a time per unit area basis decreased, as the rate of increase in concentration was not 1:1 with time. This is consistent with the slopes of the responses in Figures 5 and 6 being linear but, but without an R^2 value of 1. Indicating that there is either leakage of gases from the sampling chambers or the gas concentrations in the headspace affects efflux from the soil surface, or both. In any case, this emphasises the importance of a common methodology including sampling time for the measuring flux of these gases from the soil.

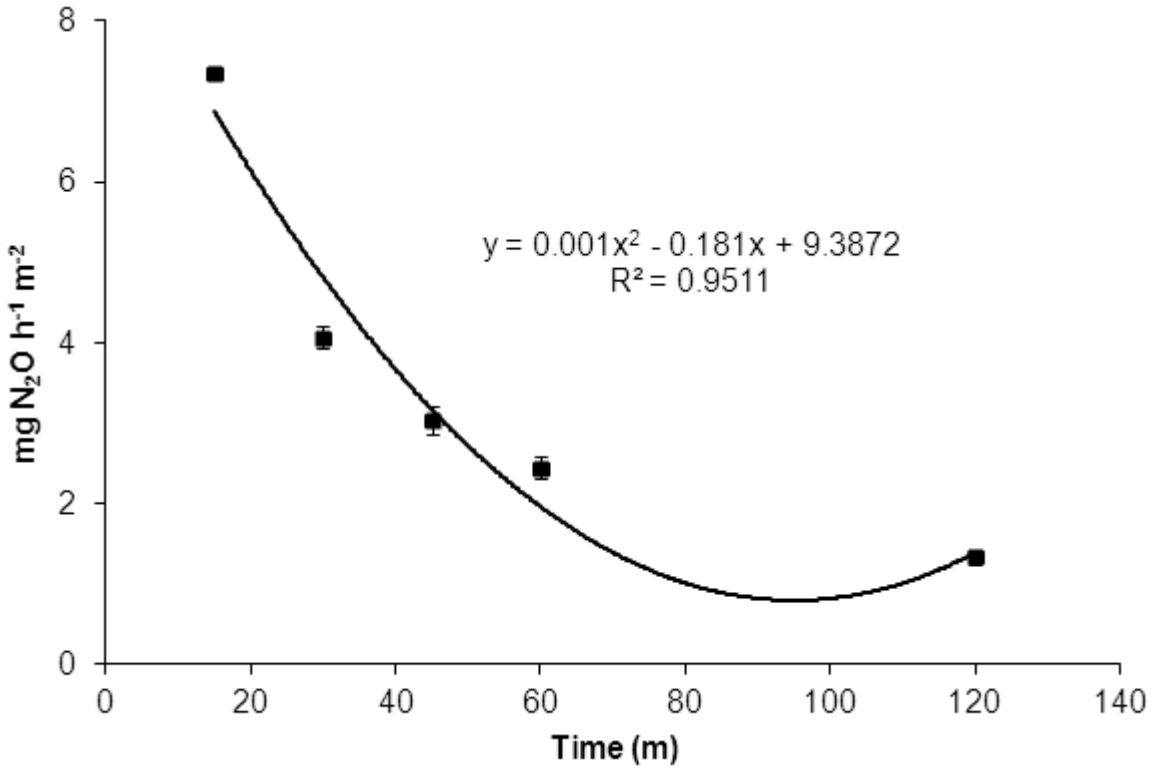

Figure 7: Concentration of N_2O emissions on a time area basis for samples taken from manual static gas chambers after the lid was closed.

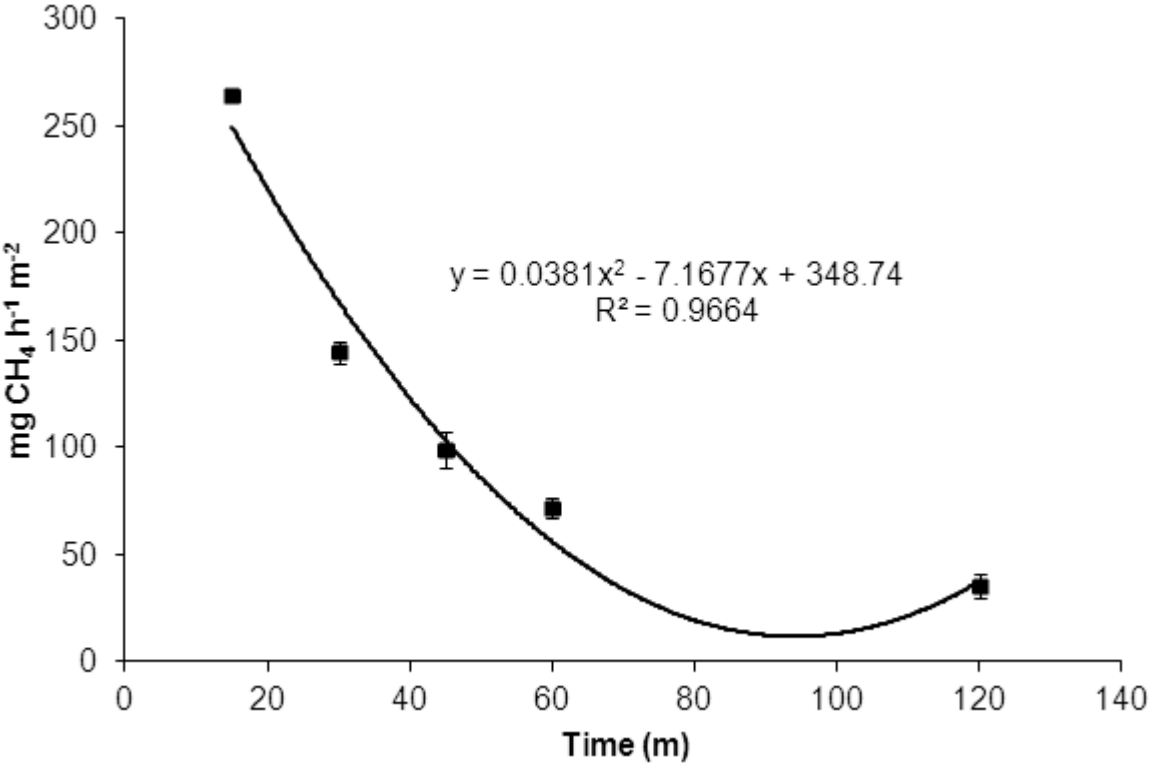

Figure 8: Concentration of CH_4 emissions on a time area basis for samples taken from manual static gas chambers after the lid was closed.

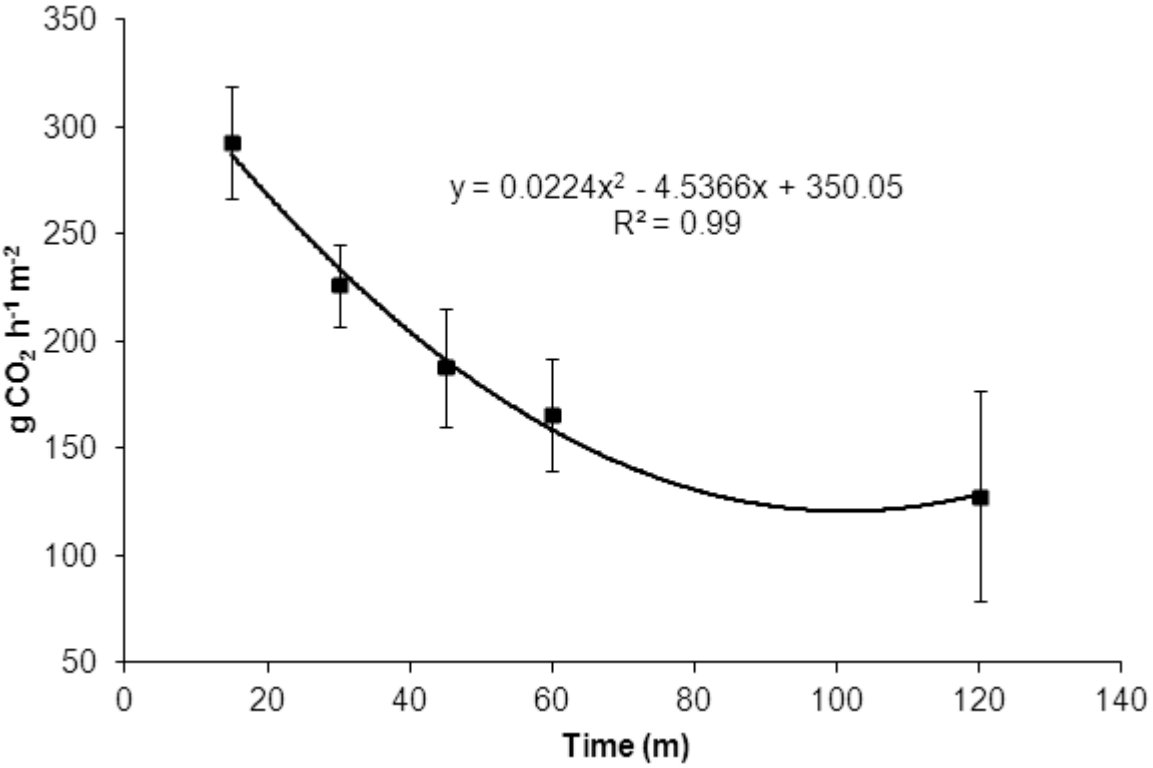

Figure 9: Concentration of CO_2 emissions on a time area basis for samples taken from manual static gas chambers after the lid was closed.

When the concentration of gas emissions was converted to a time area basis, the time of day when gas samples were taken influenced the concentrations of N_2O and CO_2 (Table 17). Emissions of these gases were higher in the afternoon, which is a similar response when compared to the absolute concentration (Table 17).

Table 17: Change in concentration of nitrous oxide and carbon dioxide depending on the time of day.

Time of day	mg N_2O h^{-1} m^{-2}	g CO_2 h^{-1} m^{-2}
Morning	3.5 b	194.1 b
Afternoon	3.8 a	205.7 a

Experiment 3: Impact of cover crops and no-till

Cover crops

Before cover crops were killed, the fresh and dry weight of vegetative biomass was measured. The fresh weights between cover crops were different and this reflects differences between the structure and form of these plants. However, when viewed on a dry-weight basis the biomass produced by these cover crops is similar (Table 18).

Table 18: The average fresh and dry weight biomass produced by cover crops.

	Fresh weight t/ha	**Dry weight t/ha**
Lucerne cover crop	20.1	4.1
Annual rye grass cover crop	44.5	5.5

Yield and head characteristics

There were no significant differences between the head characteristics of either lettuce or cabbage plants when grown across different land use treatments. Average values pooled over treatments for these characteristics are shown in Table 19.

Table 19: Average head characteristics for lettuce and cabbage plants.

	Lettuce	Cabbage
Head weight (kg)	1.2	1.5
Trimmed head weight (kg)	0.7	0.9
Head diameter (cm)	15.7	13.9

Crops were harvested once they reached commercial maturity. The harvesting of the cover crop treatments for lettuce took place a week later than the other treatments. This was due to a slower rate of development in these plots, possibly due to initial N drawdown by soil organisms. This may have slowed the early development of plants in these treatments; however delayed development under organic mulch is a common observation.

CO_2, N_2O and CH_4 emissions

The emission of greenhouse gases from the soil followed the same trend for lettuce and cabbage. The effect of time on gas emissions was significant for all gases, meaning that their emissions from soil fluctuate over time (Table 20). The only gas emissions that were influenced by land use was CO_2, with cover crops generally emitting higher quantities of CO_2 compared other land uses examined (Figures 10 and 11).

There was a significant drop in N_2O emissions for both lettuce and cabbage after transplanting from about 23 mg $N_2O/h/m^2$ to about 13 $N_2O/h/m^2$ by week 6. The N_2O emission rose sharply following a side dressing of 50 kgN/ha in week 7, except for the manure treatment which did not receive this application. The results are clearer in the lettuce experiment (Figure 10). Following this peak, there was a gradual decline in N_2O emissions for lettuce (Figure 10) and a sharper one for cabbage (Figure 11), and then a gradual increase in N_2O emissions to harvest.

There was a peak in CH_4 emissions in week 4 in both experiments and this corresponded to 38mm of rainfall over 4 days from the 18th-22nd August 2011, which may have resulted in temporary anaerobic conditions.

Table 20: REML table of the effect of time and land use on emissions and their interaction for a lettuce and cabbage crop.

Factor	N_2O	CH_4	CO_2
		Lettuce	
Time (T)	0.001	0.001	0.001
Land use (L)	ns	ns	0.001
Interaction			
T × L	ns	ns	0.001
		Cabbage	
Time (T)	0.001	0.001	0.001
Land use (L)	ns	ns	0.001
Interaction			
T × L	ns	ns	0.023

ns, non-significant, ANOVA.

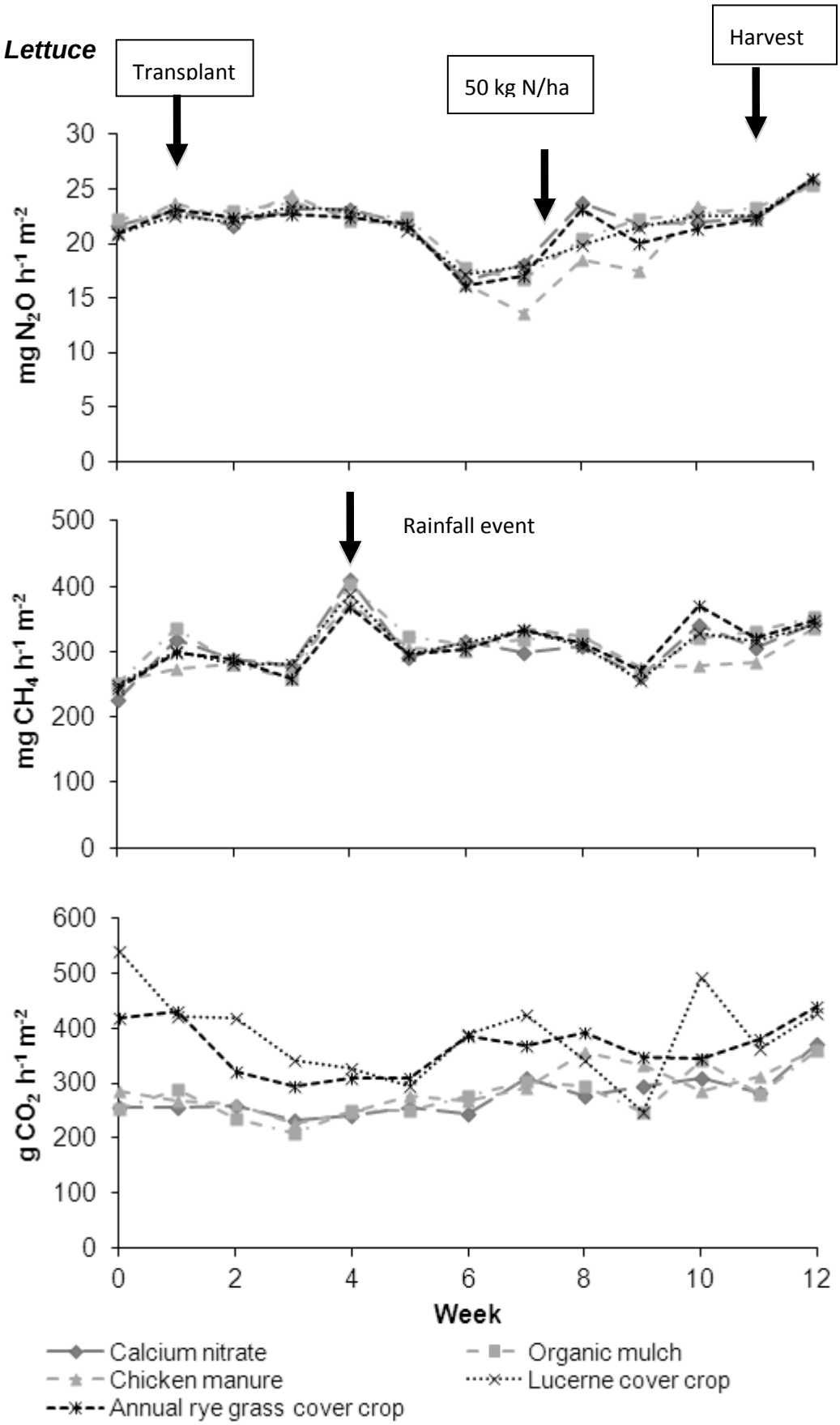

Figure 10: CO_2, CH_4 and N_2O emissions over time for head lettuce grown under different land uses.

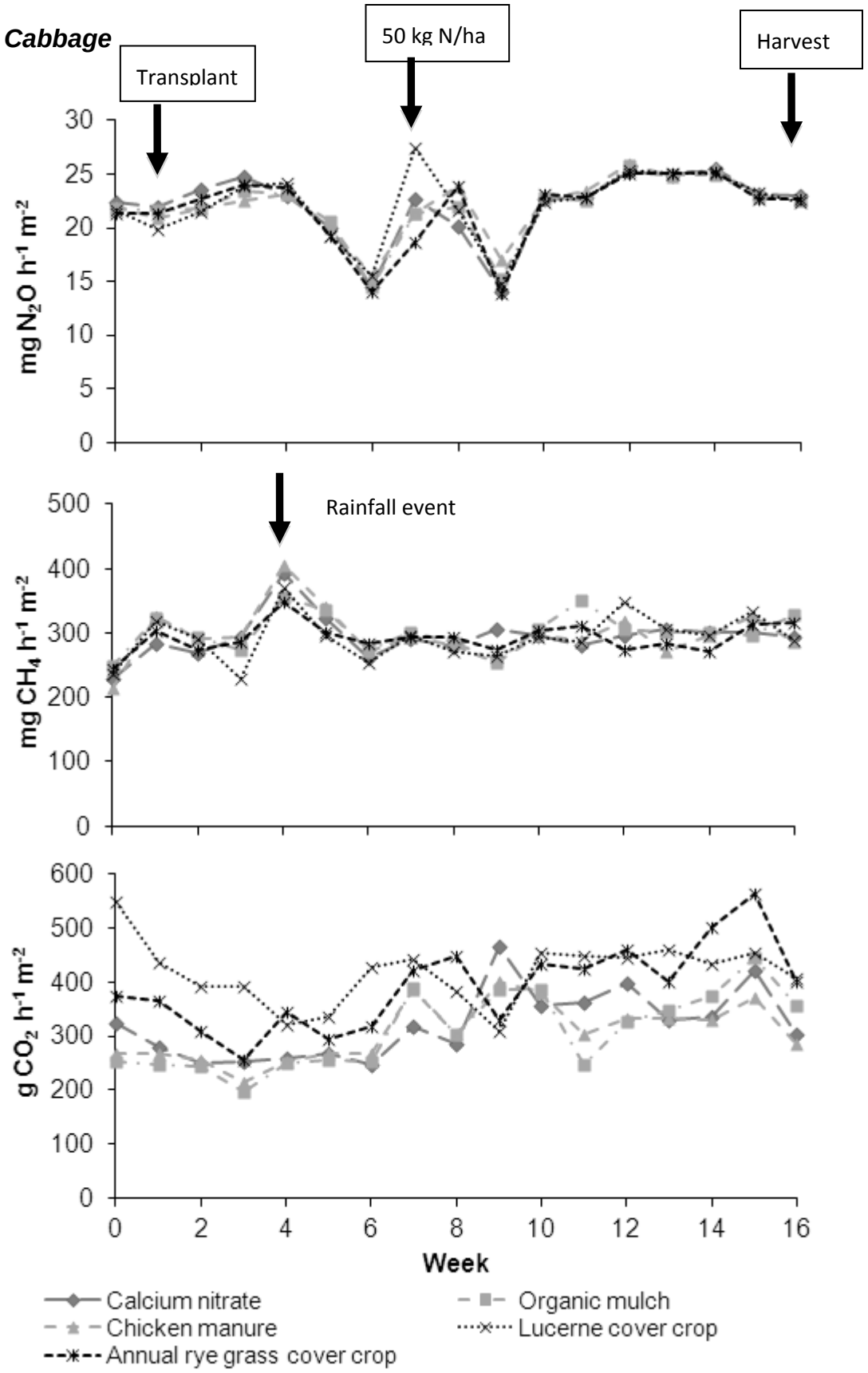

Figure 11: CO_2, CH_4 and N_2O emissions over time for cabbage grown under different land uses.

Soil microbial biomass

Land use did not affect SMC or SMN in either crop, meaning that SMB remained constant regardless of land management practices (Table 21). However, in both crops SMC and SMN was affected by the interaction between time and soil depth.

Table 21: ANOVA table of the effect of time, depth and land use on soil microbial carbon, nitrogen and their interactions for a lettuce and cabbage crop.

Factor	SMC	SMN
	Lettuce	
Time (T)	0.001	ns
Depth (D)	0.023	ns
Land use (L)	ns	ns
Interactions[a]		
T × D	0.001	0.002
	Cabbage	
Time (T)	0.001	0.001
Depth (D)	0.039	0.001
Land use (L)	ns	ns
Interactions[a]		
T × D	0.030	0.001

ns, non-significant, ANOVA.[a] shown are the only significant interactions.

The values for SMC and SMN varied greatly across time and soil depth for both crops. The response between these variables was not consistent between crops; however the relationship between statistically significant factors is consistent between crops for SMC (Table 21).

Lettuce

In soil where lettuce was grown, SMC was much higher in pre-transplant topsoil (Figure 12); while SMN was highest in pre-transplant topsoil and postharvest subsoil (Figure 13). The reasons for this response are unclear. Higher SMN in postharvest subsoil may be due the N leaching, although this response was not shown in soil from the cabbage crop.

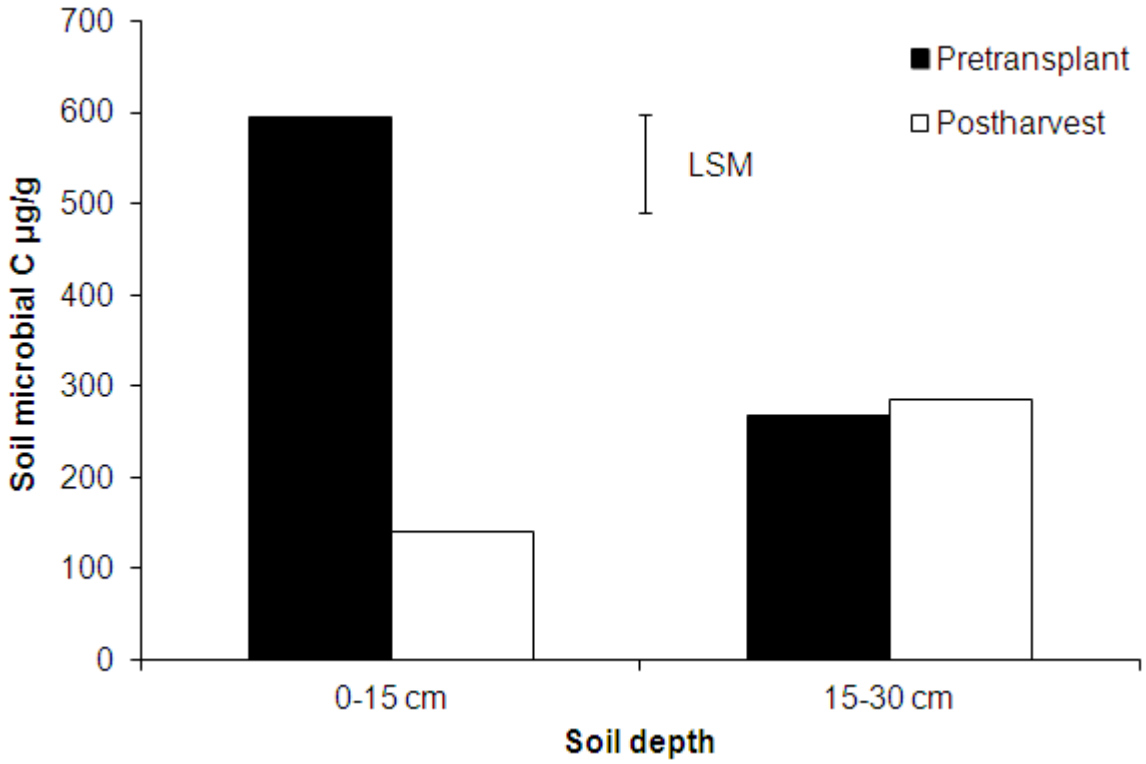

Figure 12: Differences between soil microbial carbon at different soil depths pre-transplant and postharvest for a lettuce crop. LSM, least square means.

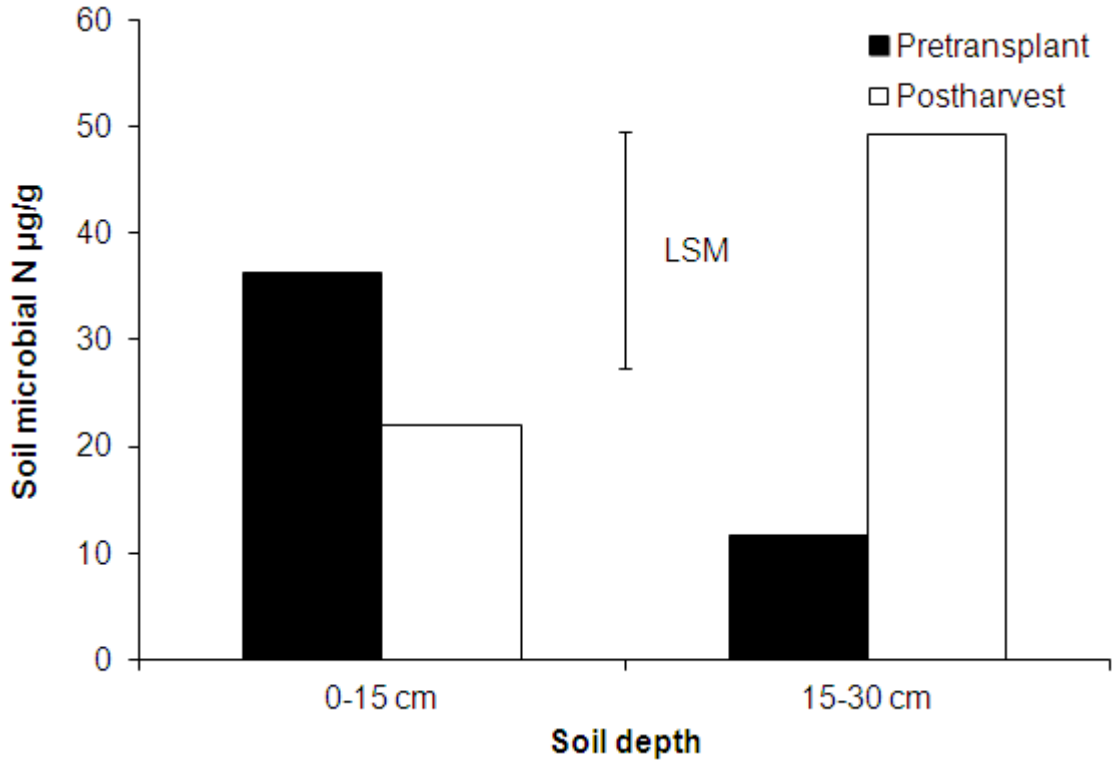

Figure 13: Differences between soil microbial nitrogen at different soil depths pre-transplant and postharvest for a lettuce crop. LSM, least square means.

Cabbage

Significantly lower SMC was measured in postharvest topsoil after a cabbage crop was grown (Figure 14). This response was also shown for lettuce, illustrating that SMC in the top soil is generally lower after a crop is grown, when compared to levels after a long fallow period. These results also show that SMC levels in the subsoil remain reasonably constant over time, the response also being shown for soil from the lettuce crop (Figure 12). Very high levels of SMN were recorded for pre-transplant subsoil (Figure 15). The reason for this response is unclear.

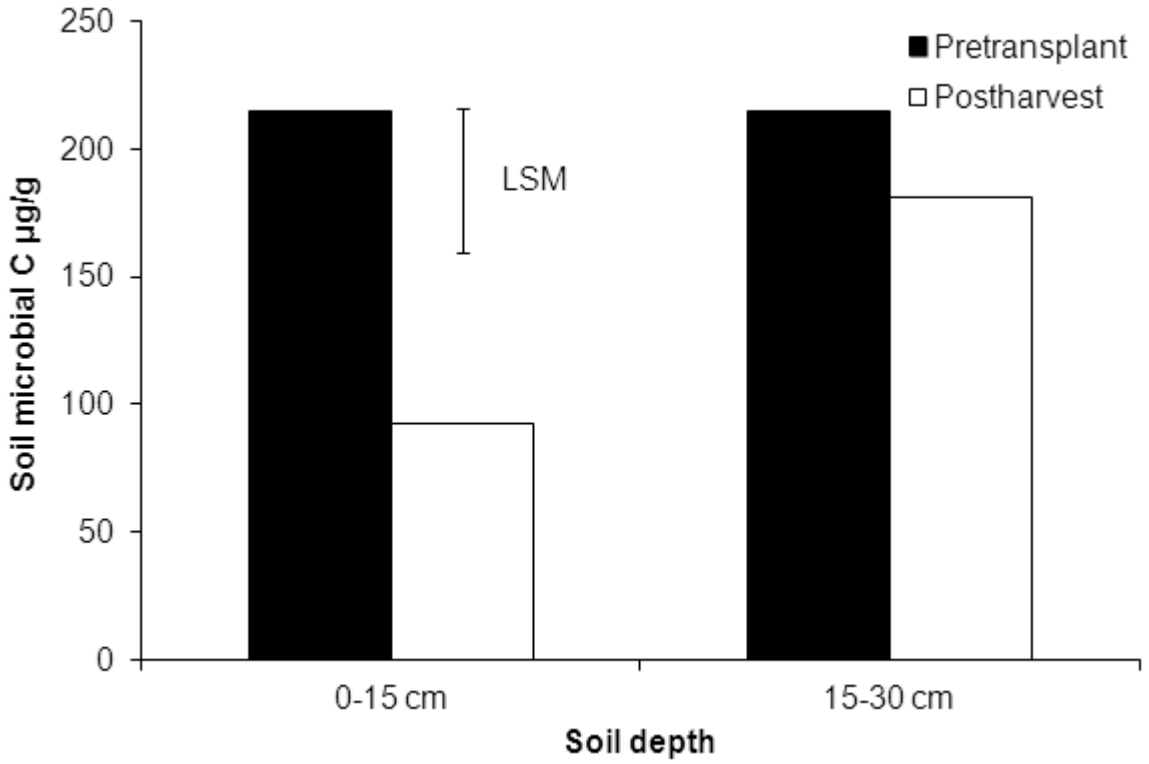

Figure 14: Differences between soil microbial carbon at different soil depths pre-transplant and postharvest for a cabbage crop. LSM, least square means.

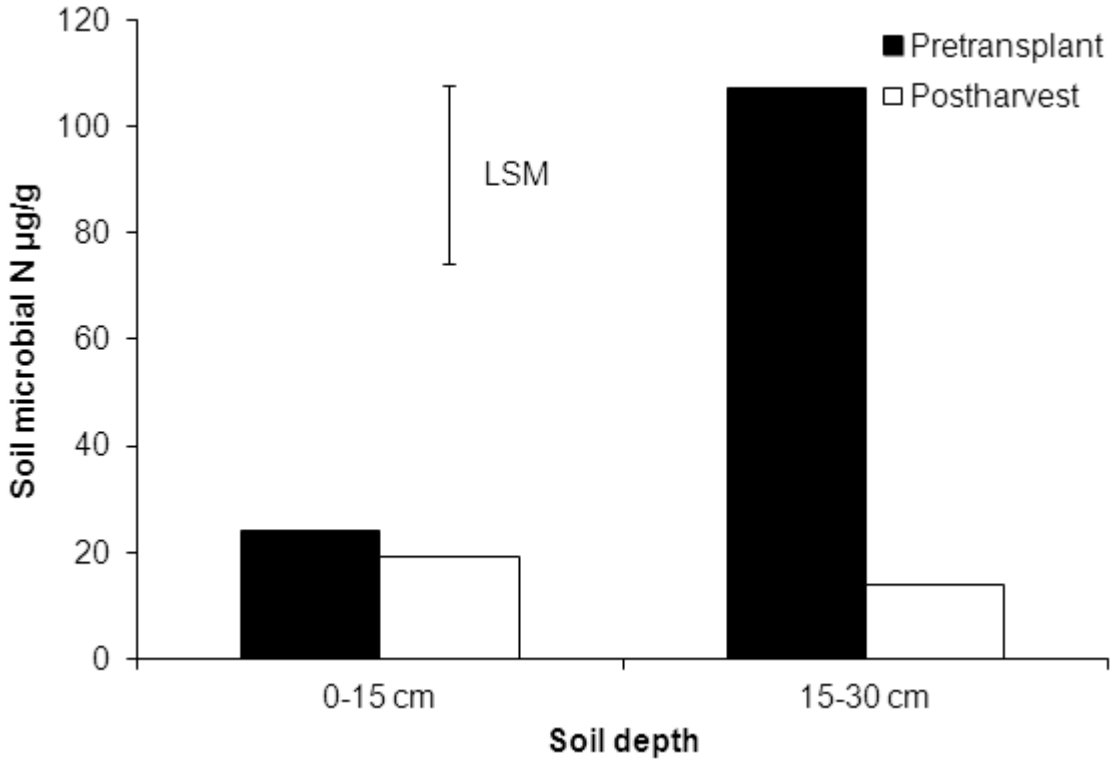

Figure 15: Differences between soil microbial nitrogen at different soil depths pre-transplant and postharvest for a cabbage crop. LSM, least square means.

Soil carbon and nitrogen

There was no significant difference between total soil C and N for either crop based on land use (Table 22). Time influenced soil C, N and the C/N ratio for soil from the cabbage crop, while time did not affect these variables for the lettuce crop.

Soil depth influenced nitrogen and the C/N ratio for soil from the lettuce crop. In cabbage the C/N ratio was influenced by land use (Table 22). The repose of soil C and N to different land use varied between crops, illustrating that large variation in soil C and N storage can occur over a small area. This highlights the difficulty of making generalisations about the way these compounds are stored and utilised in the soil.

Soil from the lettuce experiment had a higher N% in the topsoil (0.175%) when compared to the subsoil (0.168%). Although this difference is small, it shows that the location of nitrogen in the soil profile varies over different depths and across different locations. This idea is supported by the fact that no significant difference was shown for the cabbage crop, which was spatially right next to the lettuce crop.

Table 22: ANOVA table of the effect of time, soil depth and land use on soil carbon, nitrogen and their ratio and interactions.

Factor	Soil C%	Soil N%	Soil C/N ratio
		Lettuce	
Time (T)	ns	ns	ns
Depth (D)	ns	0.032	0.026
Land use (L)	ns	ns	ns
Interactions[a]			
T × D	ns	ns	0.009
		Cabbage	
Time (T)	0.005	0.001	0.003
Depth (D)	ns	ns	ns
Land use (L)	ns	ns	0.019

ns, non-significant, ANOVA. [a] shown are the only significant interactions.

Although there was a significant difference between time and soil depth for the C/N ratio in the lettuce crop, the response between these factors was not clear (Table 23). This result supports the idea that there are large differences in the spatial distribution of soil C and N in highly cultivated soils.

Table 23: The effect of time and soil depth on the carbon/nitrogen ratio of soil from a lettuce crop.

	0-15 cm	15-30 cm
Pre-transplant	11.74 ab	11.71 b
Postharvest	11.37 c	11.86 a

Soil C and N levels were higher after a long fallow period than after a cabbage crop was grown, meaning that cabbage plants remove more C an N from the soil than they return (Table 24). The C/N ratio was higher in soil after crops were harvested.

Table 24: The effect on time on soil, C, N and C/N ratio for cabbage.

	Pre-transplant	Postharvest
Soil C%	2.124 a	2.033 b
Soil N%	0.179 a	0.168 b
Soil C/N ratio	11.90 b	12.13 a

Modelling of soil carbon and CO_2 losses

Long-term comparison of different land uses

The quantity of CO_2 released by different land uses varied greatly, and was strongly related to the amount of organic matter either introduced or produced by respective farming systems. The conventional practice (calcium nitrate) would result in the lowest CO_2 emissions over time, and the organic mulch treatment would result in the highest emissions, followed by annual ryegrass, lucerne and chicken manure in that order (Figure 16).

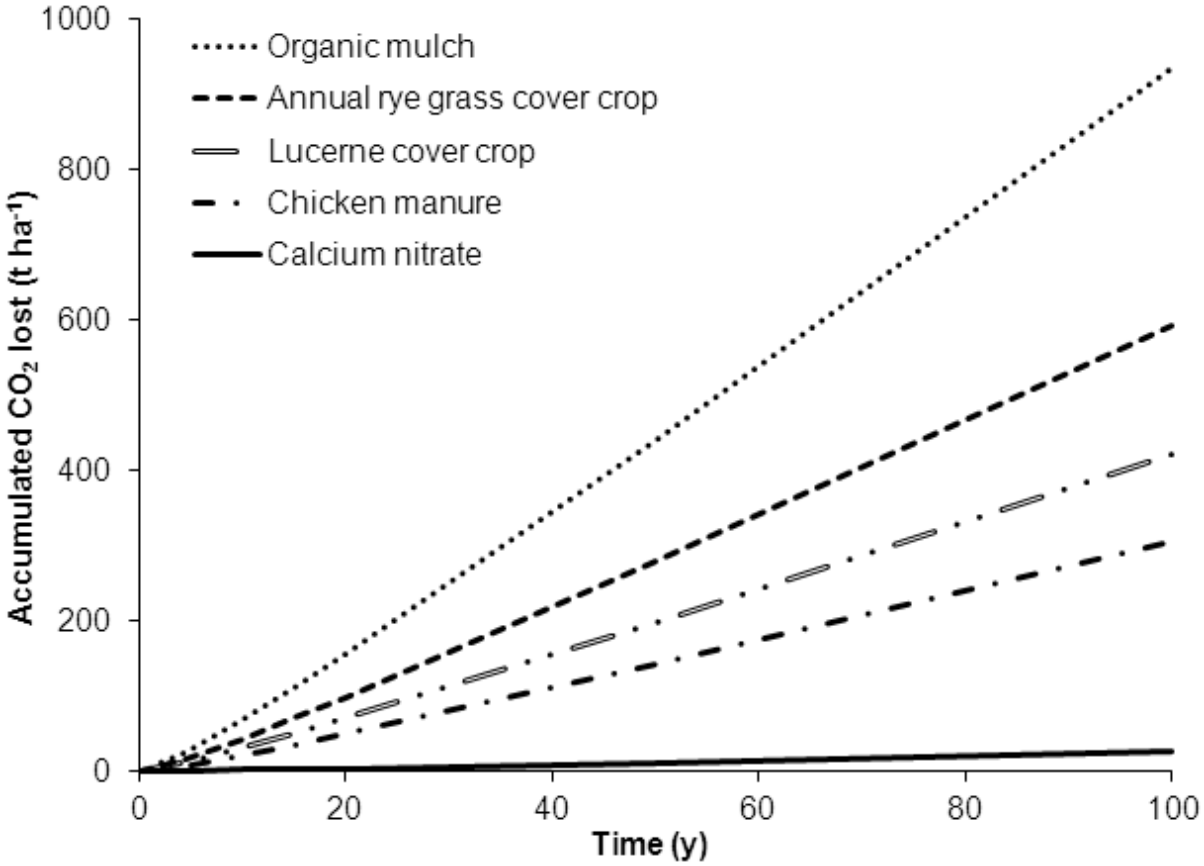

Figure 16: Estimated accumulated carbon dioxide lost to the atmosphere for vegetable land under different land management practices over 100 years.

The amount of C stored in soil also varied greatly across different land uses. The soil C levels followed a similar relationship to the amount of plant material either produced or supplied to the cropping system (Figure 17). This means interventions that supply the most organic carbon to the soil also generate the greatest accumulations of soil C over time. The conventional farming system will maintain current soil C levels, which have already been degraded by cultivation.

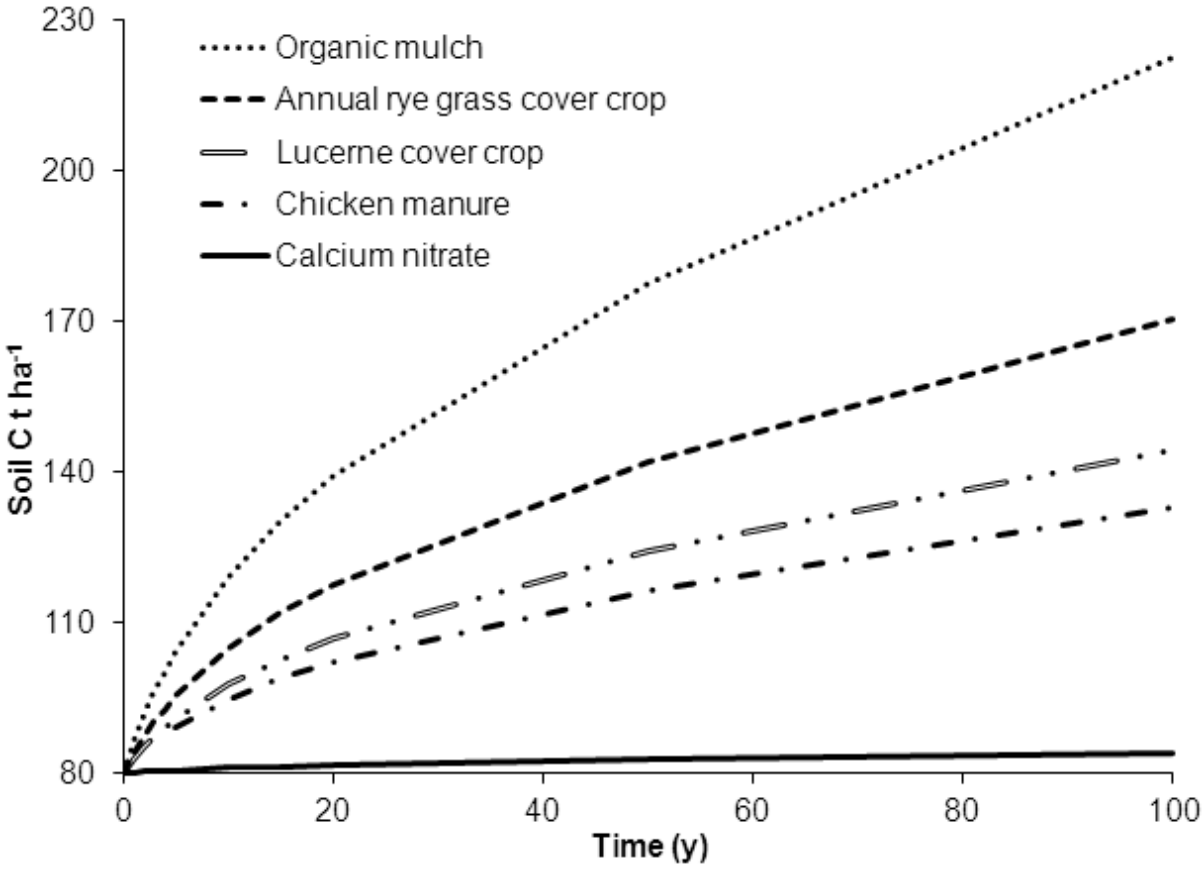

Figure 17: Predicted carbon storage potential of soil under different land management practices over 100 years.

Longer-term modelling

Scenario 1: *20 years of organic mulch amendments followed by 80 years of chicken manure amendments*

The amount of CO_2 released by this scenario was the same as organic mulch for the first 20 years, but levelled off after land management practices were changed to chicken manure amendments (Figure 18).

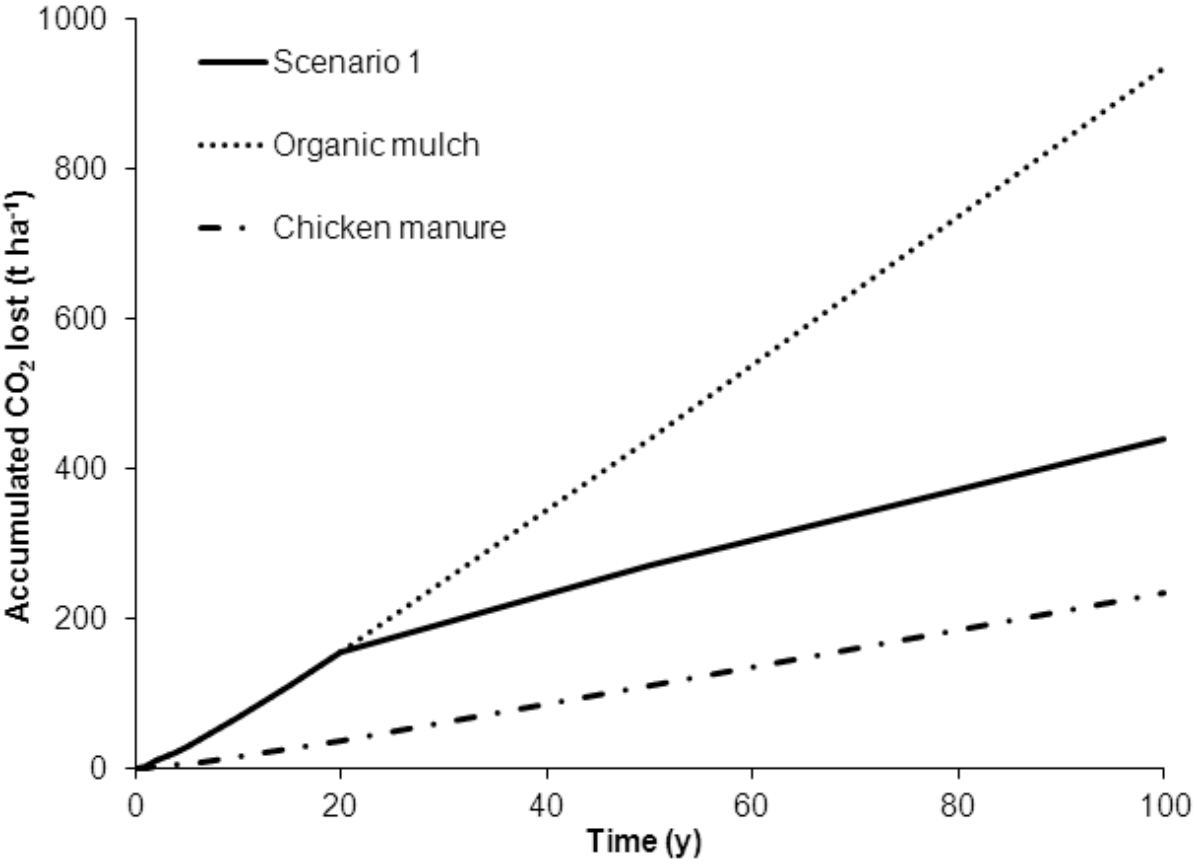

Figure 18: Estimated accumulated carbon dioxide lost to the atmosphere for vegetable land under different land management practices over 100 years.

High volumes of organic mulch supplied to this system quickly increase soil C levels in the first 20 years. After land management practices change, soil C levels decrease and then slowly started to increase again (Figure 19).

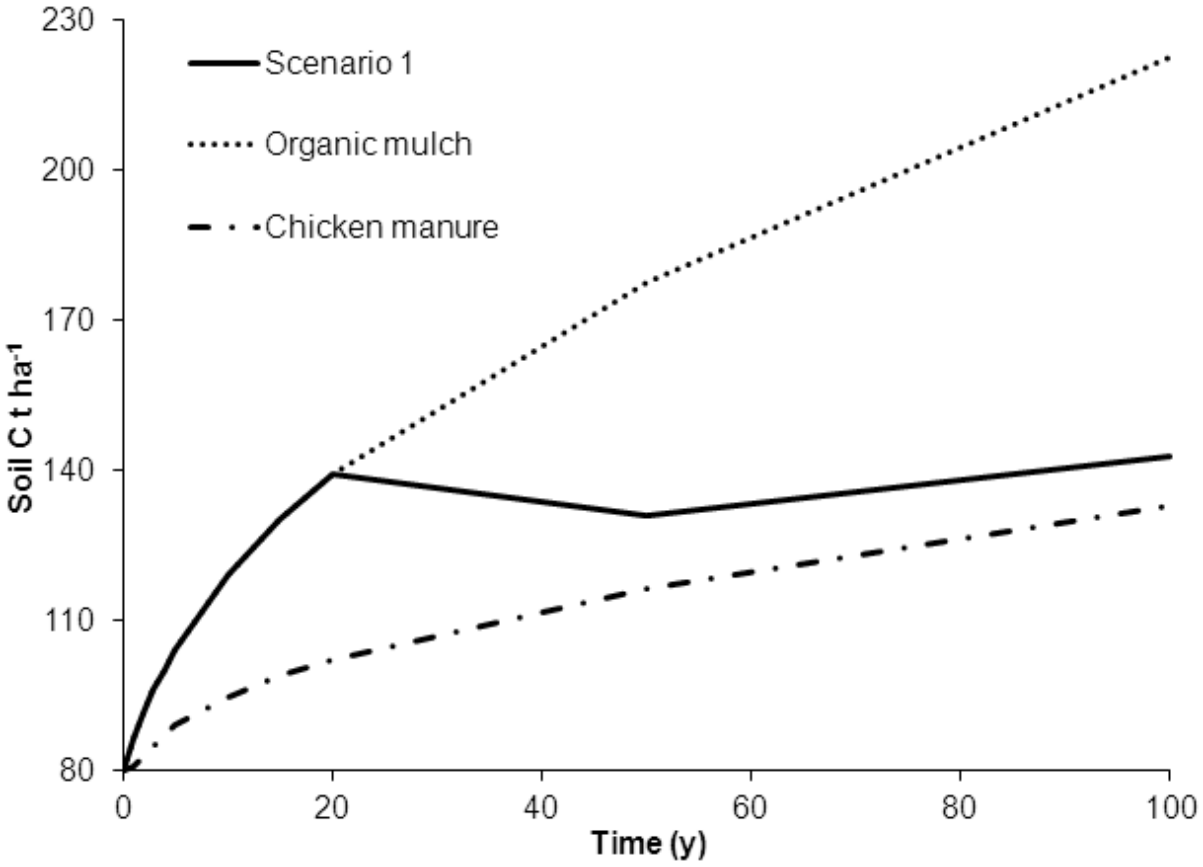

Figure 19: Predicted carbon storage potential of soil under different land management practices over 100 years.

Mid-term modelling

Scenario 2: *Annual rye grass cover cropping system for 5 years, followed by 10 years of reverting back to synthetic fertiliser amendments, and then again adoption of a cover cropping system for another 5 years.*

For the first 5 years the amount of CO_2 lost is the same as the annual rye grass cover cropping system, after which emissions increase at a much slower rate. Once cover cropping of land is resumed, CO_2 emissions resume at a similar rate as before (Figure 20).

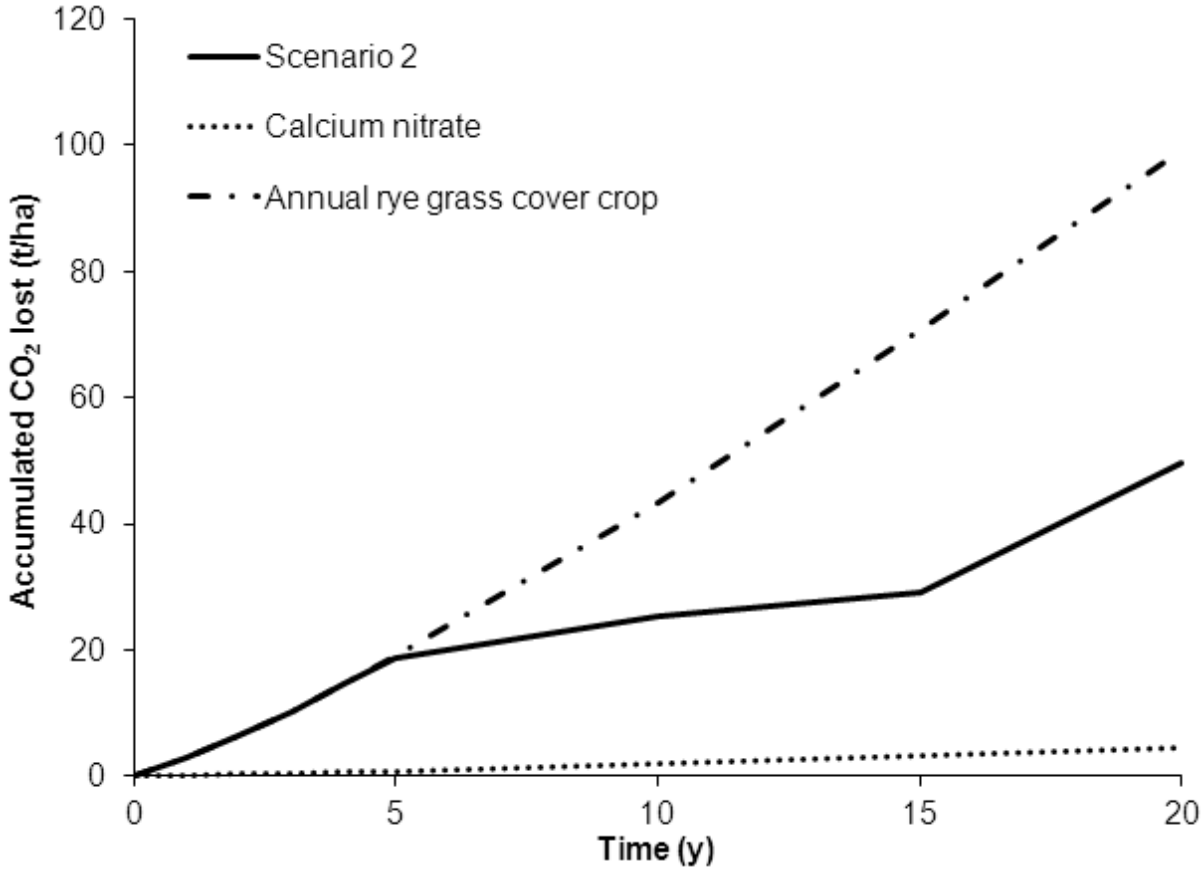

Figure 20: Estimated accumulated carbon dioxide lost to the atmosphere for vegetable land under different land management practices over 20 years.

Soil C levels increase sharply for the first 5 years and then progressively decrease over the 10 years of synthetic fertiliser applications. Once cover cropping of land resumes, soil C levels quickly increase again (Figure 21).

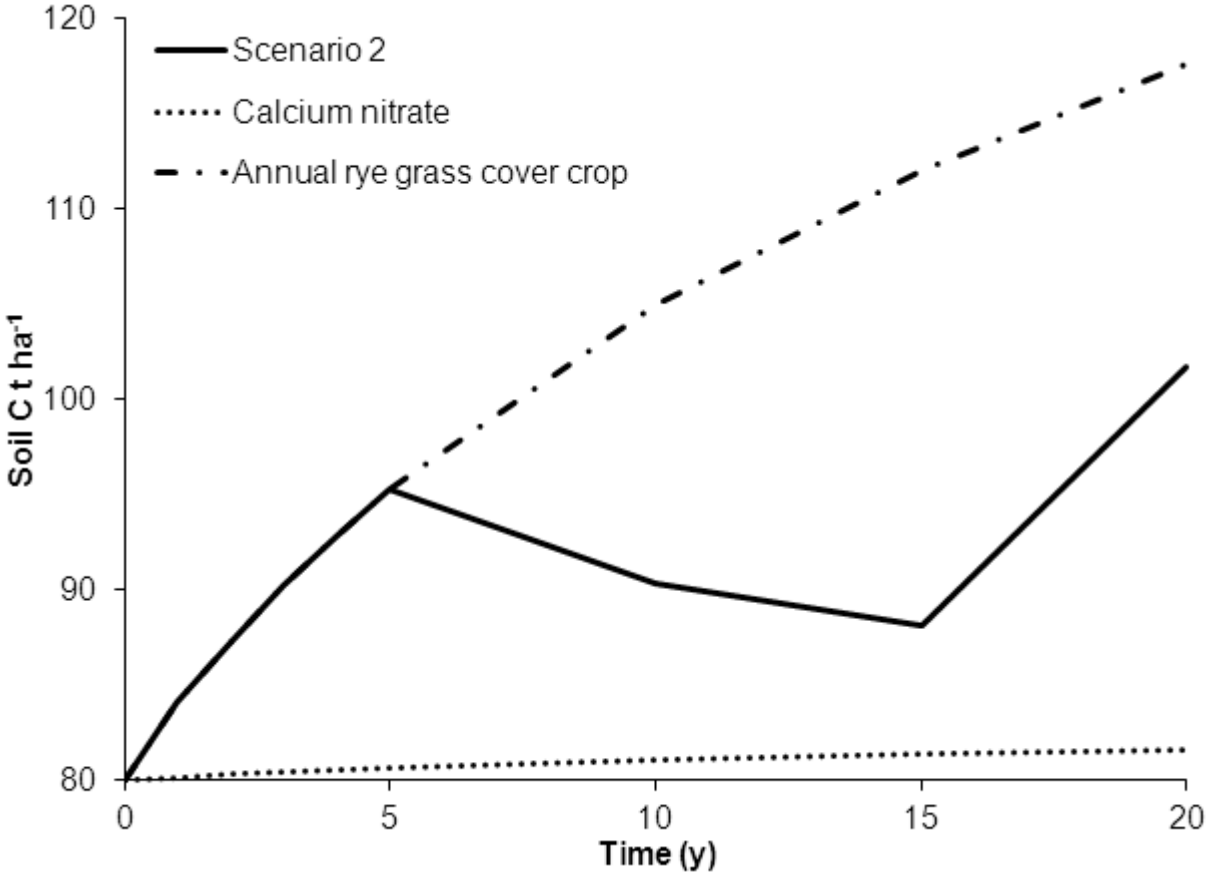

Figure 21: Predicted carbon storage potential of soil under different land management practices over 20 years.

Shorter-term modelling

Scenario 3: *5 years organic mulch followed by 5 chicken manure.*

For the first 5 years emissions of CO_2 follow the organic mulch land use pattern, but when management of land changes to chicken manure amendments, the quantity of CO_2 emitted increases at a much slower rate (Figure 22).

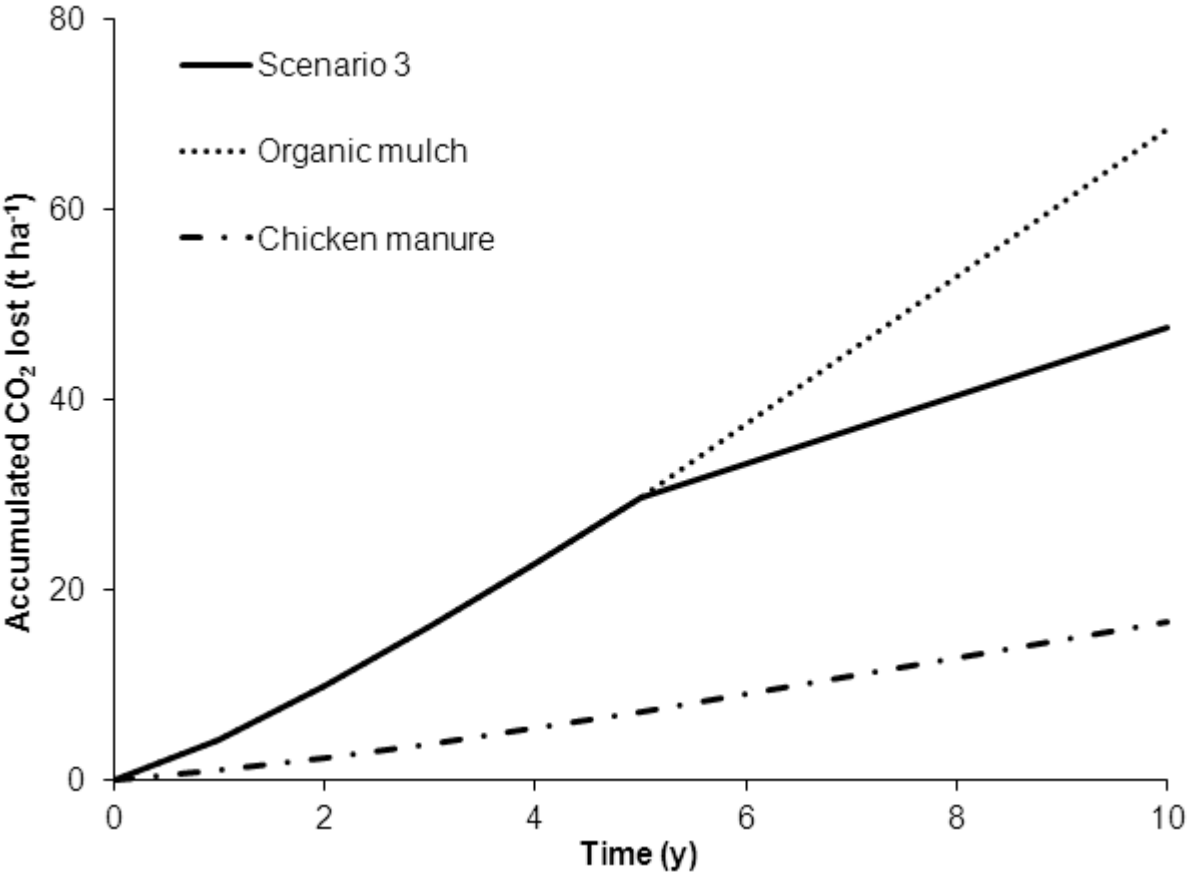

Figure 22: Estimated accumulated carbon dioxide lost to the atmosphere for vegetable land under different land management practices over 10 years.

Soil C levels increase sharply in the first 5 years during additions of organic mulch. Once land use is changed to chicken manure, soil C levels slowly decrease (Figure 23).

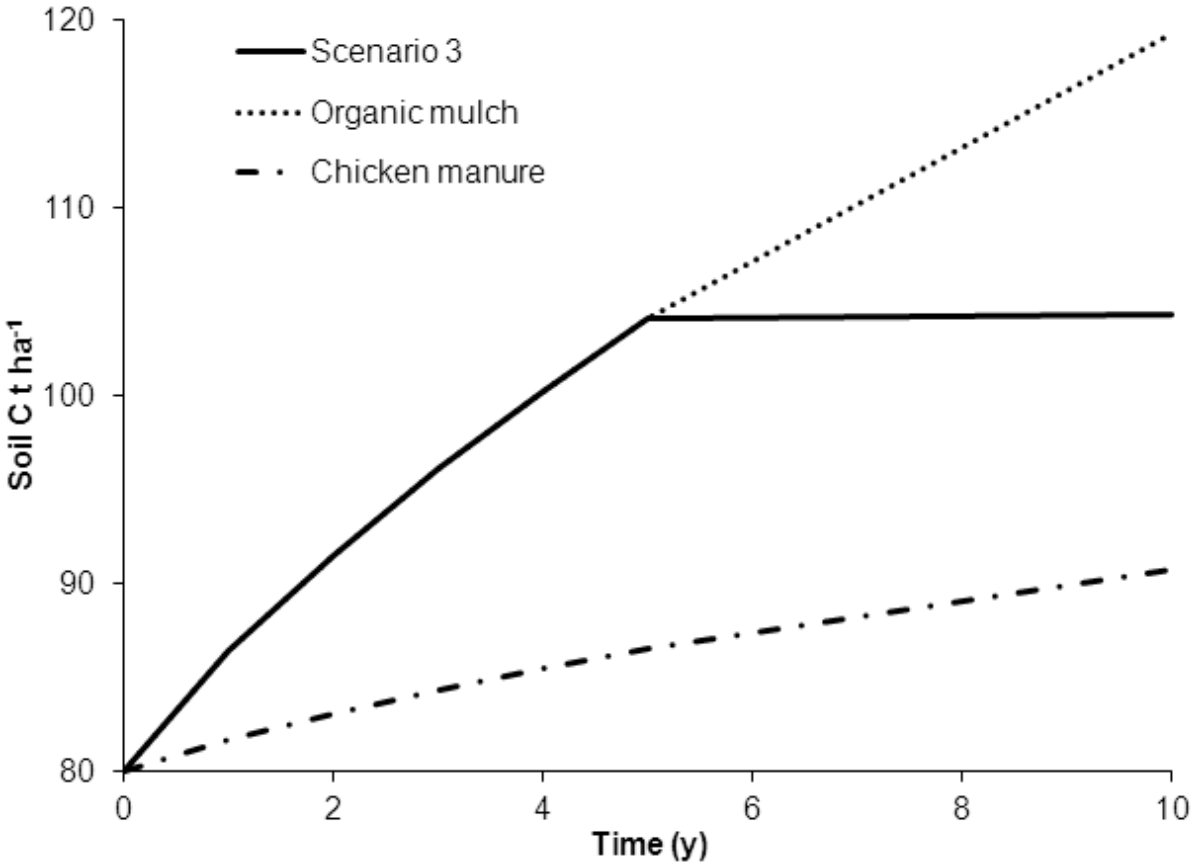

Figure 23: Predicted carbon storage potential of soil under different land management practices over 10 years.

Scenario 4: *Organic mulch amendments for 5 years and then reverting back to synthetic fertilizer for another 5 years.*

The emission of CO_2 increases for the first 5 years at the same rate as organic mulch land use. Once N is supplied in the form of calcium nitrate, the rate of CO_2 lost from the system drastically reduces (Figure 24).

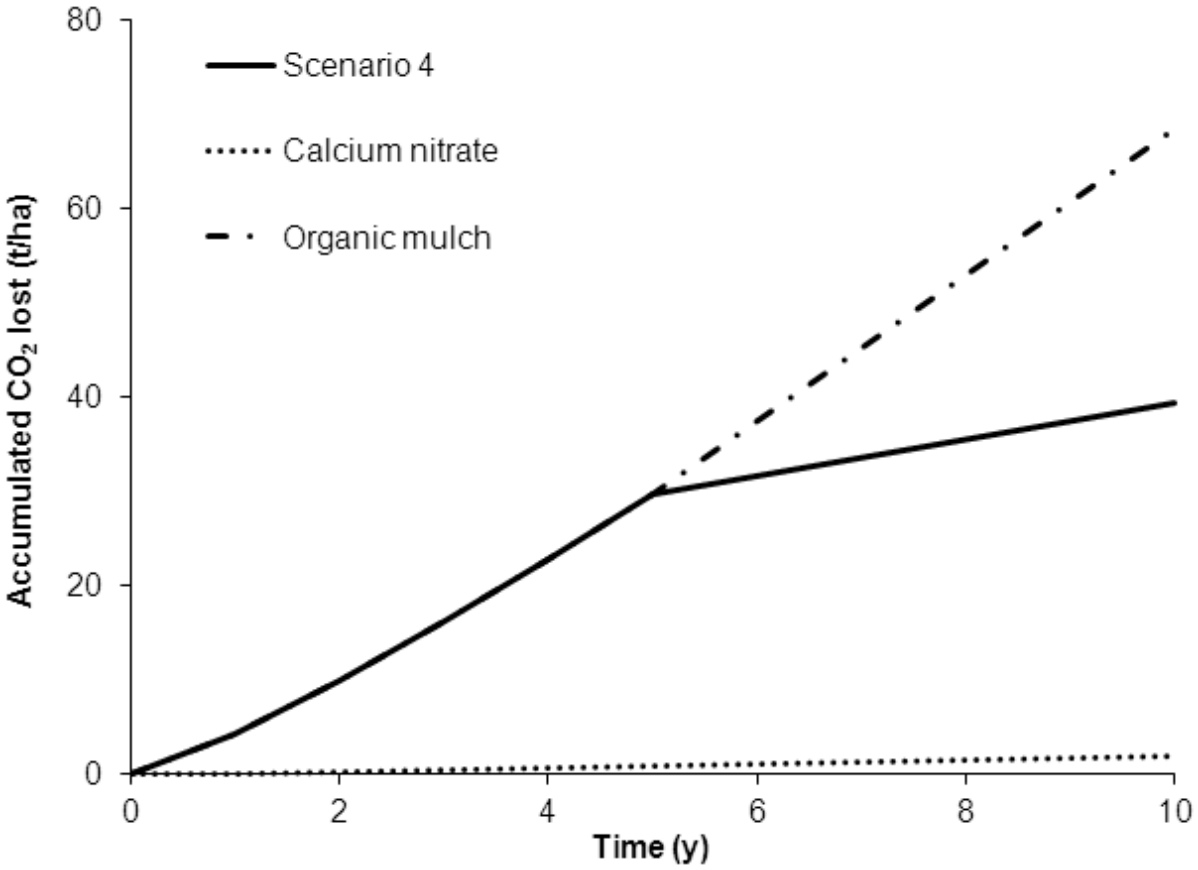

Figure 24: Estimated accumulated carbon dioxide lost to the atmosphere for vegetable land under different land management practices over 10 years.

Soil C levels sharply increase for the first 5 years but steadily decrease once N is supplied to land in the form of calcium nitrate (Figure 25). This is due to the very small amounts of C supplied by this land management practice.

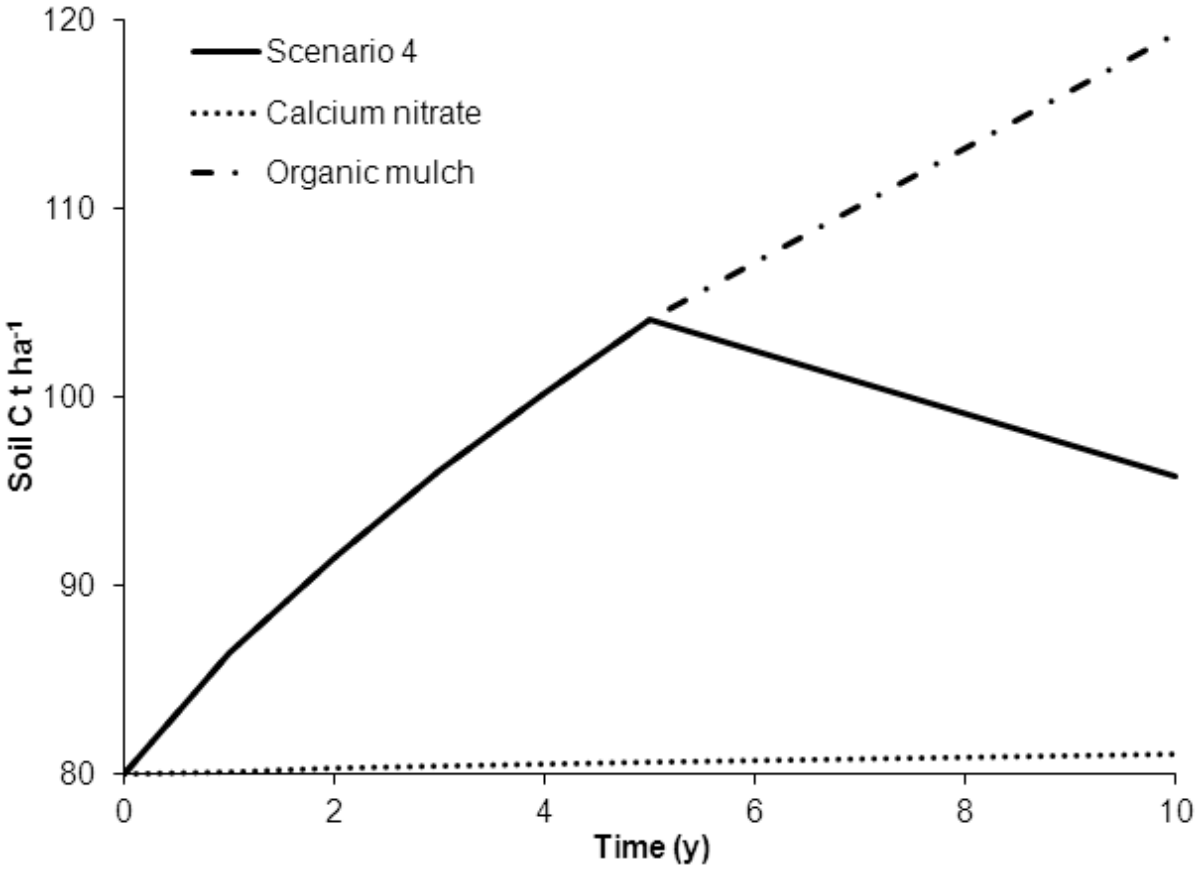

Figure 25: Predicted carbon storage potential of soil under different land management practices over 10 years.

Scenario 5: *5 years of synthetic fertilizer amendments followed by 5 years of lucerne cover cropping.*

The emission of CO_2 for this scenario is very low for the first 5 years, but then starts to increase at a similar rate to the lucerne cover crop once this land management practices is adopted (Figure 26).

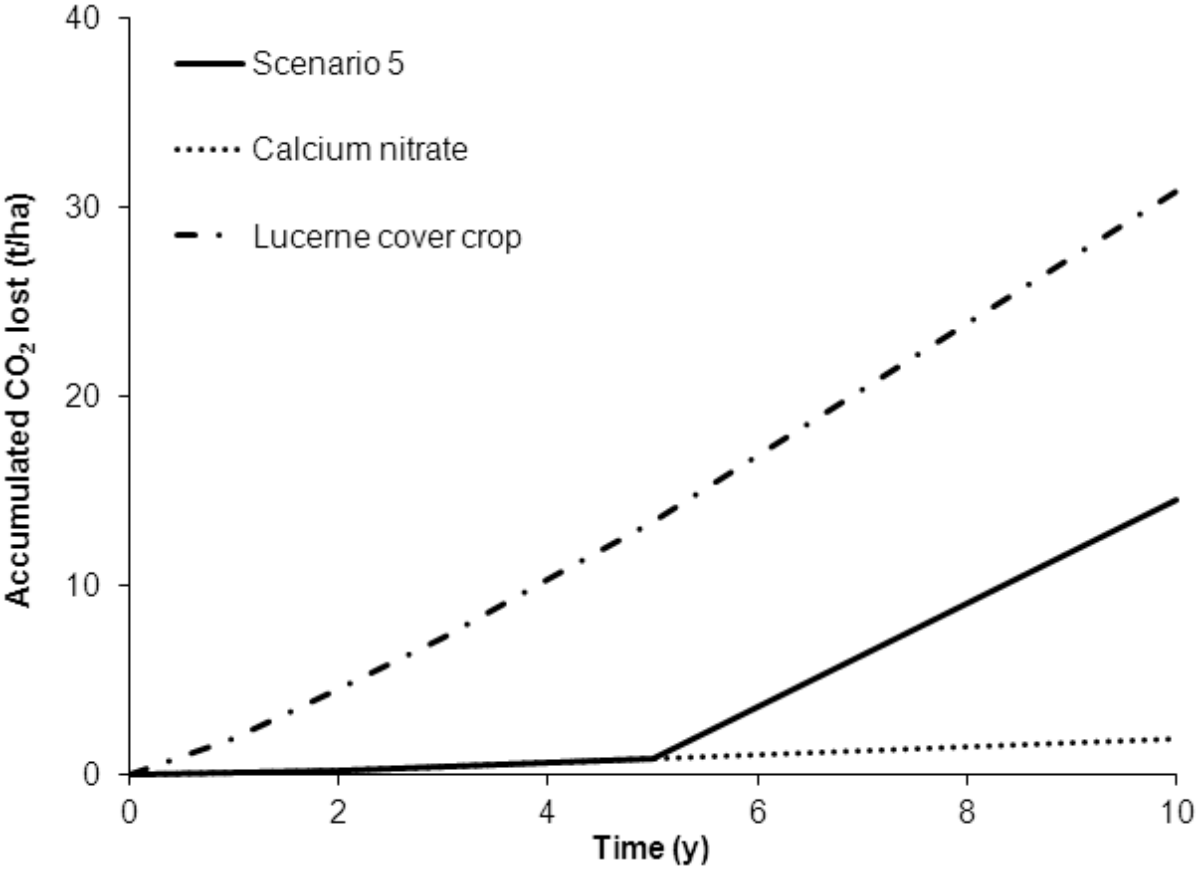

Figure 26: Estimated accumulated carbon dioxide lost to the atmosphere for vegetable land under different land management practices over 10 years.

Soil C levels remain very low for the first 5 years during calcium nitrate land management. Once lucerne cover crops start to be grown soil C levels start to increase quickly (Figure 27).

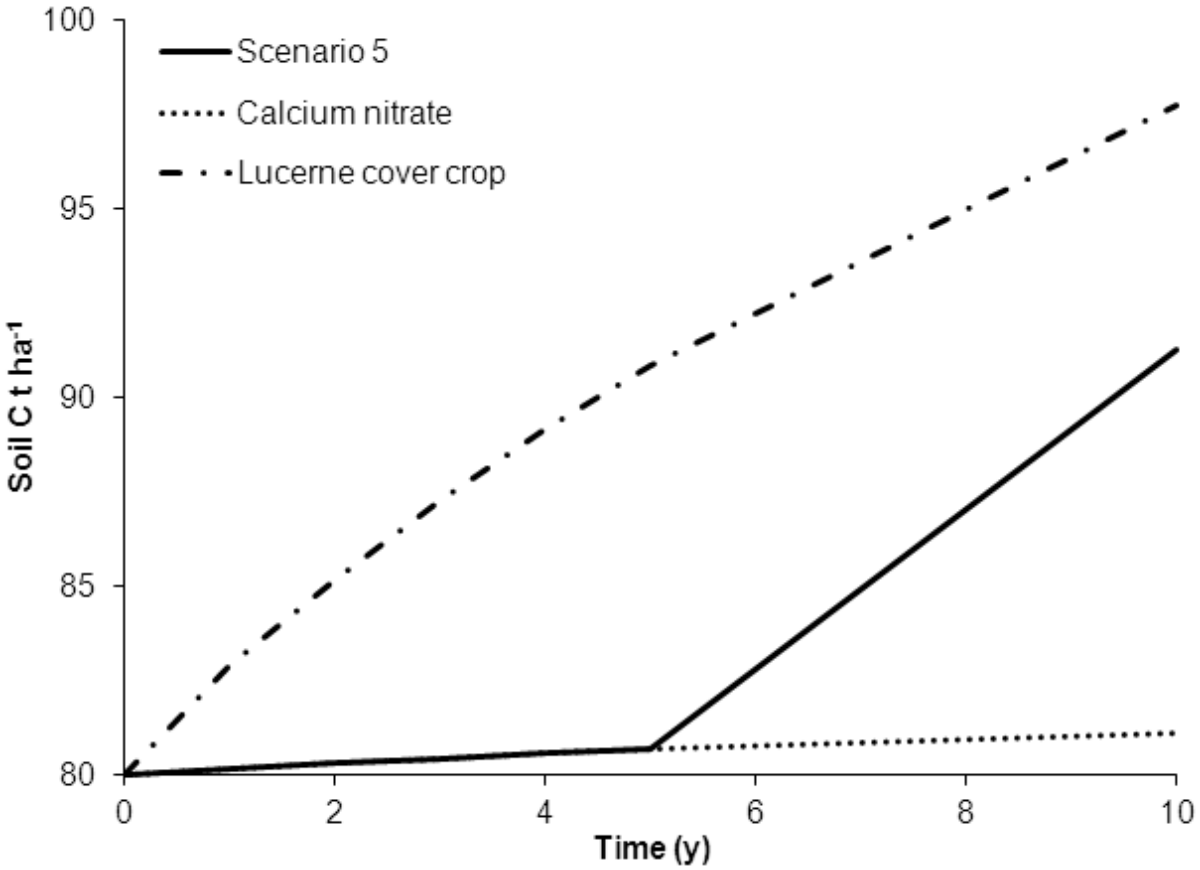

Figure 27: Predicted carbon storage potential of soil under different land management practices over 10 years.

Discussion

Variation in gas emissions from different vegetable crops

The measurement of greenhouse gas emissions from soil over a period of approximately one month has illustrated that the release of CO_2 and N_2O from soil is strongly correlated with rainfall. Although gas sampling avoid irrigation periods, this is also likely to increase emissions of these gases due to anaerobic conditions. Increases in emissions of these gases corresponded exactly with rainfall events. Higher levels of CO_2 emissions during periods of rainfall have also been reported by Komatsuzaka & Ohta (2007).

Broccoli plants generally had higher CO_2 emissions when compared to the other crops. This result may have been influenced by the stage of maturity between respective crops, with broccoli plants at an earlier developmental stage than other crops.

This experiment shows, importantly, that greenhouse gas emissions are the same from bare soil as from bare soil with a plant growing. This idea is supported by the fact that there were no differences in the emissions of CO_2 between lettuce and cabbage crops. Emissions from lettuce included a plant in the chamber while the inter-row area was sampled in the cabbage crop. A similar trend was shown for N_2O emissions, where broccoli and cabbage emissions were similar. Therefore, emissions between soil near a plant and in the inter-row area are similar; this may be due to the lack of any difference between these spatial locations, as the roots are able spread into the inter-row area. This means that any differences in emissions between these locations in a crop are likely to be minimal.

The lettuce crop had higher N_2O emissions when compared to other crops, which may have been due to higher fertilizer input for this crop. This relationship between higher N_2O emission and higher fertilizer supply is supported by higher NO_3 levels in soil for the lettuce crop when compared to other crops. Therefore the quantity of N_2O released from soils likely follows an increasing trend with increases in the supply of nitrogen fertiliser. This response confirms the findings of other studies (Shan *et al*., 2010; Bing, C. *et. al*., 2005 and Neetson et al. 1999).

The emission of CH_4 from soil is relatively low when compared to the other gases measured. Its release from soil is also constant over time and is not clearly influenced by crop type. Constant low levels of emissions of CH_4 have also been reported by Lui *et al* (2006) and Elder and Lal (2008). There was no clear relationship between CH_4 emissions and crop, illustrating that emissions of this gas from soil are constant regardless of the crop grown.

Importance of a unified method for gas sampling

There is no recognised method of sampling emissions from soil. The most complex and costly is the use of automated portable chambers, such as those used in experiment 1, which can sample gases in situ and cost approximately $3000/chamber. A less costly alternative that has been increasingly used is static PVC chambers, where gas samples are taken manually and analysed off site at a

later date. These chambers cost approximately $80/each, and have hence become widely used for gas sampling. Static chambers are useful to increase the range of treatments that can be assessed in an experiment but it is important to “calibrate” these against automatic chambers at some stage so that data collected using static chambers can be compared to benchmark automatic chamber data.

As with most equipment, there is a compromise between cost and the quality of the job it can do. We examined the time required for manual static chambers to accumulate gases before sampling. The concentration of N_2O and CO_2 followed a linear increase over time, while CH_4 emissions remained constant. The time of day of gas sampling also influenced the concentration of N_2O and CO_2, with afternoon sampling recording higher emissions than during the morning.

The conversion of a concentration to emissions on an area per unit time basis is the most common way to express the quantity of gases released from soil. When this is done, and as the time for which chambers are closed increases, emissions decrease dramatically. The reason for this is that although the absolute concentration increases over time its rate of increase is much slower than the increase in time. So when emissions are expressed on an area time basis they become lower with increasing time after lids are closed.

It is therefore important that a unified methodology for sampling greenhouse gases from static chambers be adopted by Australian researchers. As in the case of CO_2 emissions, the concentration after 30 min is approximately half of that after 15 min. If there is no uniformity between studies it makes comparisons difficult. The standard time required to accumulate gases before samples should be taken is 15 min. It is recommended that this be a standard adopted for the measurement of greenhouse gases from soil, using PVC chambers with an internal diameter of $0.063m^{-2}$. It is also recommended that samples be collected in the morning, before higher temperatures start to affect the density of gases. However, it should be pointed out that N_2O and CO_2 emissions are slightly lower in the morning.

Gas emissions from different land uses

The emissions of greenhouse gases from soil varied over time for both lettuce and cabbage crops. Gas emissions were measured on a weekly basis for a total of 17 weeks for lettuce and 19 weeks for cabbage. The peaks in concentration of N_2O and CO_2 were strongly correlated with rainfall events, further supporting the results from experiment 1.

The emission of N_2O and CH_4 from vegetables crops is not affected by land use, with no differences between any of the treatments examined. There were, however, higher CO_2 emissions for cover crop treatments, compared to other land uses. This slightly higher level of emissions is likely to be offset by the higher cumulative amounts of soil C stored by cover crop treatments.

The emission of greenhouse gases over the measurement period was reasonably consistent for all gases, illustrating that over the longer term emissions are predictable and therefore able to be modelled with some certainty. Over the course of the measurement period the amount of N_2O released from soil ranged from 15 to

25 mg h^{-1} m^{-2}; the amount of CH_4 released was from 200 to 350 mg h^{-1} m^{-2}; and CO_2 was from 200 to 450 g h^{-1} m^{-2}. These results represent some of the earliest greenhouse gas emission levels measured from horticultural crops in Australia.

Soil microbial biomass

The levels of SMC and SMN varied greatly for soil where lettuce and cabbage crops were grown. However, the land use imposed on these crops clearly did not influence either SMC or SMN. This factor would be expected to alter soil microbial levels; however the cumulative effect of this was not examined in this experiment. If the effects of these land uses were measured over a succession of crops, differences between land use patterns may have become evident.

Soil carbon and nitrogen storage

The spatial distribution of C and N in the soil profile varied greatly and was likely influenced by high levels of historic cultivation at Grech Farms. This made it difficult to measure the effect of different land use patterns on soil C and N; particularly considering that the cumulative effect of this factor was not measured at the same site. The only clear response for soil C and N is that there are higher levels in the soil after a long fallow period than after a crop is grown. This means that the production of lettuce and cabbage crops removes more C and N from the soil than is supplied or returned.

Effect of cover crops on yield

The growth of cover crops and planting of lettuce and cabbage seedlings through the residue slowed the development of plants in both crops. The harvest date for plants in these treatments was about one week later than that for other treatments. The reduced growth rate of plants under this crop management regime may have resulted from nitrogen drawdown caused by soil microbes, indicating lower soil nitrogen was available to plants as it was being utilised by soil microbes.

Long-term comparison of different land uses

The prediction of CO_2 lost to the atmosphere under different land management practices followed a similar relationship with the amount of plant residue applied to or incorporated into soil, i.e. the more plant residue applied the greater the amount of CO_2 released to the atmosphere. In the case of organic mulch the CO_2 loss would occur regardless, as this plant residue is sourced from council green waste. The comparison between land use patterns therefore becomes somewhat arbitrary, but still clearly shows the relationship between higher levels of plant residue and higher accumulated loss of CO_2 from cropping systems.

Soil C storage was higher for land management practices such as organic mulch, where large volumes of green waste were added to supply enough N for efficient crop growth. Very little C was stored for conventional synthetic fertiliser applications, as almost no additional C was added for this cropping system. The release of CO_2 and storage of C in the soil is strongly related to the amount of organic matter grown on the land or incorporated from elsewhere. Additional storage of C in the soil will

help offset higher CO_2 loss, particularly considering that this loss will occur regardless, as in the case of council green waste.

Longer-term modelling

Scenario 1: *20 years of organic mulch amendments followed by 80 years of a combination of organic mulch and chicken manure amendments***.** The scenario examined the effect of 20 years of organic mulch additions to a cropping system, three times a year. This land management practice supplies large quantities of mulch to soil in order to supply comparable N to crops. This means that high soil C storage results but at the expense of CO_2 lost. Therefore, after 20 years the land management practice reverted to a combination of organic mulch and chicken manure. This still supplied organic mulch to the cropping system but also utilized a waste product of intensive poultry production. The amount of CO_2 released from this scenario was compared with constant organic mulch and organic mulch/chicken manure cropping systems. Predicted release of CO_2 follows the same trend as organic mulch for the first 20 years but then levels out and parallels the amount of CO_2 released by organic mulch and chicken manure land use.

The effect on soil C storage by changing between land use patterns results in an estimated lower soil C after 100 years than either of the land management regimes compared. The reason for this response is likely due to the stability of C derived from the organic mulch once the volume supplied to the system is significantly reduced.

Mid-term modelling

Scenario 2: *Annual rye grass cover cropping system for 5 years, followed by 10 years of reverting to synthetic fertiliser amendments, and then again adopting a cover cropping system for a further 5 years.* As has been previously shown, the amount of plant residue supplied to the system is proportionate to the amount of CO_2 released to the atmosphere. As a result CO_2 levels increase for the first 5 years, then increase at a much slower rate when conventional land use resumes, and then pick up again after cover cropping is resumed.

The change of land management practices, as in scenario 1, altered the amount of soil C stored, in scenario 2. The changing land use patterns have a negative effect on soil C in both cases. An increase in soil C occurs at a similar rate to the cover cropping system for the first 5 years, and then it decreases during the conventional fertilizer regime. Importantly, once cover cropping resumes, the rate of increase in soil C resumes at the same rate as previously.

Shorter-term modelling

Scenario 3: *5 years of organic mulch followed by 5 years of organic mulch and chicken manure.* For the first 5 years, emissions of CO_2 are the same as the organic mulch land use pattern, but when management of land changes to organic mulch and chicken manure amendments, the quantity of CO_2 emitted increases at a much slower rate. CO2 emissions are reduced after 5 years because the mulch plus chicken manure combination results in lower emissions. Soil C levels also plateau

after 5 years because of the lower residual organic matter content of chicken manure.

Scenario 4: *Organic mulch amendments for 5 years and then reverting to synthetic fertilizer for a further 5 years.* The emission of CO_2 increases for the first 5 years at the same rate as organic mulch land use. Once N is supplied in the form of calcium nitrate, the rate of CO_2 lost from the system declines. This could be a useful strategy to quickly increase soil C levels, but soil C levels decline rapidly once the organic supplements are ceased.

Scenario 5: *5 years of synthetic fertilizer amendments followed by 5 years of lucerne cover cropping.* The emission of CO_2 for this scenario is very low for the first 5 years, but then starts to increase at a similar rate to the lucerne cover crop when this land management practice is adopted. The soil C accumulation is minimal without the addition of organic supplements, but once the lucerne cover crop is established, soil C levels start to rise rapidly. This could be a useful strategy to rapidly increase soil C levels in degraded soil systems.

Technology Transfer

This project centres on providing real data on vegetable crops that can be incorporated into the Carbon Vegetable Tool. This data has now been made available to the research team managing this project (formerly VG09142).

An abstract has been submitted to the second annual National Climate Change Adaptation Research Facility (NCCARF) Conference to be held in Melbourne from 26-28 June, Melbourne 2012: *Quantifying the effects of no-till vegetable farming and organic mulch on greenhouse gas emissions and soil carbon*. This abstract was accepted for poster presentation.

The work, including the more recent modelling work, will be presented at the Climate Change Research Strategy for Primary Industries (CCRSPI) conference to be held in Melbourne in November 2012.

An article on the work will be published in *Vegetables Australia* magazine.

AHR will make the research available via its website and also make the results available to the nitrous oxide and soil carbon research groups in Australia.

The work will be published in a recognised international scientific journal, as it represents some of the first baseline vegetable soil greenhouse gas emissions data available for the Australian vegetable industry.

Recommendations

The mulch and no-till systems need to be established for a longer period than was possible with this relatively short-term experiment. The data clearly shows there is great potential in cover crop, mulch and compost treatments for building soil C levels, and there is potential for greenhouse gas emissions to stabilise over time. Data needs to be collected from 5-year experiments to confirm these trends. The other area of great potential is in managing the inter-row area in perennial tree crops, where soil disturbance is minimal and long-term C sequestration is feasible. Data should be collected on these systems.

As rainfall and fertilizer events clearly influence N_2O and CH_4 emissions from soils, these events need to be taken into consideration when interpreting greenhouse gas emission data.

For static chambers, there should be a standardised chamber size and sampling time, so that data collected can be compared between research groups. There is also a need to calibrate the static systems by comparing them alongside automatic systems for a period of time. Initial data suggests that manual static chambers that have an internal volume of $0.063m^3$ should be closed for 15 minutes before gas samples are taken.

Acknowledgements

The authors would like to acknowledge the assistance of Tony Winters in analytical aspects of gas measurement. Tony helped to commission and optimise the gas chromatography systems used to quantify greenhouse gas emission from soil. Authors would also like to thank Jonathan Mangmang for his efforts in the extraction of soil microbial biomass.

References

Alvaro-Fuentes J, Lopez MV, Arrue JL, Moret D, Paustian K (2009) Tillage and cropping effects on soil organic carbon in Mediterranean semi-arid agroecosystems: Testing the Century model. *Agriculture, Ecosystems and Environment*. **134**, 211-217.

Bing, C., Jin, X., Cai, G., Fan, X. and Sun. H. (2004) Effects of low rate nitrogen application on *Brassica chinensis* growth and N losses. Plant Nutrition and Fertilizer Science. 11:4 pp 519-523.

Chatskikh D, Olesen JE (2007) Soil tillage enhanced CO_2 and N_2O emissions from loamy sand soil under spring barley. *Soil & Tillage Research*. **97**, 5-18.

Dalal, R.C., Wang, W. et al. (2003) Nitrous oxide emission from Australian agricultural lands and mitigation options: a review. Australian Journal of Soil Research 41:165-195.

Del Grosso SJ, Mosier AR, Parton WJ, Ojima DS (2005) DAYCENT model analysis of past and contemporary soil N_2O and net flux for major crops in the USA.

Denef K, Six J, Merckx R, Paustian K (2004) Carbon Sequestration in Microaggregates of No-Tillage Soils with Different Clay Mineralogy. *Soil Sci Am. J.* **68**, 1935-1944.

Drury CF, Reynolds WD, Tan CS, Welacky TW, Calder W, McLaughlin NB (2006) Emissions of Nitrous Oxide and Carbon Dioxide: Influence of Tillage Type and Nitrogen Placement Depth. *Soil Sci. Soc. Am. J.* **70**, 570-580.

Elder JW, Lal R (2008) Tillage effects on gaseous emissions from an intensively farmed organic soil in North Central Ohio. *Soil & Tillage Research*. **98**, 45-55.

Filipovic D, Kosutic S, Gospordaric Z, Zimmer R, Banaj D (2006) The possibilities of fuel savings and the reduction of CO_2 emissions in the soil tillage in Croatia. *Agriculture, Ecosystems and Environment*. **115**, 290-294.

Forster, P., Ramaswamy, V., Araxo, P., Berntsen, T., Betts, R.A., Fahey, D.W., Haywood, J., Lean, J., Lowe, D.C., Myhre, G., Nganga, J., Prinn, R., Raga, G., Schulze M. and Van Dorland R., in Climate Change 2007: The Physical Science Basis (eds Solomon,S. et al.) 129–234 (Cambridge Univ. Press, 2007).

Garnaut, R. (2008). Garnaut CLIMATE CHANGE REVIEW Draft Report, Attorney-General's Department, Robert Garran Offices, National Circuit, Canberra ACT 2600: 537.

Garnaut, R. (2011) Garnaut Climate Change Review - Update 2011

Govaerts B, Verhulst N, Castellanos-Navarrete A, Sayre KD, Dixon J, Dendooven L (2009) Conservation Agriculture and Soil Carbon Sequestration: Between Myth and Farmer Reality. *Critical Reviews in Plant Sciences*. **28** (3), 97-122.

Grace, P. Queensland University of Technology (GRDC Update Autumn (2008).

Gu S, Komatsuzaki M, Moriizumi S, Mu Y (2004) Soil nitrogen dynamics in relation to cover cropping (in Japanese). *Jpn J Farm Work Res.* **39** (1), 9-16.

GRDC Update (2008) Autumn. Carbon trading and the science behind it. *Research Information for Farm Advisers.* **42**, 1-3.

Horwath, W.R. & Paul, E.A. (1994). Microbial Biomass. In *Methods of Soil Analysis, Part 2. Microbial and Biochemical properties* (ed SSSA). SSSA, Madison.

Howden, M (2009) Australian agriculture in a climate of change. Greenhouse 2009: Climate change and resources, Perth 23-26th March 2009.

Jarecki MK, Parkin TB, Chan ASK, Kaspar TC, Moorman TB, Singer JW, Kerr BJ, Hatfield JL, Jones R (2009) Cover crop effects on nitrous oxide emission from a manure-treated Mollisol. *Agriculture, Ecosystems and Environment*. **134**, 29-35.

Johnson JMF, Reicosky DC, Allmaras RR, Sauer TJ, Venterea RT, Dell CJ (2005) contributions and mitigation potential of agriculture in the central USA. *Soil Till Res.* **83** (1), 73-94.

Komatsuzaki M (1999) Cropping system and rotation. In: Endo O (ed) *Sustainable agriculture system management* (in Japanese). Nourin Toukei Kyoukai, Tokyo, Japan.

Komatsuzaki M, Ohta H (2007) Soil management practices for sustainable agro-ecosystems. *Sustain Sci*. **2**, 103-120.

La Scala Jr., N., Lopes, A., Spokas, K., Bolonhezi, D., Archer, D.W., Reicosky, D.C., (2008). Short-term temporal changes of soil carbon losses after tillage described by a first-order decay model. Soil Till. Res. 99, 108–118.

Liu XJ, Mosier AR, Halvorson AD, Zhang FS (2006) The impact of nitrogen placement and tillage on NO, N_2O, CH_4 and CO_2 fluxes from a clay soil. *Plant and Soil*. **280**, 177-188.

Liu XJ, Mosier AR, Halvorson AD, Reule CA, Zhang FS (2007) Dinitogen and N2O emissions in arable soils: Effects of tillage, N source and soil moisture. *Soil Biology & Biochemistry*. **39**, 2362-2370.

Metay A, Oliver R, Scopel E, Douzet JM, Moreira JAA, Maraux F, Feigl BJ, Feller C (2007) N_2O and CH_4 emissions from soils under conventional and no-till management practices in Goiania (*Cerrados*, Brazil). *Geoderma.* **141**, 78-88.

Michelsen, A., Andersson, M., Jensen, M., Kjoller, A., & Gashew, M. (2004) Carbon stocks, soil respiration and microbial biomass in fire-prone tropical grassland, woodland and forest ecosystems. *Soil Biology and Biochemistry*, **36**, 1707-1717.

Neeteson, J. J, Booij, R., and Whitmore, A. P. (1999) A review on sustainable nitrogen management in intensive vegetable production systems. Acta Horticulturae. 506 pp 17-26.

Neufeldt, H. and M. Schafer (2008). "Mitigation strategies for emissions from agriculture using a regional economic-ecosystem model." Agriculture, Ecosystems & Environment 123(4): 305-316.

Ohlinger, R. (1995). Biomass-C by Fumigation-Extraction Technique. In *Methods in Soil Biology* (eds F. Schinner, R. Ohlinger, E. Kandeler & R. Margesin), pp. 56-58. Springer, Berlin.

Olson KR, Lang JM, Ebelhar SA (2005) Soil and organic carbon changes after 12 years of no-tillage and tillage of Grantsburg soils in southern Illinois. *Soil & Tillage Research*. **81**, 217-225.

Omonode RA, Vyn TJ, Smith DR, Hegymegi P, Gal A (2007) Soil carbon dioxide and methane fluxes from lon-term tillage systems in continuous corn and corn-soybean rotations. *Soil & Tillage Research*. **95**, 182-195.

Shan, L., Iqbal, J. Hu, R. and Feng, M. (2010) N_2O emissions from different land uses in mid-subtropical China. Agriculture, Ecosystems & Environment. 136:1/2 pp 40-48.

Six J, Ogle SM, Breidt FJ, Conant RT, Mosiers AR, Paustian K (2004) The potential to mitigate global warming with no-tillage management is only realized in the long term. *Global Change Biology.* **10**, 155-160.

Ussiri DAN, Lal R (2009) Long term effects on soil carbon storage and carbon dioxide emissions in continuous corn cropping system from alfisol in Ohio. *Soil & Tillage Research*. **104**, 39-47.

van Groenigen, KJ, Osenberg, CW, Hungate, BA (2011) Increased soil emissions of potent greenhouse gases under increased atmospheric CO_2. *Nature* **475**, 214–216.

Venterea RT, Burger M, Spokas KA (2005) Nitrogen Oxide and Methane Emissions under Varying Tillage and Fertilizer Management. *J. Environ. Qual*. **34**, 1467-1477.

Wagger MG, Mengel DE (1988) The role of non-leguminous cover crops in the efficient use of water and nitrogen. In: Hargrove WL (ed) Cropping strategies for efficient use of water and nitrogen. American Society of Agronomy, Madison, Wisconsin, *Special publication.* **51**, 115-117.

Yagi K (2002) Mitigation options for methane emission in rice fields, In: Lal R (ed) *Encyclopedia of soil science*. Dekker, New York, 814-818.

Yan H, Cao M, Liu J, Tao B (2007) Potential and sustainability for carbon sequestration with improved soil management in agricultural soils of China. *Agriculture, Ecosystems and Environment*. **121**, 323-335.

Appendix I Abstract submitted to the NCARF conference, Melbourne 2012: *Quantifying the effects of no till vegetable farming and organic mulch on greenhouse gas emissions and soil carbon*

Gordon Rogers and Matthew Hall

University of Sydney and Applied Horticultural Research

The vegetable industry in Australia uses high levels of inputs including water and nitrogenous fertilizer and the potential to release significant quantities of carbon dioxide and nitrous oxide into the atmosphere is high. Techniques such as minimum tillage, cover crop residues as organic mulches and legumes as a source of nitrogen have the potential to reduce emissions, especially nitrous oxide, while at the same time sequestering carbon in soils.

There is very little data available on emissions of greenhouse gases from vegetable cropping systems in Australia, either from conventional high-input cropping systems or modified cropping systems.

Emission rates of carbon dioxide, nitrous oxide and methane from soil were measured using a combination of automatic and static sampling techniques from potato, lettuce, broccoli, cabbage and cauliflower crops on a commercial vegetable farm in NSW. Crops were produced using conventional practices, minimum tillage and the use of legumes. Time series studies were carried out to identify optimum sampling times and duration for static chambers, and the data compared to automatic chambers.

Nitrous oxide emission rates averaged 57, 17 and 20 mg $N_2O/m^2/h$ from lettuce, cabbage and broccoli crops (automatic chambers). This data was compared to subsequent data sets collected using static chambers where N_2O emissions ranged from 15 – 25 $N_2O/m^2/h$ from lettuce and cabbage crops. Peaks in both nitrous oxide and carbon dioxide emissions occurred in response to applications of nitrogenous fertilizers. Emissions declined as nitrogen was taken up by the crop, and in lettuce there was a general increase in nitrous oxide emissions as the crop matured. Nitrous oxide emissions were lower when lucerne was used to supply nitrogen to the crop. No-till, however, had little impact on emissions. The impacts of no-till and mulches on soil organic carbon and microbial biomass will also be presented.

Appendix II Roth C model settings and outputs

General settings

```
********************************************************************************
****
    ROTHC-26.3 (DLL) : A MODEL FOR THE TURNOVER OF ORGANIC CARBON IN THE
SOIL
                                  October 1997
            K.W. Coleman, D.S. Jenkinson, L.C. Parry and J.H. Rayner
               IACR - Rothamsted, Harpenden, Herts. AL5 2JQ. U.K.
                      Contact K.W. Coleman or D.S. Jenkinson
                            Copyright IACR - Rothamsted

********************************************************************************
****
   Start year  = 2012
   Start month = JANUARY
 Month       Mean temperature  Rainfall  Evaporation
 -----       ----------------  --------  -----------
 JANUARY            23.1          85.4       170.5
 FEBRUARY           22.7          86.2       131.6
 MARCH              20.9          80.9       120.9
 APRIL              17.4          62.9        90.0
 MAY                13.8          56.8        62.0
 JUNE               11.1          59.8        48.0
 JULY               10.1          44.2        55.8
 AUGUST             11.5          39.9        80.6
 SEPTEMBER          14.4          39.6       108.0
 OCTOBER            17.0          57.2       136.4
 NOVEMBER           19.5          65.9       150.0
 DECEMBER           21.8          67.5       176.7
 Percentage clay =  40.00
 Sample depth 30.0 cm
 ( From Ther.dat)

                Soil
               Moisture
 Month          Deficit
 -----          --------
 JANUARY          -73.04
 FEBRUARY         -73.04
 MARCH            -73.04
 APRIL            -73.04
 MAY              -62.74
 JUNE               0.00
 JULY               0.00
 AUGUST           -20.55
 SEPTEMBER        -61.95
 OCTOBER          -73.04
 NOVEMBER         -73.04
 DECEMBER         -73.04
 Rate modifying factors
 ----------------------
```

Month	Mean temp.	Moisture	Crop Retainment	Product
JANUARY	3.4261	0.2000	0.6000	0.4111
FEBRUARY	3.3474	0.2000	0.6000	0.4017
MARCH	2.9954	0.2000	0.6000	0.3594
APRIL	2.3305	0.2000	0.6000	0.2797
MAY	1.6925	0.4029	0.6000	0.4091
JUNE	1.2605	1.0000	0.6000	0.7563
JULY	1.1133	1.0000	0.6000	0.6680
AUGUST	1.3214	1.0000	0.6000	0.7929
SEPTEMBER	1.7945	0.4185	0.6000	0.4506
OCTOBER	2.2569	0.2000	0.6000	0.2708
NOVEMBER	2.7256	0.2000	0.6000	0.3271
DECEMBER	3.1708	0.2000	0.6000	0.3805

Calcium nitrate

Starting conditions 2012

==========

Radiocarbon activity scaling factor = 1.0590

	Amount	Radio Age	Delta Value
DPM	0.0298	-460.19	58.94
RPM	0.1135	-459.92	58.91
BIO	0.0153	-459.86	58.90
HUM	0.0203	-459.84	58.90
IOM	80.0000	50000.00	-998.02
Total	80.1789	43699.96	-995.65

The accumulated CO2 lost to the atmosphere is 0.1211 tonnes / ha

After year 2 (2013)

Radiocarbon activity scaling factor = 1.0570

	Amount	Radio Age	Delta Value
DPM	0.0301	-445.15	56.96
RPM	0.2124	-451.34	57.78
BIO	0.0311	-451.90	57.85
HUM	0.0467	-452.71	57.96
IOM	80.0000	50000.00	-998.02
Total	80.3203	40844.99	-993.80

The accumulated CO2 lost to the atmosphere is 0.2797 tonnes / ha

After year 3 (2014)

Radiocarbon activity scaling factor = 1.0560

	Amount	Radio Age	Delta Value
DPM	0.0301	-437.47	55.95
RPM	0.2985	-445.32	56.99
BIO	0.0444	-445.70	57.04
HUM	0.0752	-447.28	57.25
IOM	80.0000	50000.00	-998.02
Total	80.4482	38928.46	-992.13

The accumulated CO2 lost to the atmosphere is 0.4518 tonnes / h

```
After year      4    (2015)
 -----------------
 Radiocarbon activity scaling factor =  1.0550
                           Radio       Delta
              Amount        Age        Value
              ------       -----       -----
 DPM          0.0301     -429.86       54.95
 RPM          0.3736     -439.83       56.26
 BIO          0.0557     -440.09       56.30
 HUM          0.1053     -442.56       56.62
 IOM         80.0000    50000.00     -998.02
 Total       80.5647    37515.10     -990.62
 The accumulated CO2 lost to the atmosphere is      0.6353 tonnes / ha
 After year      5    (2016)
 -----------------
 Radiocarbon activity scaling factor =  1.0530
                           Radio       Delta
              Amount        Age        Value
              ------       -----       -----
 DPM          0.0301     -414.69       52.97
 RPM          0.4391     -432.49       55.30
 BIO          0.0653     -432.83       55.35
 HUM          0.1368     -436.98       55.89
 IOM         80.0000    50000.00     -998.02
 Total       80.6712    36415.71     -989.24
 The accumulated CO2 lost to the atmosphere is      0.8288 tonnes / ha
 After year     10    (2021)
 -----------------
 Radiocarbon activity scaling factor =  1.0490
                           Radio       Delta
              Amount        Age        Value
              ------       -----       -----
 DPM          0.0301     -384.04       48.96
 RPM          0.6596     -403.38       51.48
 BIO          0.0960     -402.83       51.41
 HUM          0.3082     -413.99       52.87
 IOM         80.0000    50000.00     -998.02
 Total       81.0939    33146.37     -983.84
 The accumulated CO2 lost to the atmosphere is      1.9061 tonnes / ha
 After year     15    (2026)
 -----------------
 Radiocarbon activity scaling factor =  1.0460
                           Radio       Delta
              Amount        Age        Value
              ------       -----       -----
 DPM          0.0301     -360.96       45.95
 RPM          0.7705     -378.85       48.28
 BIO          0.1106     -377.95       48.16
 HUM          0.4908     -395.41       50.44
 IOM         80.0000    50000.00     -998.02
 Total       81.4020    31419.73     -979.97
 The accumulated CO2 lost to the atmosphere is      3.0980 tonnes / ha
```

```
After year     20    (2031)
 -----------------
 Radiocarbon activity scaling factor =  1.0430
                           Radio       Delta
              Amount        Age        Value
              ------       -----       -----
 DPM          0.0301     -337.96       42.96
 RPM          0.8261     -358.03       45.57
 BIO          0.1181     -357.30       45.47
 HUM          0.6751     -379.56       48.37
 IOM         80.0000    50000.00     -998.02
 Total       81.6494    30272.70     -976.8
 The accumulated CO2 lost to the atmosphere is      4.3506 tonnes / ha
 After year     50    (2061)
 -----------------
 Radiocarbon activity scaling factor =  1.0390
                           Radio       Delta
              Amount        Age        Value
              ------       -----       -----
 DPM          0.0301     -307.02       38.95
 RPM          0.8814     -307.52       39.01
 BIO          0.1285     -308.33       39.12
 HUM          1.6820     -320.79       40.73
 IOM         80.0000    50000.00     -998.02
 Total       82.7220    26672.25     -963.83
 The accumulated CO2 lost to the atmosphere is     12.2780 tonnes / ha
 After year    100    (2111)
 -----------------
 Radiocarbon activity scaling factor =  1.0390
                           Radio       Delta
              Amount        Age        Value
              ------       -----       -----
 DPM          0.0301     -307.02       38.95
 RPM          0.8823     -299.99       38.04
 BIO          0.1334     -298.48       37.85
 HUM          2.9243     -276.96       35.07
 IOM         80.0000    50000.00     -998.02
 Total       83.9701    23927.15     -949.10
 The accumulated CO2 lost to the atmosphere is     26.0299 tonnes / ha
```

Organic mulch

```
Starting conditions    2012
 ===================
 Radiocarbon activity scaling factor =  1.0590
                           Radio       Delta
              Amount        Age        Value
              ------       -----       -----
 DPM          1.0693     -460.19       58.94
 RPM          4.0742     -459.92       58.91
 BIO          0.5498     -459.86       58.90
 HUM          0.7296     -459.84       58.90
 IOM         80.0000    50000.00     -998.02
 Total       86.4229    20235.69     -919.41
 The accumulated CO2 lost to the atmosphere is      4.3471 tonnes / ha
```

```
After year      2    (2013)
 -----------------
 Radiocarbon activity scaling factor =  1.0570
                            Radio       Delta
              Amount         Age        Value
              ------       -----       -----
 DPM          1.0802     -445.15       56.96
 RPM          7.6244     -451.34       57.78
 BIO          1.1161     -451.90       57.85
 HUM          1.6782     -452.71       57.96
 IOM         80.0000    50000.00     -998.02
 Total       91.4989    16105.94     -865.27
 The accumulated CO2 lost to the atmosphere is     10.0411 tonnes / ha
 After year      3    (2014)
 -----------------
 Radiocarbon activity scaling factor =  1.0560
                            Radio       Delta
              Amount         Age        Value
              ------       -----       -----
 DPM          1.0803     -437.47       55.95
 RPM         10.7179     -445.32       56.99
 BIO          1.5947     -445.70       57.04
 HUM          2.6992     -447.28       57.25
 IOM         80.0000    50000.00     -998.02
 Total       96.0921    13835.03     -821.26
 The accumulated CO2 lost to the atmosphere is     16.2179 tonnes / ha
 After year      4    (2015)
 -----------------
 Radiocarbon activity scaling factor =  1.0550
                            Radio       Delta
              Amount         Age        Value
              ------       -----       -----
 DPM          1.0803     -429.86       54.95
 RPM         13.4135     -439.83       56.26
 BIO          1.9999     -440.09       56.30
 HUM          3.7798     -442.56       56.62
 IOM         80.0000    50000.00     -998.02
 Total      100.2735    12342.28     -784.77
 The accumulated CO2 lost to the atmosphere is     22.8065 tonnes / ha
 After year      5    (2016)
 -----------------
 Radiocarbon activity scaling factor =  1.0530
                            Radio       Delta
              Amount         Age        Value
              ------       -----       -----
 DPM          1.0803     -414.69       52.97
 RPM         15.7624     -432.49       55.30
 BIO          2.3439     -432.83       55.35
 HUM          4.9107     -436.98       55.89
 IOM         80.0000    50000.00     -998.02
 Total      104.0973    11271.46     -754.09
 The accumulated CO2 lost to the atmosphere is     29.7527 tonnes / ha
```

```
After year     10    (2021)
 -----------------
 Radiocarbon activity scaling factor =  1.0490
                            Radio       Delta
              Amount         Age        Value
              ------       -----       -----
 DPM          1.0803     -384.04       48.96
 RPM         23.6811     -403.38       51.48
 BIO          3.4453     -402.83       51.41
 HUM         11.0650     -413.99       52.87
 IOM         80.0000    50000.00     -998.02
 Total      119.2716     8487.24     -652.25
 The accumulated CO2 lost to the atmosphere is     68.4284 tonnes / ha
 After year     15    (2026)
 -----------------
 Radiocarbon activity scaling factor =  1.0460
                            Radio       Delta
              Amount         Age        Value
              ------       -----       -----
 DPM          1.0803     -360.96       45.95
 RPM         27.6592     -378.85       48.28
 BIO          3.9721     -377.95       48.16
 HUM         17.6195     -395.41       50.44
 IOM         80.0000    50000.00     -998.02
 Total      130.3311     7234.70     -593.59
 The accumulated CO2 lost to the atmosphere is    111.2189 tonnes / ha
 After year     20    (2031)
 ----------------
 Radiocarbon activity scaling factor =  1.0430
                            Radio       Delta
              Amount         Age        Value
              ------       -----       -----
 DPM          1.0803     -337.96       42.96
 RPM         29.6577     -358.03       45.57
 BIO          4.2392     -357.30       45.47
 HUM         24.2376     -379.56       48.37
 IOM         80.0000    50000.00     -998.02
 Total      139.2149     6479.96     -553.57
 The accumulated CO2 lost to the atmosphere is    156.1851 tonnes / ha
 After year     50    (2061)
 -----------------
 Radiocarbon activity scaling factor =  1.0390
                            Radio       Delta
              Amount         Age        Value
              ------       -----       -----
 DPM          1.0803     -307.02       38.95
 RPM         31.6429     -307.52       39.01
 BIO          4.6125     -308.33       39.12
 HUM         60.3831     -320.79       40.73
 IOM         80.0000    50000.00     -998.02
 Total      177.7188     4476.29     -427.13
 The accumulated CO2 lost to the atmosphere is    440.7812 tonnes / ha
```

```
After year    100    (2111)
 ----------------
 Radiocarbon activity scaling factor =  1.0390
                            Radio       Delta
              Amount         Age        Value
              ------       -----       -----
 DPM          1.0803     -307.02       38.95
 RPM         31.6753     -299.99       38.04
 BIO          4.7897     -298.48       37.85
 HUM        104.9808     -276.96       35.07
 IOM         80.0000    50000.00     -998.02
 Total      222.5261     3287.17     -335.76
 The accumulated CO2 lost to the atmosphere is    934.4739 tonnes / ha
```

Chicken manure

```
Starting conditions    2012
====================
Radiocarbon activity scaling factor =  1.0590
                            Radio       Delta
              Amount         Age        Value
              ------       -----       -----
 DPM          0.4308     -460.28       58.96
 RPM          1.6023     -460.00       58.92
 BIO          0.1492     -459.91       58.91
 HUM          0.2550     -459.91       58.91
 IOM         80.0000    50000.00     -998.02
 Total       82.4373    27346.63     -966.74
 The accumulated CO2 lost to the atmosphere is      1.1627 tonnes / ha
After year      2    (2013)
 -----------------
 Radiocarbon activity scaling factor =  1.0570
                            Radio       Delta
              Amount         Age        Value
              ------       -----       -----
 DPM          0.4352     -445.24       56.98
 RPM          2.9986     -451.42       57.79
 BIO          0.3216     -452.38       57.92
 HUM          0.5954     -452.88       57.98
 IOM         80.0000    50000.00     -998.02
 Total       84.3506    23091.90     -943.52
 The accumulated CO2 lost to the atmosphere is      2.8494 tonnes / ha
 After year      3    (2014)
 -----------------
 Radiocarbon activity scaling factor =  1.0560
                            Radio       Delta
              Amount         Age        Value
              ------       -----       -----
 DPM          0.4352     -437.56       55.97
 RPM          4.2152     -445.40       57.00
 BIO          0.4713     -446.21       57.10
 HUM          0.9628     -447.45       57.27
 IOM         80.0000    50000.00     -998.02
 Total       86.0845    20643.18     -923.40



 The accumulated CO2 lost to the atmosphere is      4.7155 tonnes / ha
 After year      4    (2015)
 -----------------
```

```
 Radiocarbon activity scaling factor =  1.0550
                           Radio       Delta
              Amount        Age        Value
              ------       -----       -----
 DPM          0.4352     -429.95       54.97
 RPM          5.2754     -439.91       56.28
 BIO          0.6012     -440.69       56.38
 HUM          1.3526     -442.73       56.65
 IOM         80.0000    50000.00     -998.02
 Total       87.6644    18980.04     -905.78
 The accumulated CO2 lost to the atmosphere is      6.7356 tonnes / ha
 After year      5    (2016)
 -----------------
 Radiocarbon activity scaling factor =  1.0530
                           Radio       Delta
              Amount        Age        Value
              ------       -----       -----
 DPM          0.4352     -414.78       52.98
 RPM          6.1992     -432.57       55.31
 BIO          0.7140     -433.74       55.46
 HUM          1.7615     -437.19       55.92
 IOM         80.0000    50000.00     -998.02
 Total       89.1099    17755.14     -890.27
 The accumulated CO2 lost to the atmosphere is      8.8901 tonnes / ha
After year     10    (2021)
 -----------------
 Radiocarbon activity scaling factor =  1.0490
                           Radio       Delta
              Amount        Age        Value
              ------       -----       -----
 DPM          0.4352     -384.13       48.97
 RPM          9.3135     -403.46       51.50
 BIO          1.0930     -404.21       51.59
 HUM          3.9985     -414.23       52.91
 IOM         80.0000    50000.00     -998.02
 Total       94.8401    14412.96     -833.67
 The accumulated CO2 lost to the atmosphere is     21.1599 tonnes / ha
After year     20    (2031)
 -----------------
 Radiocarbon activity scaling factor =  1.0430
                           Radio       Delta
              Amount        Age        Value
              ------       -----       -----
 DPM          0.4352     -338.05       42.97
 RPM         11.6640     -358.12       45.58
 BIO          1.3863     -359.01       45.69
 HUM          8.8207     -379.85       48.41
 IOM         80.0000    50000.00     -998.02
 Total      102.3063    11814.26     -770.15
 The accumulated CO2 lost to the atmosphere is     49.6937 tonnes / ha

After year     50    (2061)
 -----------------


 Radiocarbon activity scaling factor =  1.0390
                           Radio       Delta
              Amount        Age        Value
              ------       -----       -----
 DPM          0.4352     -307.11       38.96
 RPM         12.4448     -307.61       39.03
```

```
 BIO          1.5282     -308.40       39.13
 HUM         22.1090     -320.94       40.75
 IOM         80.0000    50000.00     -998.02
 Total      116.5172     8971.10     -672.58
 The accumulated CO2 lost to the atmosphere is    143.4828 tonnes / ha
After year    100    (2111)
 -----------------
 Radiocarbon activity scaling factor =  1.0390
                           Radio       Delta
              Amount        Age        Value
              ------       -----       -----
 DPM          0.4352     -307.11       38.96
 RPM         12.4575     -300.08       38.05
 BIO          1.5935     -297.81       37.76
 HUM         38.5148     -276.98       35.07
 IOM         80.0000    50000.00     -998.02
 Total      133.0011     7084.21     -585.91
 The accumulated CO2 lost to the atmosphere is    306.9989 tonnes / ha
```

Lucerne cover crop

```
Starting conditions    2012
 ===================
 Radiocarbon activity scaling factor =  1.0590
                           Radio       Delta
              Amount        Age        Value
              ------       -----       -----
 DPM          0.4825     -460.19       58.94
 RPM          1.8385     -459.92       58.91
 BIO          0.2481     -459.86       58.90
 HUM          0.3292     -459.84       58.90
 IOM         80.0000    50000.00     -998.02
 Total       82.8984    26073.86     -961.03
 The accumulated CO2 lost to the atmosphere is      1.9616 tonnes / ha
```

```
After year      2    (2013)
 -----------------
 Radiocarbon activity scaling factor =  1.0570
                            Radio       Delta
              Amount         Age        Value
              ------       -----       -----
 DPM          0.4874     -445.15       56.96
 RPM          3.4405     -451.34       57.78
 BIO          0.5036     -451.90       57.85
 HUM          0.7573     -452.71       57.96
 IOM         80.0000    50000.00     -998.02
 Total       85.1889    21799.31     -933.67
 The accumulated CO2 lost to the atmosphere is      4.5311 tonnes / ha
 After year      3    (2014)
 -----------------
 Radiocarbon activity scaling factor =  1.0560
                            Radio       Delta
              Amount         Age        Value
              ------       -----       -----
 DPM          0.4875     -437.47       55.95
 RPM          4.8365     -445.32       56.99
 BIO          0.7196     -445.70       57.04
 HUM          1.2180     -447.28       57.25
 IOM         80.0000    50000.00     -998.02
 Total       87.2616    19363.05     -910.17
 The accumulated CO2 lost to the atmosphere is      7.3184 tonnes / ha
 After year      4    (2015)
 -----------------
 Radiocarbon activity scaling factor =  1.0550
                            Radio       Delta
              Amount         Age        Value
              ------       -----       -----
 DPM          0.4875     -429.86       54.95
 RPM          6.0529     -439.83       56.26
 BIO          0.9024     -440.09       56.30
 HUM          1.7057     -442.56       56.62
 IOM         80.0000    50000.00     -998.02
 Total       89.1485    17718.20     -889.76
 The accumulated CO2 lost to the atmosphere is     10.2915 tonnes / ha
 After year      5    (2016)
 -----------------
 Radiocarbon activity scaling factor =  1.0530
                            Radio       Delta
              Amount         Age        Value
              ------       -----       -----
 DPM          0.4875     -414.69       52.97
 RPM          7.1128     -432.49       55.30
 BIO          1.0577     -432.83       55.35
 HUM          2.2160     -436.98       55.89
 IOM         80.0000    50000.00     -998.02
 Total       90.8740    16511.92     -871.91
 The accumulated CO2 lost to the atmosphere is     13.4260 tonnes / ha
```

```
After year     10    (2021)
 -----------------
 Radiocarbon activity scaling factor =  1.0490
                            Radio       Delta
              Amount         Age        Value
              ------       -----       -----
 DPM          0.4875     -384.04       48.96
 RPM         10.6862     -403.38       51.48
 BIO          1.5547     -402.83       51.41
 HUM          4.9931     -413.99       52.87
 IOM         80.0000    50000.00     -998.02
 Total       97.7215    13241.19     -807.55
 The accumulated CO2 lost to the atmosphere is     30.8785 tonnes / ha
 After year     15    (2026)
 -----------------
 Radiocarbon activity scaling factor =  1.0460
                            Radio       Delta
              Amount         Age        Value
              ------       -----       -----
 DPM          0.4875     -360.96       45.95
 RPM         12.4813     -378.85       48.28
 BIO          1.7924     -377.95       48.16
 HUM          7.9509     -395.41       50.44
 IOM         80.0000    50000.00     -998.02
 Total      102.7121    11684.51     -766.41
 The accumulated CO2 lost to the atmosphere is     50.1879 tonnes / ha
 After year     20    (2031)
 -----------------
 Radiocarbon activity scaling factor =  1.0430
                            Radio       Delta
              Amount         Age        Value
              ------       -----       -----
 DPM          0.4875     -337.96       42.96
 RPM         13.3832     -358.03       45.57
 BIO          1.9130     -357.30       45.47
 HUM         10.9373     -379.56       48.37
 IOM         80.0000    50000.00     -998.02
 Total      106.7209    10711.94     -736.36
 The accumulated CO2 lost to the atmosphere is     70.4791 tonnes / ha
 After year     50    (2061)
 -----------------
 Radiocarbon activity scaling factor =  1.0390
                            Radio       Delta
              Amount         Age        Value
              ------       -----       -----
 DPM          0.4875     -307.02       38.95
 RPM         14.2790     -307.52       39.01
 BIO          2.0814     -308.33       39.12
 HUM         27.2481     -320.79       40.73
 IOM         80.0000    50000.00     -998.02
 Total      124.0960     7968.10     -629.04
 The accumulated CO2 lost to the atmosphere is    198.9040 tonnes / ha
```

```
After year    100    (2111)
 -----------------
 Radiocarbon activity scaling factor =  1.0390
                            Radio       Delta
              Amount         Age        Value
              ------       -----       -----
 DPM          0.4875     -307.02       38.95
 RPM         14.2936     -299.99       38.04
 BIO          2.1614     -298.48       37.85
 HUM         47.3730     -276.96       35.07
 IOM         80.0000    50000.00     -998.02
 Total      144.3154     6190.11     -537.17
 The accumulated CO2 lost to the atmosphere is    421.6846 tonnes / ha
```

Annual rye grass cover crop

```
Starting conditions    2012
 ===================
 Radiocarbon activity scaling factor =  1.0590
                            Radio       Delta
              Amount         Age        Value
              ------       -----       -----
 DPM          0.6791     -460.19       58.94
 RPM          2.5875     -459.92       58.91
 BIO          0.3492     -459.86       58.90
 HUM          0.4634     -459.84       58.90
 IOM         80.0000    50000.00     -998.02
 Total       84.0792    23557.20     -946.70
 The accumulated CO2 lost to the atmosphere is      2.7608 tonnes / ha
 After year      2    (2013)
 -----------------
 Radiocarbon activity scaling factor =  1.0570
                            Radio       Delta
              Amount         Age        Value
              ------       -----       -----
 DPM          0.6860     -445.15       56.96
 RPM          4.8422     -451.34       57.78
 BIO          0.7088     -451.90       57.85
 HUM          1.0658     -452.71       57.96
 IOM         80.0000    50000.00     -998.02
 Total       87.3029    19316.48     -909.65
 The accumulated CO2 lost to the atmosphere is      6.3771 tonnes / ha
 After year      3    (2014)
 -----------------
 Radiocarbon activity scaling factor =  1.0560
                            Radio       Delta
              Amount         Age        Value
              ------       -----       -----
 DPM          0.6861     -437.47       55.95
 RPM          6.8069     -445.32       56.99
 BIO          1.0128     -445.70       57.04
 HUM          1.7142     -447.28       57.25
 IOM         80.0000    50000.00     -998.02
 Total       90.2200    16932.79     -878.44
 The accumulated CO2 lost to the atmosphere is     10.3000 tonnes / ha
```

```
After year      4    (2015)
 -----------------
 Radiocarbon activity scaling factor =  1.0550
                            Radio       Delta
              Amount         Age        Value
              ------       -----       -----
 DPM          0.6861     -429.86       54.95
 RPM          8.5189     -439.83       56.26
 BIO          1.2701     -440.09       56.30
 HUM          2.4006     -442.56       56.62
 IOM         80.0000    50000.00     -998.02
 Total       92.8757    15339.57     -851.79
 The accumulated CO2 lost to the atmosphere is     14.4843 tonnes / ha
 After year      5    (2016)
 -----------------
 Radiocarbon activity scaling factor =  1.0530
                            Radio       Delta
              Amount         Age        Value
              ------       -----       -----
 DPM          0.6861     -414.69       52.97
 RPM         10.0107     -432.49       55.30
 BIO          1.4886     -432.83       55.35
 HUM          3.1188     -436.98       55.89
 IOM         80.0000    50000.00     -998.02
 Total       95.3041    14180.77     -828.79
 The accumulated CO2 lost to the atmosphere is     18.8959 tonnes / ha
 After year     10    (2021)
 -----------------
 Radiocarbon activity scaling factor =  1.0490
                            Radio       Delta
              Amount         Age        Value
              ------       -----       -----
 DPM          0.6861     -384.04       48.96
 RPM         15.0398     -403.38       51.48
 BIO          2.1881     -402.83       51.41
 HUM          7.0273     -413.99       52.87
 IOM         80.0000    50000.00     -998.02
 Total      104.9413    11088.15     -748.42
 The accumulated CO2 lost to the atmosphere is     43.4587 tonnes / ha
 After year     15    (2026)
 -----------------
 Radiocarbon activity scaling factor =  1.0460
                            Radio       Delta
              Amount         Age        Value
              ------       -----       -----
 DPM          0.6861     -360.96       45.95
 RPM         17.5663     -378.85       48.28
 BIO          2.5227     -377.95       48.16
 HUM         11.1901     -395.41       50.44
 IOM         80.0000    50000.00     -998.02
 Total      111.9651     9647.54     -699.01
The accumulated CO2 lost to the atmosphere is     70.6349 tonnes / ha
```

```
After year     20    (2031)
 -----------------
 Radiocarbon activity scaling factor =  1.0430
                            Radio       Delta
              Amount         Age        Value
              ------       -----       -----
 DPM           0.6861     -337.96       42.96
 RPM          18.8356     -358.03       45.57
 BIO           2.6923     -357.30       45.47
 HUM          15.3933     -379.56       48.37
 IOM          80.0000    50000.00     -998.02
 Total       117.6073     8760.07     -663.86
 The accumulated CO2 lost to the atmosphere is     99.1927 tonnes / ha
 After year     50    (2061)
 -----------------
 Radiocarbon activity scaling factor =  1.0390
                            Radio       Delta
              Amount         Age        Value
              ------       -----       -----
 DPM           0.6861     -307.02       38.95
 RPM          20.0963     -307.52       39.01
 BIO           2.9294     -308.33       39.12
 HUM          38.3492     -320.79       40.73
 IOM          80.0000    50000.00     -998.02
 Total       142.0610     6316.93     -544.42
 The accumulated CO2 lost to the atmosphere is    279.9390 tonnes / ha
 After year    100    (2111)
 -----------------
 Radiocarbon activity scaling factor =  1.0390
                            Radio       Delta
              Amount         Age        Value
              ------       -----       -----
 DPM           0.6861     -307.02       38.95
 RPM          20.1169     -299.99       38.04
 BIO           3.0419     -298.48       37.85
 HUM          66.6730     -276.96       35.07
 IOM          80.0000    50000.00     -998.02
 Total       170.5180     4790.59     -449.11
 The accumulated CO2 lost to the atmosphere is    593.4820 tonnes / ha
```