



FINAL REPORT 2013

Part 1 - Summary Details

Please use your TAB key to complete Parts 1 & 2.

CRDC Project Number: **CRC1117**

Project Title: Assessing greenhouse gas emission from broadacre irrigated cropping systems

Project Commencement Date: 1/07/2010 **Project Completion Date:** 30/06/2013

CRDC Program: 4 Farming Systems

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Part 3 – Final Report

(The points below are to be used as a guideline when completing your final report.)

Background

1. Outline the background to the project.

CSIRO is involved in environmental research into atmospheric and climate changes associated with human activity. Green house gases (GHG's - N₂O, CO₂ and CH₄) contribute to climate change by altering the solar radiation balance of the earth. In Australia, current research indicates that cotton crops are over-fertilised by an average of ~50 kg N ha⁻¹ which leads to a potentially high N₂O emission. Emissions of GHG's have been monitored from cotton systems with Professor Peter Grace in the past, but these measurements were only short term. To adequately assess the contribution of irrigated cotton rotation's to the GHG emission long term measurements that encompass the complete rotation are required. This will help improve the fundamental understanding of the processes (soil denitrification) and practices (fertiliser rate, rotation) that contribute to GHG emissions in irrigated cropping systems, encompassing the full crop rotation, to develop better management practices that mitigate GHG emissions.

Objectives

2. List the project objectives and the extent to which these have been achieved.

This project aims to thoroughly investigate the cause of and differences in the levels of GHG emissions during sequences of crops and fallows.

Objectives:

1. Measure GHG emissions (N₂O, CH₄ and CO₂) in crops and fallows;

During 2011-2013 the project undertook measurements of GHG emissions from irrigated cropping fields during a cotton-faba bean-fallow rotation cycle at the ACRI site. The data has been collated and analysed ready for publication

2. Improved knowledge of emissions from irrigated cropping systems developed

During 2012 we have publish an industry article on impact of nitrogen fertiliser losses from cotton in the Australian Cottongrower magazine. In 2013 we also submitted a paper to *Nutrient Cycling in Agroecosystems* titled Greenhouse gas emissions in high-yielding cotton cropping systems: Impact of nitrogen fertiliser rate. This paper is currently under review.

3. Develop low emissions/C-neutral irrigated cropping systems

The research clearly shows that excess fertilisation causes a significant increase in the emission of nitrous oxide the cotton crop. Nitrogen rates >180 kg ha⁻¹ were excessive to crop requirements and that to develop low emission cropping systems, the maximum N fertilisation rate should not exceed 250 kg N ha⁻¹. At this stage it is not possible to compare which rotation system is the most carbon neutral because only the faba-cotton rotation has been measured.

Methods

3. Detail the methodology and justify the methodology used. Include any discoveries in methods that may benefit other related research.

The GHG monitoring equipment was installed in a cropping system experiment that started in 1994, and compared 2-year rotation cycles. We selected the cotton-faba bean-fallow rotation system for this experiment. Following the cotton crop (October to April), faba beans (*Vicia faba* L.), are sown (May) and harvested for grain (November), then the soil remained fallow until cotton is sown again (October).

Emissions from the soil and crop were measured using soil chambers connected to a fully automated system that enabled simultaneous determination of CO₂, CH₄ and N₂O emissions. This system has been used to measure emissions from forest systems (Papen and Butterbach-bahl 1999, Breuer et al. 2000; Kiese et al. 2003), semi arid wheat production (Barton et al. 2008) and subtropical sugarcane production systems (Denmead et al. 2010; Wang et al. 2011) and details of the design and operation of the systems can be found in those studies. The system consisted of a gas chromatograph (SRI Instruments, SRI 8610C, Torrance, CA, USA) fitted with a ⁶³Ni electron capture detector with sodium hydroxide pre-column for N₂O analysis and flame ionisation detector for CH₄ analysis, an infra-red analyser (Licor, LI 820, St Joseph, MI, USA) for CO₂ analyses, an automated control unit for chamber lid control and gas sample collection and distribution, and 12 chambers (0.5 m x 0.5 m) with automatically operated lids placed on metal bases inserted into the ground (0.1 m). Two bases were located at each chamber measurement site to enable the chambers to be moved to a new position to minimize the effect of chambers on soil properties and plant growth. The height of the chambers was progressively increased to accommodate crop growth, with a maximum height of 1 m.

A measurement cycle for the determination of CO₂, CH₄ and N₂O commenced with the simultaneous lid closure of the first set of four chambers, one in each of the sub-plots and finished 60 minutes later when the chambers opened. In each 15 minute block each chamber was sequentially measured every 3 minutes (12 minutes) and during the last 3 minutes a sample of standard calibration gas (0.5±0.1 ppmv N₂O; 4.1±0.1 ppmv CH₄; 799±16 ppmv CO₂) was measured. This allowed for the calibration of each measurement block and correction for temperature induced drift in detector response. Thus, during a 60 minute cycle, four N₂O and CH₄ measurements (15 minutes apart) were collected from each chamber. The concentration of CO₂ in the gas samples was measured every 10 s during each 3 minute measurement of each chamber.

Once completed, the next set of four chambers were then closed and the gas concentrations analysed; a measurement cycle of all 12 chambers took 3 hours. Each set of four chambers remained open for 2 hours between each measurement cycle. The automated gas sampling unit enabled CO₂, CH₄ and N₂O emissions to be monitored continuously, providing up to eight (hourly) emission rates per chamber per day. Chamber humidity and air temperature were measured in three chambers within one of the sub-plots, one from each of the three ganged chamber sets. Humidity was measured every 6 minutes using Dallas Semiconductor iButton® Hygrochron™ loggers; temperature was measured every 10 s using generic PT100 platinum resistance thermometers. The chambers are vented to atmosphere and barometric pressure was measured every 15 minutes using a Vaisala PTB101B analogue barometer.

Analysis of Emission Data

Carbon dioxide flux was calculated from the slope of the linear increase in concentration during the first 3 minute sampling period for each chamber. Thus when the set of 4

chambers were closed the carbon dioxide flux was calculated from chamber A between 0-2 minutes, B 3-6 minutes, C 7-9 minutes and D 9-12 minutes. During each 3-minute sampling period, CO₂ concentration was measured 18 times; the first 7 measurements were not used in the regression analysis. This approach was used to calculate the CO₂ flux because during the daytime, plant photosynthesis ceased 15 minutes after chamber closure due to the rapid increase in air temperature (10-15°C) and plant respiration increased under these conditions. The sampling times at 15-60 minutes were not representative of the carbon dioxide flux under ambient conditions. The flux was calculated using equation 1 and CO₂ flux measurement were discarded if F-probability was

$$P > 0.1 \text{ for } \frac{dG_{abs}}{dt}$$

Fluxes of CH₄ and N₂O-N (mg m⁻² h⁻¹) were calculated from the slope of the linear increase in concentration during the chamber lid closure period. All three gases were corrected for chamber air temperature, air pressure, vapour pressure, and the ratio of chamber volume to planar ground area (0.5 x 0.50 m), as follows:

$$\text{Flux} = \frac{\frac{dG_{abs}}{dt} \times V_c \times \text{constant}}{A_c} \quad (1)$$

where Flux is the unit area gas emission rate (µg m⁻².s⁻¹), $\frac{dG_{abs}}{dt}$ is the rate of change of the dry absolute gas concentration in the chamber headspace during the closure period (µg.L⁻¹), V_c is the chamber volume (cm³), A is the planar ground area of the chamber (cm²) and constant is a unit conversion factor

$$G_{abs} = \frac{G \times MW \times \left(1 + \frac{VP}{BP}\right) \times \text{constant}}{MV \times \left(1 + \frac{T}{273.15}\right) \times \frac{100}{BP}} \quad (2)$$

where G₁ is the gas concentration of each chamber headspace sample during the closure period, MW is the gas molecular weight, VP is the gas sample vapour pressure, BP is the gas sample pressure (barometric pressure, MV is the ideal gas molar volume at standard temperature and pressure and the constant is a unit conversion factor.

The rate of change of the dry absolute CH₄ and N₂O gas concentrations in the chamber headspace was determined by the linear regression slope of the four samples analysed at 15 minute intervals from each chamber during closure of the set of four. The regression was rejected (null slope) if the F statistic was less than the critical F value of 18.5 for P=0.05 and 2 denominator degrees of freedom. Regressions resulting in the greatest flux rates in the smallest chamber volumes were those most likely to exhibit non-linear response due to suppression of gas diffusion by excessive chamber gas concentrations (see Kroon et al 2008). These regressions were selected for manual inspection and none were found to exhibit non-linear response.

It should be noted that the sequential sampling of the four concurrently closed chambers resulted in delays between time of lid closure and initial sampling that ranged from 3 to 12 minutes after lid closure.

The calculated methane, carbon dioxide and nitrous oxide emissions will be an underestimate of the actual emissions due to chamber deployment suppressing the concentration gradient at the soil-atmosphere interface (Venterea et al 2009). Based on the chamber height (200mm-1000mm) soil bulk density (1.4) and soil moisture (0.1-0.4 cm³/cm³) values measured in a nearby experimental field it is expected that the measured gas fluxes underestimate the actual flux by 1-5% according to the corrections proposed by Venterea et al. (2009).

Gap filling missing flux data

The missing CO₂ data was not gap filled because no satisfactory model was available to simulated plant uptake and respiration. The N₂O data from each chamber was gap filled by linear interpolation between the missing data points.

Environmental Variables

Environmental variables, including soil and air temperatures, soil water and nutrient levels were measured periodically to interpret interactions between N₂O emissions and the environment. The project has used measurement protocols to provide the information needed for the FullCAM model. Plant growth (cotton and its rotation crops) was monitored for growth and nutrient accumulation.

Soil carbon balance

There was not a complete measurement of CO₂ exchange in the cotton or fallow cycle of the crop rotation. The total fallow emission was calculated from the average measured monthly CO₂ emission multiple by 9 months. The CO₂ flux in the cotton crop was calculated from the measured crop biomass (negative flux) and the estimated soil respiration. The first 50 days of crop+soil measurement were used to estimate the soil respiration. It was assumed during the first 50 days that the average measured CO₂ exchange represented the 24hr soil respiration. This average was multiple by 220 days to calculate the net soil respiration during the cotton phase. The faba beans were not harvested but incorporated into the soil. There was a complete measurement of the faba bean rotation and the measured flux represents the amount of carbon added to the soil.

Results

4. Detail and discuss the results for each objective including the statistical analysis of results.

Objective 1: Measure GHG emissions (N₂O, CH₄ and CO₂) in crops and fallows. .

A - Nitrous oxide emissions

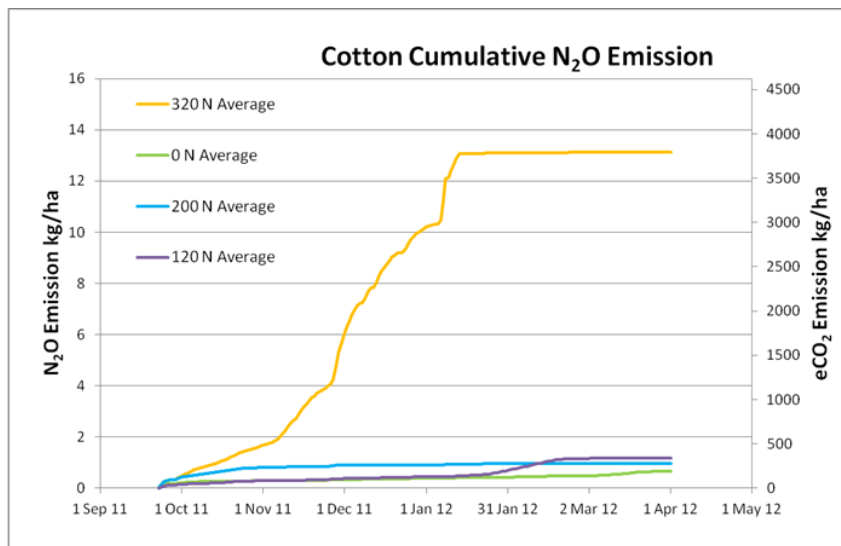


Figure 1. Cumulative daily N₂O flux from the cotton crop that had received N fertiliser prior to sowing the cotton.

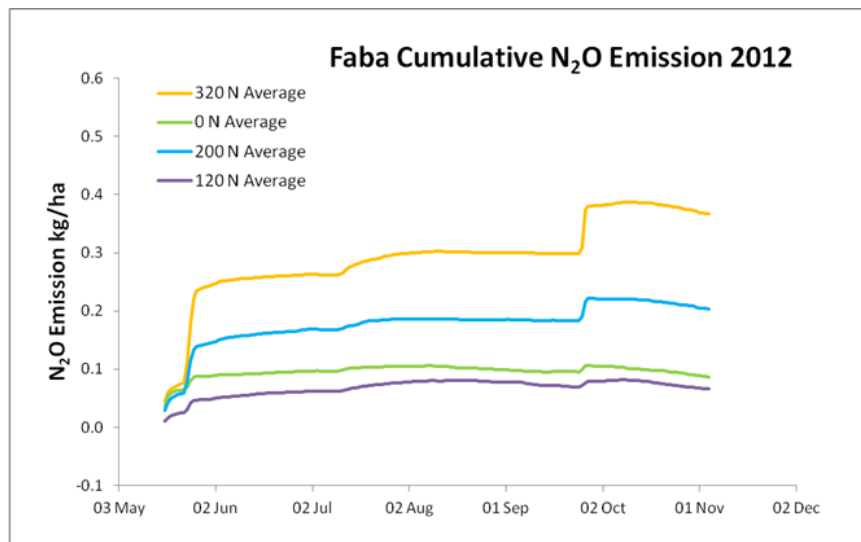


Figure 2. Cumulative daily N₂O flux from the faba bean crop that followed cotton in plots that had received N fertiliser prior to sowing the cotton crop.

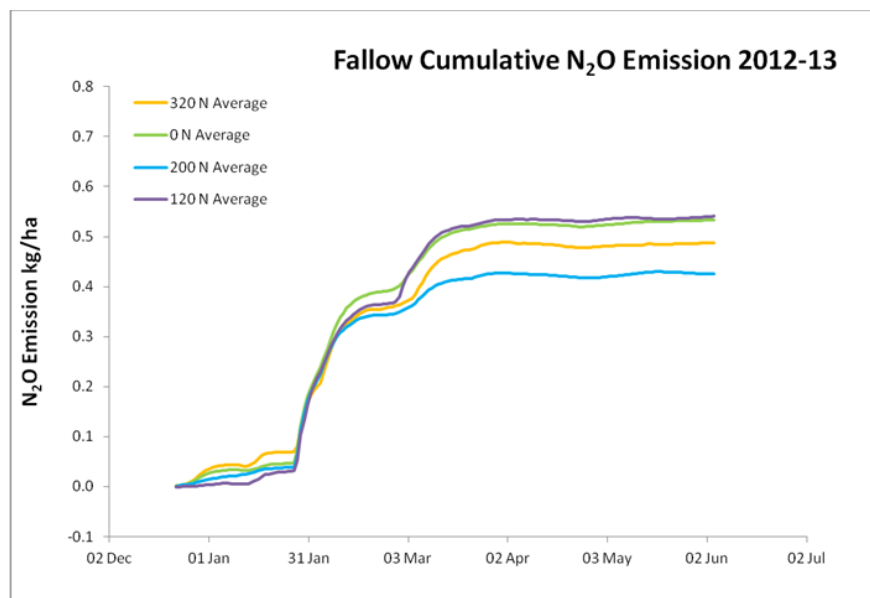


Figure 3. Cumulative daily N₂O flux from the fallow that followed cotton and faba beans in plots that had received N fertiliser prior to sowing the cotton crop.

Table 1. Summary of N₂O emissions (kg N/ha) – values followed by the same letter are not statistically different.

N rate (kg/ha)	cotton	faba beans	fallow	Total
0	0.66 a	0.09 a	0.53 a	1.28 a
120	1.19 a	0.07 a	0.54 a	1.80 a
200	0.97 a	0.20 b	0.43 a	1.60 a
320	13.13 b	0.37 c	0.49 a	13.99 b

The emissions of N₂O clearly are increased following irrigation or rainfall during all measure cropping sequences (Figure 1-3). The emissions of N₂O were higher after N fertiliser application at the start of the season compared with the end of the season (Figure 1 and 2) and at the start of the fallow (Figure 3). At the end of the season the nitrogen source was exhausted and de-nitrification rate had reduced.

Overall for the 0, 120 and 200 kg /ha N applications, 60% of the N₂O was emitted from the cotton phase, 8% from the faba bean phase and 32% from the fallow. For the over-fertilised 320 kg N/ha treatment, 94% of the N₂O was emitted from the cotton phase, 3% from the faba bean phase and 3% from the fallow (Table 1). Less N₂O was emitted during the faba bean phase possibly because of the cooler soil temperatures during the growth of the winter crop (Figures 1-3). During the fallow there was no significant difference between the N₂O-N cumulative emission at each fertiliser rate. This contrasts with the cotton and faba bean crops where the high fertiliser rates produced significantly higher emissions (Table 1). It would appear that the available soil N has been consumed during the cropping season and/or lost via denitrification or leaching and that in the fallow there is a small and equal background emission.

B – Carbon dioxide emissions

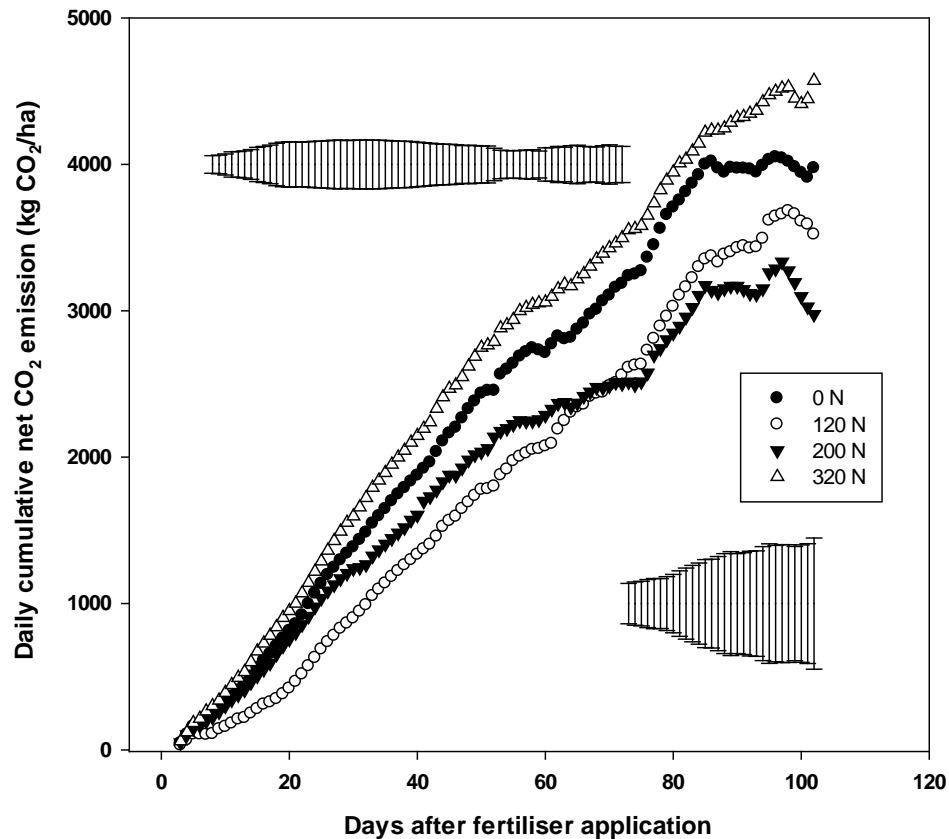


Figure 4. Cumulative daily CO₂ flux from the cotton crop that had received N fertiliser prior to sowing the cotton. Error bars indicate the lsd ($P < 0.05$). Measurements were stopped due to flooding and equipment damage before the plant biomass increased significantly.

The net emission of CO₂ is a balance the soil heterotrophic respiration and the crop photosynthesis and respiration. During the cropping phase CO₂ is consumed by the crop during photosynthesis, some of the carbon is returned to the soil as residue and the remainder is transported off-site as food or fibre. Soil heterotrophic respiration produces carbon dioxide from the decomposition of organic residues. Typically photosynthesis consumes more CO₂ than produced by heterotrophic respiration.

During the first 50 days of measurement in the cotton crop there was an overall emission of carbon dioxide from the soil and crop and represents overall soil respiration (Figure 4). There are significant differences between the average carbon dioxide emission rate for each fertiliser treatment between days 3-58 and the average emissions were 47, 40, 51 and 57 kg eCO₂ ha⁻¹ d⁻¹ for the 0, 120, 200 and 320 kg N ha⁻¹ treatments, respectively. Between 56 and 115 days there were days of negative emissions indicating overall uptake of carbon dioxide by the plants. There were significant differences in the average carbon dioxide emission rates for the fertiliser treatments between days 59-118; the average emissions were 45.5, 35.6, 16.4 and 17.0 kg eCO₂ ha⁻¹ d⁻¹ for the 0, 120, 200 and 320 kg N ha⁻¹ treatments, respectively.

Overall the cumulative emission measurements of carbon dioxide from the first 118 days of the cotton phase of the experiment shows that about 4-5 t eCO₂ ha⁻¹ was emitted during the growth of the cotton crop using the fertiliser rates of 0, 120 and 320 kg N ha⁻¹. These emissions were significantly higher than from 200 kg N ha⁻¹ treatment which had a net emission of 2.74 t eCO₂ ha⁻¹ (Figure 4). The measurements stopped due to flood damage to the equipment during the middle of the peak of plant's vegetative growth. It is expected that

the overall net emission prior to defoliation will significantly lower due to plant photosynthetic uptake between 100 and 200 days.

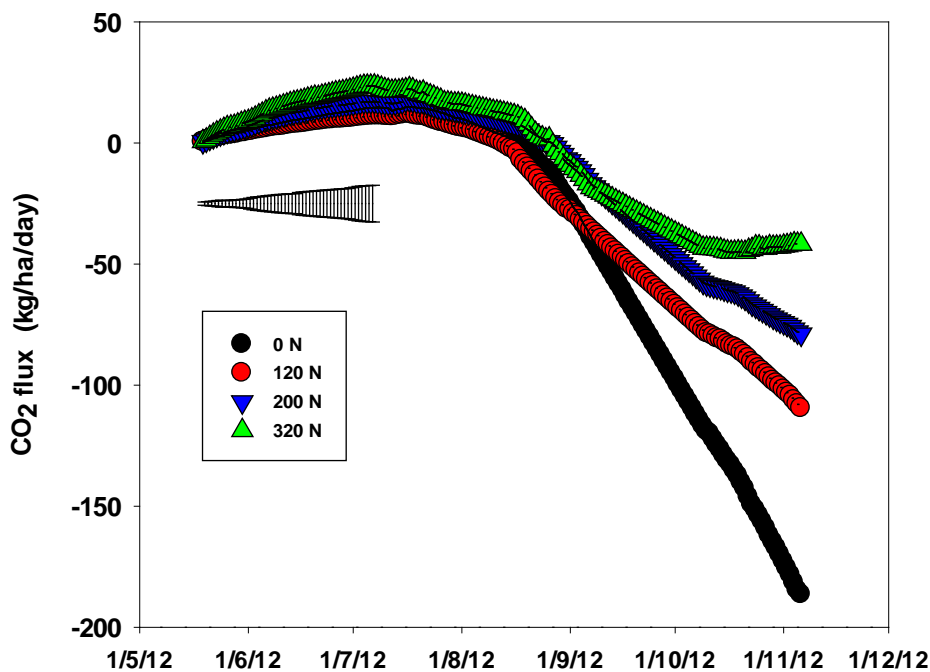


Figure 5. Cumulative daily CO₂ flux from the faba bean crop that followed cotton in plots that had received N fertiliser prior to sowing the cotton crop. Error bars indicate the lsd ($P < 0.05$)

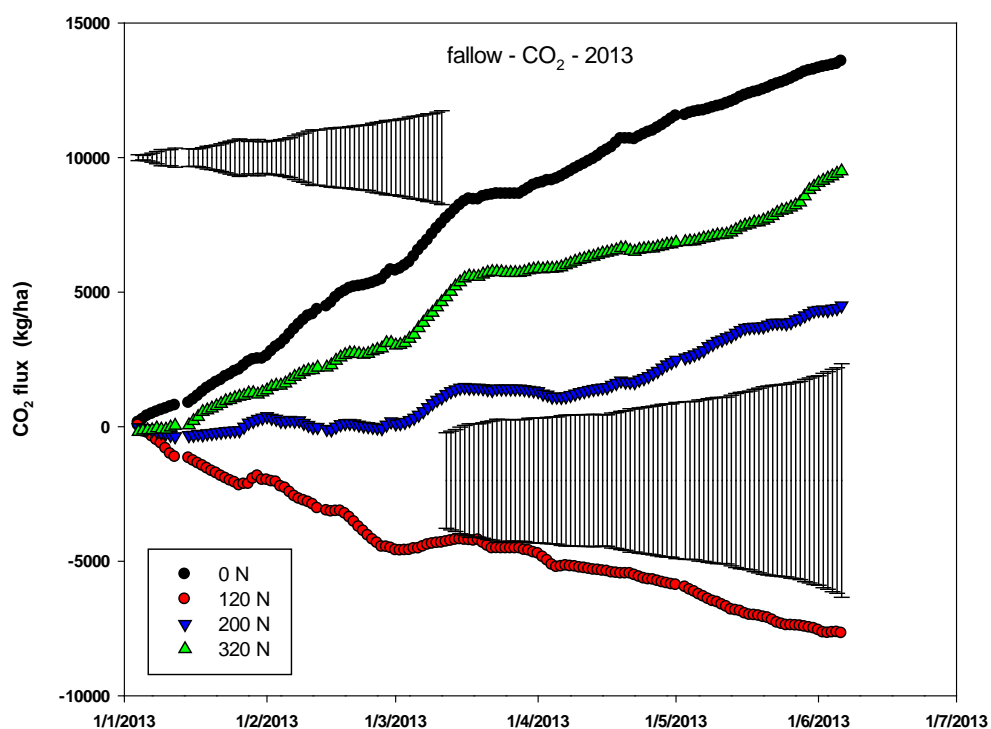


Figure 6. Cumulative daily CO₂ flux from the fallow that followed cotton and faba beans in plots that had received N fertiliser prior to sowing the cotton crop... Error bars indicate the lsd ($P < 0.05$)

Table 2. Summary of net measured CO₂ emissions (t/ha) as affected by N fertiliser applied prior to sowing cotton.

N rate (kg/ha)	Cotton (118 days)	Faba beans	Fallow	Total
0	4.39	-0.19	12.27 a	16.47 a
120	4.82	-0.12	-7.66 c	-2.96 c
200	4.28	-0.08	5.64 b	9.84 a
320	5.11	-0.02	9.65 ab	14.73 a
lsd (5%)	ns	Ns	8.69	7.88

CO₂ emissions were less influenced by the application of N fertiliser. Most (52%) of the CO₂ was emitted during the fallow (Table 2 Figure 6) due to the heterotrophic decomposition. No net emission occurred during the growth of faba beans during winter of 2012 (Table 2 Figure 5). There are two issues with the CO₂ measurements which need further investigations:

1. The net uptake of CO₂ during the fallow in the 120 N fertiliser treatment could be an anomaly and further work is needed to validate the result. It has been shown by Xie (2009) that alkaline soils can absorb CO₂ from the atmosphere which may explain the significant uptake in the 120N treatment. It is unclear why this apparent uptake was only present in this treatment. Alternatively, the greatest emission was measured from the 0 N treatment, but we would expect this treatment to emit less CO₂ than the 120 N treatment and in proportion to the other N treatments. One possible explanation of this anomaly is that the N treatment received the highest N rate (200 kg N/ha) for the cotton crop in the 2009-2010 season. In that season, no response to applied N was found, despite high yields between 11.5 and 12.5 b/ha, hence much of the applied N could have remained in the soil for use by the 2012 cotton crop.
2. The measurement of the cotton phase of the rotation finished before the peak vegetative growth phase and therefore the reported net emission does not represent the full cotton plant CO₂ uptake and the defoliation and post harvest emission.

C – Methane emissions

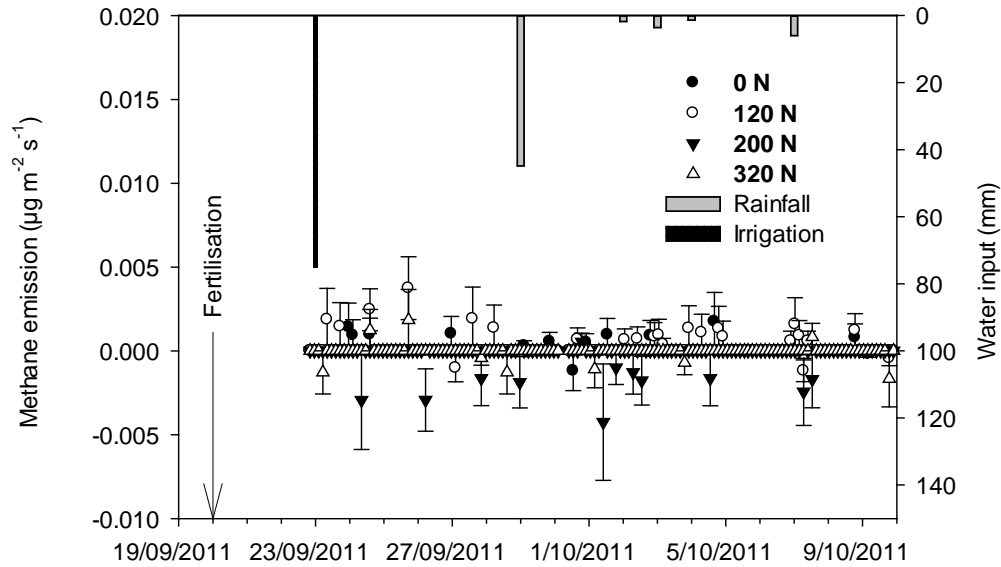


Figure 7. Average methane emissions (n=3) and standard errors for each nitrogen treatment plot, field irrigation and rainfall during the cotton season

Methane concentrations were consistently at or near atmospheric concentrations within all the treatments during the cotton growing season. Only the data from the first 16 days following N fertiliser application was processed to quantify differences between the treatments and emissions trend. This period was selected because it included an irrigation and a large rainfall event. There was no significant effect of N fertiliser application on CH₄ emission (Figure 7). The cumulative net CH₄ emissions for this period from the 0, 120, 200 and 320 kg N ha⁻¹ treatments were 6.9, 20.0, -19.8 and -2.3 g CH₄ ha⁻¹, respectively. It is evident from Figure 7 that the soil periodically emitted and consumed methane with no clear emissions after rainfall. This is surprising because it was assumed that there would be no methane emissions or production but only uptake because the soils are anaerobic. The positive emissions were in the plots that received the least N fertiliser (0 and 120 kg N ha⁻¹). These positive emissions indicate that there is soil Achaea producing methane through the decomposition of organic residues at depth.

The negative emissions in the 200 and 320 kg N ha⁻¹ fertiliser rates indicate that nitrate leaching and denitrification is occurring in these treatments and preventing methane production. The inhibition of methane production is caused by the presence of denitrification intermediates (Roy and Conrad 1999) and indicates that denitrification is occurring in these two fertiliser treatments.

Objective 2: Improved knowledge of emissions from irrigated cropping systems developed

Soil carbon balance

Table 3. Summary of change in soil C (t/ha) as affected by N fertiliser applied prior to sowing cotton. Negative values represent net decrease in soil carbon and positive values represent net increase.

N rate (kg/ha)	Cotton (220 days)	Faba beans (240 days)	Fallow (270 days)	Total SOC change (730 days)
0	-0.2	0.1	-6.0	-6.2
120	1.9	0.0	3.8	5.7
200	2.0	0.0	-2.8	-0.8
320	1.3	0.0	-4.7	-3.5

Post harvest, stubble of each crop was incorporated into the soil. For cotton, this amounted to 4.25 t C/ha and for faba bean stubble, 1.85 t C/ha. The total stubble input of C was 6.10 t/ha. The average (standard error) soil respiration in the cotton phase was 2.9 (± 0.09) t C/ha.

Excluding 120 N treatment overall the average SOC change determined by the flux chamber measurements was -3.5 ± 1.2 t C/ha. This indicates a net flux of C from the system. However, the long term trend of SOC increase in the profile (0-90 cm) in this cropping system is 2.12 t C/ha (Rochester 2011) over the 2-year monitoring period (2006-2008). The difference between two is caused by the different periods of time over which the measurements were taken. Rochester's (2011) measurement is a long term measure over 10 year period whereas this study is only a two year period, subsequent to his measurements. Our study also included a severe flooding event during which considerable C may have been lost. Also during this study measurement the chambers were devoid of vegetation, whereas Rochester's (2011) fallow management allows the growth of volunteer plants (Figure 8). These plants were killed before the end of the fallow with tillage and stubble incorporated. It is estimated that up to 2-3 tonnes of biomass ha^{-1} could be incorporated by this approach. This is an interesting result because it shows that to improve the in-field carbon balance it may be wise to grow cover crops rather than fallows in order to offset C losses.



Figure 8. The vegetation cover and the measurement chamber in the fallow cropping sequence of field 6, ACRI. The vegetation inside the chamber was manually removed to measure the soil respiration and typical fallow periods are devoid of vegetation.

Nitrogen Balance

Thus, there is a substantial capacity for Australian cotton producers to moderate N fertiliser application and thereby reduce N₂O emissions.

Recent surveys of N fertiliser use in the Australian cotton industry have indicated that N fertiliser is often applied in excess of the economic optimum rate. Rochester (2011a) indicated that of the 82 crops monitored, 79% of them indicated poor N fertiliser use-efficiency and averaged over all crops, an excess of 49 kg N ha⁻¹ was applied. Using seed N concentration as an indicator of N use-efficiency, Rochester (2012) indicated that 45% of cotton crops assessed were over-fertilised by an average of 83 kg N ha⁻¹ in excess of the optimum N application rate (180-200kg N ha⁻¹). The data collected during the cotton phase of the project shows that excess N is lost from the cotton system under urea applications >200 kg N ha⁻¹ and N₂O emissions increase exponentially as the economic optimum N fertiliser rate is exceeded. The critical urea application that reduces N₂O emission is below 200 kg N ha⁻¹ and above 120 kg N ha⁻¹ (Figure 9 Table 2).

In the cotton phase of the rotation an exponential relationship ($P=0.03$) between the fertiliser and emission rate

$$N_2O \text{ emission (t eCO}_2\text{ha}^{-1}) = 1.66 * 0.005 \frac{(\exp^{0.041x} - 1)}{0.0141}$$

where x is the fertiliser rate, and the upper bound is 320 N ha⁻¹.

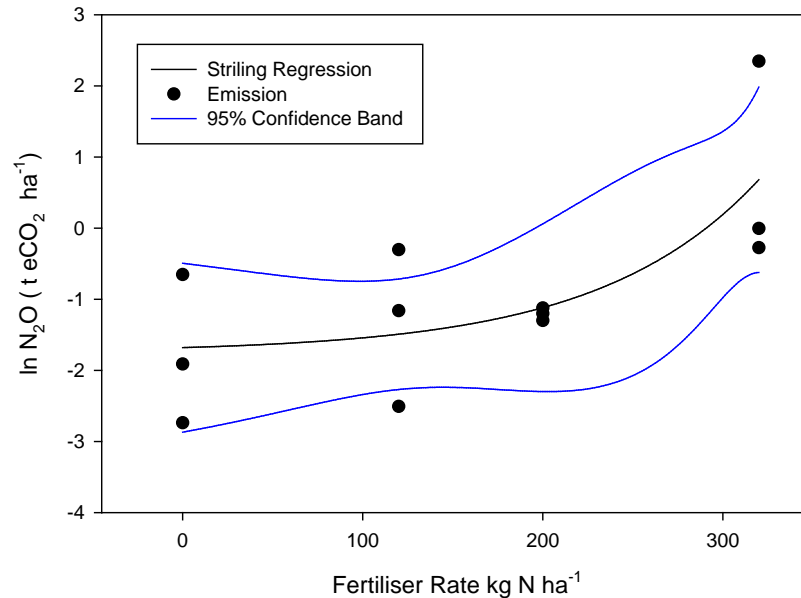


Figure 9. The relationship between cumulative N₂O emission (as t eCO₂ ha⁻¹) and N fertiliser application rate within the plant row during the cotton rotation.

Our work indicates that in irrigated cropping rotation systems, fertiliser applications at rates higher than the economic optimum (180 kg N ha⁻¹ in this experiment) result in significant N₂O losses during the cotton phase. Rochester's (2011a, 2012) N use-efficiency research indicated that the application of N fertiliser in excess of the economic optimum reduced the profitability of cotton production.

The average fertiliser rate across the industry is 217 kg N ha⁻¹ (n=187, Roth 2011) with a range of 30-534 kg N ha⁻¹. About 28% of the fields received N fertiliser at or greater than 250 kg N ha⁻¹. The lowering of the maximum fertilisation rate to <250 kg N ha⁻¹ would significantly reduce de-nitrification losses and improve nitrogen use efficiency in cotton-faba-fallow rotation systems on similar soils. Further analysis of the Roth (2011) survey data indicated that if N fertiliser application was optimised for lint yield, then the average N fertiliser used would be around 118 kg N ha⁻¹ for this data set. Lint yields averaged 9 bales ha⁻¹, but ranged from 2.5 to 13.4 bales ha⁻¹.

Objective 3: Develop low emissions/C-neutral irrigated cropping systems

The project measured the effect of nitrogen fertiliser rate on the emissions of N₂O, CH₄, CO₂ from a cotton-faba fallow rotation during the 2011-2013 season. At this time the study can only report on the effect of the fertiliser treatment on the emission rate and not the comparison between rotation types.

Methane emissions

There was no significant methane emissions measured during the study.

Nitrous Oxide Emissions

The amount of fertiliser applied to the cotton crop caused a significant variation in the emissions of N₂O. The results clearly show that to reduce N₂O emissions from the cotton-faba rotation that fertiliser rates should be less than 200 kg N ha⁻¹.

Carbon Dioxide Emissions

Our results show that the fallow period is when the bulk of the carbon dioxide losses occur during the cotton-faba-fallow rotation. There is a clear need to increase the amount of SOC in the soil to off-set the carbon losses during the fallow. The work by Rochestor (2011) shows that by allowing the growth of volunteer legume plants during the fallow will in the long-term increase the net SOC. But the water use and system profitability implications of this rotation and the water conservation and disease and pest management implications of the volunteer crops still need to be explored and rigorously tested.

Outcomes

- Describe how the project's outputs will contribute to the planned outcomes identified in the project application. Describe the planned outcomes achieved to date.

Key question(s) to be researched in project	Expected Science Outcomes <i>(NB: A direct science outcome might not be applicable for all extension</i>	Expected Industry/Applied Outcomes <i>Eg. These growers gain knowledge and change practices in pesticide application</i>
How much GHG is emitted from high-yielding furrow-irrigated crops?	Levels of GHG emissions quantified for cotton-faba-fallow and 4 nitrogen fertiliser rates during 2012-2014 rotation cycle.	-200 kg N ha ⁻¹ rotation identified as the most N-efficient system
Do legume-based cropping systems mitigate GHG emissions?	<200 kg N ha ⁻¹ rotation identified as the most N-efficient system. Further measurements are continuing to identify differences between legume-cotton rotations vs back to back cotton.	-200 kg N ha ⁻¹ rotation identified as the most N-efficient system
Do irrigated cropping soils sequester and retain significant quantities of CO ₂ ?	Cropping systems developed with enhanced ability to sequester and retain atmospheric CO ₂ to build soil organic C levels	Our CO ₂ emission data indicates that there is substantially less C lost from the soil than is added with the return of crop stubbles, and confirms that soil organic C levels should be increasing during the cropping phase. Our short term measurements show that during the fallow phase significant C losses occur from the soil which offset the C gains during the cropping phase. Long term measurements indicate that there is an increase in SOC. Increase plant residues during the cropping phase or the use of a cover crop rather than a bare fallow could further increase SOC.
Will the	Robust GHG dataset produced for	The emissions from irrigated

measurement of GHG from irrigated systems be improved?	cotton-faba-fallow rotations	cropping were properly and accurately accounted Weaknesses in the measurement approach identified and corrected
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6. Please describe any:-

- a) Technical advances achieved (eg commercially significant developments, patents applied for or granted licenses, etc.);

None at this time.

- b) Other information developed from research (eg discoveries in methodology, equipment design, etc.)

Methodology.

An initial oversight in the work was the power requirements and housing of the instrument in the field. Nadelko spent the first 6 months of the project organising power supply to field 6 ACRI and the construction of an instrument trailer for the instrument.

The GHG system was hard wired to measure gas concentrations in 12 chambers over one hour sampling periods. Unfortunately this creates a significant measurement artefact, where air temperature (Figure 8) and humidity increase in the chamber, which can then alter photosynthesis, soil temperatures (1-15 degrees), soil respiration and de-nitrification. We have tried to minimise this artefact by only analysing the first 15 minutes of CO₂ data and carefully assessing the linearity of the N₂O and CH₄ emission rate.

There was significant variation in the emission of N₂O, CH₄ and CO₂ between chambers in each fertiliser treatment. The capturing of spatial and temporal variation of greenhouse gas emissions is a fundamental problem with the use of chambers. In the current application, the three chambers collectively measured emissions from an area of only 0.75 m². Ideally, a larger area should be sampled, particularly in cracking soils, where emissions may be greater from the large cracks that extend into the subsoil. Also during farm operations all of the measurement equipment must be removed from the field. This has resulted in significant gaps in the greenhouse gas emission data set.

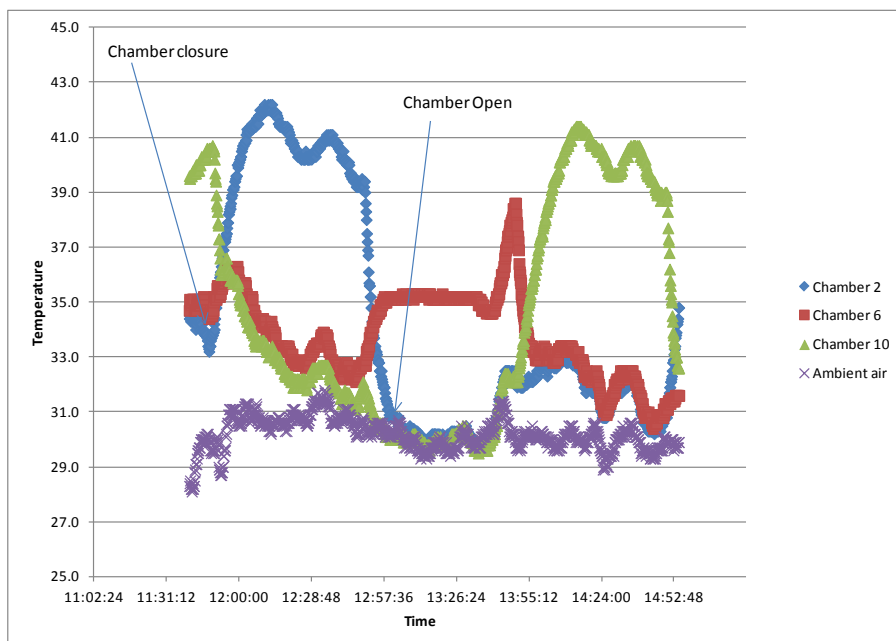


Figure 8. Temperature increase in measurement chambers during closure. Note the temperature increase between 5-10 degrees during the first 10-15 minutes. The chamber closure and opening times of chamber 2 are shown in the graph.

It is recommended that a micro-meteorological measurement experiment be established to measure N₂O CO₂ and CH₄ emissions and water vapour exchange. This approach samples >100m², has greater representation of the land-plant exchange with the atmosphere and less measurement artefact than the chamber approach.

c) required changes to the Intellectual Property register.

No changes were required.

Conclusion

7. Provide an assessment of the likely impact of the results and conclusions of the research project for the cotton industry. What are the take home messages?
 1. If the N fertiliser application was reduced by to near the economic optimum N fertiliser rate (180-200kg N ha⁻¹ in 2012-3), then N₂O losses would be reduced to 0.5% of the applied fertiliser.
 2. Our short term results show that the fallow period when the bulk of the carbon dioxide losses occur during the cotton-faba-fallow rotation. Over the short-term (1-4 yrs) there is a clear need to increase the amount of SOC in the soil to off-set the carbon losses during the fallow. However longer term measures show that the incorporation of residues has seen the increase in SOC in the subsoil. Soil organic carbon cycles and nitrogen cycles work at different time scales.
 3. Over the longer term it therefore possible to grow a carbon neutral crop using a cotton-faba bean-fallow rotation with N rates <200 kg ha⁻¹ but further biomass would need to be incorporated into the soil.

Extension Opportunities

8. Detail a plan for the activities or other steps that may be taken:
 - (a) to further develop or to exploit the project technology.

The measurement system is being upgraded as the project continues.

- (b) for the future presentation and dissemination of the project outcomes.

Scientific and extension articles are planned to describe the GHG emissions from the faba bean and fallow phases. A scientific article describing the cotton phase emissions is in review.

- (c) for future research.

Future findings will be published as data becomes available.

9. A. List the publications arising from the research project and/or a publication plan.
(NB: Where possible, please provide a copy of any publication/s)

Macdonald B, Nadelko, T, Rochester I (2012) Impact of nitrogen fertiliser losses from cotton. Australian Cottongrower magazine, pp 27-28 Aug-Sept 2012

Macdonald B, Rochester I, Nadelko A (2013) Greenhouse gas emissions in high-yielding cotton cropping systems: Impact of nitrogen fertiliser rate. *Nutrient Cycling in Agroecosystems (submitted)*

Publication of the GHG emission data from the faba bean and fallow phases will be published in 2013/2014.

- B. Have you developed any online resources and what is the website address?
No.

Part 4 – Final Report Executive Summary

Executive summary

The project aimed to quantify emissions of CO₂, N₂O and CH₄ from broadacre irrigated cotton-based cropping systems. These three gases are of the greatest interest in green house gas production from agricultural land. Fluxes of N₂O accompanied each furrow irrigation and rainfall event. Amounts of N₂O emitted were closely related to the amounts of N fertiliser applied. Where optimal rates of N fertiliser were applied, N₂O emissions were not significantly higher than the background level. Monitoring of CO₂ showed large emissions particularly in the cotton and fallow phases, but much less during the faba bean phase. Cooler soil and air temperatures may have influenced the emission. Soil organic carbon levels are increasing in the system monitored over the 10-year period. More carbon is added in crop stubble than is respired by the soil during the cropping phase of the rotation that allows for a positive soil carbon balance. Significant carbon losses occur during the fallow phase of the rotation. Methane emissions remain of little significance in this cropping system.

Where cotton is grown with optimum amounts of N fertiliser and crop stubble is managed to encourage soil organic carbon increases, then cotton production could be carbon positive. This is an important consideration for future promotion of the industry and to progress the improvements in soil health, resilience and function that has been achieved to date.