Cotton
RESEARCH & DEVELOPMENT

Annual, Progress and Final Reports

REPORTS

Part 1 - Summary Details

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

CRDC Project Number:		**GCRC3C**
Annual Report:	☐	Due 30-September
Progress Report:	☐	Due 31-January
Final Report:	☒	Due 30-September (or within 3 months of completion of project)

Project Title: Baseline assessment of greenhouse gas emissions in cotton based farming systems

Project Commencement Date: 01/07/02 **Project Completion Date:** 30/06/03

Research Program: 2 Integrated Natural Resource Management

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Part 3.1 – Progress Reports (due end of January)

(Maximum two pages)

If this is your first Progress Report please answer the questions under Part 3.1.1 below.

If you are not in your first year of the project (ie you have previously submitted an Annual Report) please answer the questions under Part 3.1.2 below.

Part 3.1.1 – First Progress Report

1. **Is the project on schedule?**

2. **Have there been, or do you anticipate there being, any problems in meeting the project objectives, milestones and performance indicators for the first year? If so what contingency plans do you have in place to address these problems?**

3. **At this early stage are there any concerns or highlights that you believe the Corporation should be informed about?**

4. **Detail and justify any variations to the original project proposal that you anticipate for the coming financial year (July to June).** (Eg Variations to outcomes or objectives, project time-line, budgets, or personnel).

Part 3.1.2 – Second or Third Progress Report

1. **Since submitting your Annual Report, have there been, or do you anticipate any, problems in meeting the project objectives, milestones and performance indicators for the remainder of this year? If so, what contingency plans do you have in place to address these problems?**

2. **Have any concerns or highlights emerged since submitting your Annual report that you believe the Corporation should be informed about?**

3. **Detail and justify any variations to the original project proposal that you anticipate for the coming financial year (July to June).** (Eg Variations to outcomes or objectives, project time-line, budgets, or personnel).

Part 3.2 – Annual Reports (due end of September)

(Maximum four pages)

1. **What were your major project objectives, milestones and performance indicators for the past year? (Please list these.)**

2. **Which of these have been achieved? ie results**

3. **Which were not achieved and why? (Please provide detail of any problems you have had during the year and how you plan to address these problems).**

4. **Are there any aspects of your research project do you envisage having problems with in the coming year and what is your contingency plan?**

   NOTE: This question is aimed at identifying areas in which CRDC may be able to implement assistance to help avoid potential problems.

5. **What are your specific project objectives, milestones and performance indicators for the coming financial year? Have any of these changed?**

6. **Are changes to the Intellectual Property Register required? (You may also submit a separate confidential report of information, which should be included in the report but which you reasonably consider is confidential information).**

7. **How do you plan to demonstrate that your research is addressing the Corporation's three outputs - Economic, Environmental and Social?**

8. **To what extent have your research results to date been disseminated to other researchers, growers or the industry? Please provide details and list any publications.**

9. **How do you intend to communicate the results or findings of your research to other researchers /growers /industry in the next year? What assistance will you need?**

   NOTE: CRDC expects to see you develop some form of a communication plan during the life of the project. This plan should identify the expected / known outputs from the project and how best to communicate them. The plan should be revised in every Annual Report and should provide some guidance on how to proceed once the project is completed.

10. **Were there major highlights in your work over the last twelve months? Please give a brief outline.**

Part 3.2.1 - Annual Supervisor Report (Scholarships Only)

The Scholarship Recipient's Supervisor is to provide a brief statement on the Recipient's progress and achievements during the relevant year and whether the Recipient is fulfilling the requirements of the postgraduate or undergraduate course in which the Recipient is enrolled.

Part 3.3 – Final Reports (due 3 months after completion of project)

(The points below are to be used as a guideline when completing your final report. Postgraduates please note the instructions outlined at the end of this Section.)

1. Outline the background to the project.

The greenhouse effect is widely considered one of the major threats to Australia agriculture. There is increasing evidence that carbon dioxide, methane and nitrous oxide concentrations are reaching levels that will cause a significant warming of the earth's atmosphere over the next 10 to 100 years causing great changes in seasonal weather patterns. Forecasts in Australia suggest a reduction in rainfall in the interior regions and increased incidence of drought. If a concerted effort is made to reduce global greenhouse gas emissions, these changes can possibly be avoided.

Agriculture plays a significant role in both the production and removal of greenhouse gases from the atmosphere. In Australia, 20% of all emissions come from agricultural sources, and one-third of these are crop and pasture based. Plants remove CO_2 from the atmosphere which can be stored in soil carbon for long periods of time if crop residue retention and/or no-tillage is practices. Carbon sequestration is being promoted as a possible management strategy for removal of CO_2 as it is also recognised as best practice in developing a sustainable farming system.

Cotton is one of many agricultural industries heavily reliant on nitrogenous fertilizers to maintain high levels of production. The inclusion of legumes also provides a boost to the nitrogen economy of the system. Surplus nitrogen is a direct contributor to nitrous oxide (N_2O) emissions which has a Global Warming Potential (GWP) approximately 300 times that of a single molecule of carbon dioxide (CO_2). Reducing N_2O emissions from cropping systems has been widely identified as the highest priority in greenhouse gas abatement in crop production and for ensuring profitability through enhance N and water use efficiency.

Nitrous oxide is emitted from soils during both nitrification and denitrification. The significance of the latter has been identified within irrigated cropping industries (Constable, Freney and Rochester) with up to 50% of applied N lost to the atmosphere. The proportion of N_2O contributing to the total nitrogen gas loss is unknown. Rochester (2003) has estimated that just over 1% of applied N is emitted as N_2O from alkaline grey clay soils in a cotton system. There is much speculation about the actual amounts of N_2O produced in cropping systems globally. The Intergovernmental Panel for Climate Change (IPCC) suggest 1.25% of applied fertliser N as a general figure to estimate N_2O emissions.

There is now increasing emphasis on the use of dynamics simulation models to predict N_2O emissions, with speculation that the complexity of these biogeochemical reactions can only be fully described using models, providing a flexible means of developing estimates for the wide variety of crop management strategies currently being employed. These models have been developed with data sources originating from the northern hemisphere, and eventhough generally applicable, little or no information has been sourced from cotton based systems. This problem is compounded by the fact that minimal information exists on N_2O emissions from most Australian cropping systems and only with this data can models be calibrated and validated for cotton growing systems.

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

The original objectives were:

a. Quantitative baseline assessment of N_2O emissions from nitrogen fertiliser, leguminous and native soil sources in traditional cotton monoculture and rotations system on contrasting soil types.

b. A soil carbon carbon inventory to establish patterns of change and net CO_2 emissions across cotton-based farming systems.

c. Through simulation, develop estimates of N_2O and CO_2 emissions across the industry and provide the platform for future research in developing best management practices and decision support systems that reduce greenhouse emissions, whilst optimising yield and increasing profitability.

This project was an amalgamation of 2 proposals. The project focused on objectives a. and c. because the drought year made it extremely difficult to undertake detailed soil sampling on the reduced budget, combined with the need for specialised equipment for N_2O which required commissioning for this and future projects. A focus on N_2O and N_2 emisions (for nitrogen use efficiency assessment) was considered the priority as minimal data existed and management outcomes and strategies could be developed in the short, rather the long term, which is the case with the management of CO_2 emissions. The focus on N_2O is also in line with agricultural priorities established by the Australian Greenhouse Office.

Objectives a. and c. were achieved, and in future projects increased emphasis on full greenhouse gas accounting will ensure that objective b. will be met.

3. Detail the methodology and justify the methodology used.

The project was in three phases:

a. Collection of N_2O data from a range of nitrogen management treatments on a typical cotton growing soil.

A long-term cotton rotation experiment comprising continuous cotton, wheat-vetch-cotton and wheat-cotton treatments with 8 levels of N fertiliser management in accessible sub-plots at Field 6 West at the Australian Cotton Research Institute (ACRI) was selected for the collection of field data.

We used a closed chamber technique with evacuated blood collecting tubes (Exetainers) to collect gas samples of N_2O emitted from soil during the cotton growing season in 2002/03. Duplicate chambers were placed in each of 10 subplots in replicates 1 and 2 of F6 West. Of the 10 treatments, 9 were from the original factorial design i.e. rotation x N rate - continuous cotton (CC), wheat-vetch-cotton (WVC) and wheat-cotton (WC) x 0, 100 and 200 kg/N fertiliser applied as urea. The tenth treatment was WVC receiving an industry high rate of 300 kg N/ha as urea. Some additional treatments were also maintained after adding ^{15}N-labelled fertilisers, however this study was incomplete due to some damage to the chambers and analyses are still being carried out by the University of Melbourne.

The close chamber technique is widely used around the world to gain a snap-shot of emissions over short sampling periods. The chambers (5 litre lidded plastic buckets with the bottom cut off and and a rubber septum in the removable lid) were designed to demonstrate that simple techniques do enable quite detailed studies to be performed. Gas samples were taken regularly after irrigation or once or twice and week during the growing season. On closure of the lid one gas sample is taken with the evacuated (non-reusable) sampling tube, another is taken after 60 minutes to enable the flux of N_2O to be calculated. Soil water and nitrate samples were periodically taken in all sub-plots by sampling to 30 cm with a coring device. The gas samples were stored in a refrigerator until analysis using a Shimadzu gas chromatograph (GC) equipped with an Electron Capture detector commissioned at ACRI.

Gas samples were collected from 18 September to 6 December 2002, a 10 week period representing the time when we had considered most N_2O emissions to be found (i.e. low crop biomass with and little N uptake for most of this time, thus exposing free nitrates to loss through denitrification). The first irrigation event was on September 20. To develop a full N_2O budget for this period of time, N_2O values between non-successive dates where interpolated. Access to the field was restricted after irrigation, hence some emission events may be have been missed, therefore, we used the model simulations described in part c. of this methodology to give us relative changes in daily N_2O flux rates (during these events) which we then applied to our own data to fill gaps. Absolute values from the model output were not used.

b. Laboratory incubations to determine the proportion of total nitrogen gases lost as N_2O for typical cotton growing soils.

Nitrous oxide is a product of both denitrification and nitrification, both microbiological transformations of mineral nitrogen in soils. The most significant contributor to N loss in irrigated soils is considered to be denitrification (but little information exists with respect to N_2O emissions from nitrification). This experiment was conducted to measure the effect of water-filled pore space (i.e. degrees of water-logging) on denitrification, as evidence in the literature suggests as soils become more water-logged there is an increasing tendency for N_2O to be converted to N_2. This information is required for calibrating and validating simulation models and also lays the foundations for a simple means of estimating total nitrogen losses in the future.

The alkaline soils used in this study were collected from F6 West at ACRI at Narrabri (the location of the field experiment), Dalby and Dirranbandi to provide a cross section of the textural classes found in cotton growing soils. The Narrabri and Dirranbandi soils were from continuous cotton treatments, the Dalby soil had been in a cotton-maize rotation. The soils were all considered to be clay or clay loams, with a higher sand content in evidence in the Dirranbandi soil. The textural analysis provided by Dr Nilantha Hulugalle is outlined in Table 1.

Table 1. Textural analysis of soils used for laboratory incubation for N_2O/N_2 analysis.

Location	Clay (%)	Silt (%)	Sand (%)
Narrabri F6W	54	22	22
Dalby	68	8	25
Dirranbandi	54	12	34

Mineral nitrogen, soluble carbon and water-logging are all precursors for the production of nitrogen gas, whether as N_2O or converted all the way to N_2. The incubation experiments consisted of 8 (2 nitrogen x 2 carbon x 2 water) treatments in a factorial design of 3 replicates (24 incubations/soil). An acetylene inhibition technique was used to distinguish N_2O from N_2 emissions, therefore 48 incubations were prepared for each soil – 2 sets of indentical samples.

Briefly 20 gms of moist soil was packed in small plastic sample bottles to ensure their bulk density was representative of field conditions. Nitrogen was applied as nitrate, equivalent to 50 kg/ha; carbon applied as glucose, equivalent to 180 kg /ha; and water in specified amount for varying degeees of water-logging, expressed as water-filled pore space (WFPS), with 75% being on the lower end of water-logging and in the case of 90% WFPS, the soil is saturated.

The treatments consisted of a control which received no C or N amendments, a C only treatment, a N only treatment and one receiving both C and N, all incubated at both 75% and 90% WFPS. The soils were incubated in 1 litre screw capped jars (with a lid containing a rubber septum for gas sampling) for 7 days @ 27 deg C and during that time gas samples were periodically removed and analysed with GC-ECD for N_2O. The incubation jars where flushed with air and resealed after every sampling event to ensure adequate O_2 was available for heterotropic respiration. One set of the samples for each soil was incubated with 10% C_2H_2 by volume.

The production of N_2O by denitrification was estimated by the amount of N_2O evolved from soil cores without C_2H_2, whereas total denitrification (N_2+N_2O) was estimated from the amount of N_2O produced from C_2H_2 treated cores. The N_2/N_2O ratios were calculated using N_2 estimated by difference in N_2O produced between C_2H_2-treated and untreated soil samples.

c. Testing of a model for simulating N_2O emissions from a range of nitrogen management treatments on a typical cotton growing soil.

The DAYCENT simulation model is a daily time step version of the popular CENTURY agro-ecosystem model developed specifically for simulating biogeochemical processes of C, N and P in soils. CENTURY has been extensively used throughout the world, but DAYCENT (Del Grosso et al., 2000) was developed primarily for tranformations at finer temporal scales, and whilst only been tested in the USA, is based on a great deal of the global literature. It is being utilised by US-EPA for N_2O assessments across the USA and is therefore an important model in the global greenhouse gas simulation and accounting community. Like its parent model CENTURY, the concepts are generic enough that with the correct soil and climate data, the model should make accurate predictions of CO_2 and N_2O production in response to climate and soil conditions, including fertiliser and residue management. As little data exists for N_2O emissions from Australian cropping systems, let alone cotton, this study was designed to test DAYCENT's predictive capacity and to identify potential knowledge gaps in ensuring DAYCENT or similar models become accurate predictive tools for the Australian cotton industry.

In this test, we simulated the same treatments (and sequences therein) in F6 West as reported in part a. of this methodology. Simulations were based on local climate, soil and management conditions for each of treatment within the field. The input data included daily maximum and minimum temperatures and rainfall for ACRI, a soil profile describing water holding and chemical characteristics of the field (pH, mineral N, organic carbon) and full management details within each treatment (cultivations, fertiliser, irrigation and harvest details). This information was compiled from an extensive search of the local literature as well as laboratory analyses.

A single soil organic carbon value alone is not usually sufficient to initialise the 3 soil organic matter pools (active, slow, passive) in the DAYCENT model prior to commencing a simulation. To initialise the soil organic pools in the model for the start of 2002 when we commenced the cropping sequences, we first ran the model for 10,000 years under a temperate grassland scenario to give us approximate pool sizes (and relative proportions) for that year. We then ran the model for 50 years under continuous cropping to bring us to 2002. We then used the measured soil carbon value for F6 West (0-30 cm) of 1.6%, converted it to an equivalent value to run in DAYCENT (0-20 cm initialisation) and disaggregated this value based on the DAYCENT simulation results. The relatively large passive soil carbon pool, representing 83% of total soil carbon, is a typical observation after long-term cropping.

4. Detail and discuss the results including the statistical analysis of results.

a. Field data

The purpose of this study was to produce a time series of emissions for both quantitative comparisons, but also for model testing in the future. The WVC treatment produced twice as much N_2O during the 10 week sampling period as any of the other treatments assayed (Table 2). The lowest emitting treatments were from the WC rotation (0.46-0.89 kg N/ha) and these had received less N fertiliser over the 2 year cycle than in the CC treatment which would explain the lower emissions. The coefficient of variation (CV) for the total N_2O emitted at the 4 sampling points (duplicate chambers x 2 reps) for each treatment ranged from 15-72%, with the highest variation being found in the WVC 300N treatment which gave the highest emissions of all the 10 treatments assayed. The lowest CV's were found in the 0 and low N treatments. The fact that gaseous N emissions are very site specific (i.e. hot-spots) and at a fine spatial scale makes the assessment of N_2O a difficult task at the best of times. The duplicate chambers within the subplots were no more than 1 m apart which would greatly reduce variability, hence the CV's are within acceptable ranges.

Table 2. Total N_2O-N emitted from cotton production systems in ACRI F6 West at Narrabri from18 September to 6 December 2002.

	Treatment[1]		
N rate	CC	WVC	WC
		N_2O-N (kg/ha)	
0	0.75	1.05	0.46
100	0.96	1.52	0.67
200	1.62	2.22	0.89
300	n.a.	5.65	n.a.

[1](C)otton, (V)etch, (W)heat

If we assume the emissions from the 0 N treatments are our background (or non-fertiliser) emissions for each of the cropping sequences, we can then infer how much N_2O may possibly have been emitted from fertiliser sources (Table 3). All of these values, except for the WVC 300 N rate treatment lie below the IPCC default emission value of 1.25% N_2O-N emitted from fertiliser sources. This is only for a 10 week period, and emissions from all treatments would have continued, but our sampling period would have been long enough to capture the majority of emissions from these treatments from after the first irrigation.

Table 3. Total N_2O-N emitted from cotton production systems in ACRI F6 West, Narrabri from 18 September to 6 December 2002 as a proportion of the applied N fertiliser.

	Treatment[1]		
N rate	CC	WVC	WC
		N_2O-N / Fert N (%)	
0	0	0	0
100	0.20	0.47	0.21
200	0.43	0.59	0.21
300	n.a.	1.53	n.a.

[1](C)otton, (V)etch, (W)heat

b. Laboratory data

The results from the incubations for the three soils are outlined in Table 4. All soils displayed similar trends in production of N_2O and N_2 in response to amendment and water-logging i.e. the N_2O/N_2 ratio declined in all cases when the soil became more waterlogged. The Dalby soil showed a low response to the addition of soluble carbon and nitrate sources to stimulate denitrification indicating the soil from this particular site may actually have a low level of suitable denitrifying microorganisms. There was a significant increase in N_2O production however as WFPS increased when adequate levels of carbon and nitrogen were present which is usually when fresh residues have been added of a sufficent N content, or cereal residues amended in concert with fertiliser N.

The soil from the continuous cotton treatment at Narrabri appears to be carbon limited in its current state (i.e. low in decomposable carbon fractions) which is evidenced by the large response in N emissions after addition of a soluble carbon source. The Dirranbandi soil tended to be deficient in both soluble carbon and available nitrogen and did not emit as much N_2 relative to the Narrabri soil when subject to intense water-logging. This is not surprising seeing that the Dirranbandi soil is of a sandier nature and water-logging events are more effective for denitrification in heavier clay soils if sources of carbon and nitrogen are available for the organisms.

In the Dirranbandi soil, when sufficient soluble carbon was made available, N_2O losses from added N (equivalent to 50 kg N/ha in this case) exceeded 3% of applied N when water-logging did occur. Similar losses (3.9%) were also found in the Narrabri soil when the soil was saturated (WFPS @ 90%).

Table 4. Emissions of N_2O and N_2 from incubated cotton growing soils (7 days @ 27 deg C) amended with soluble carbon and nitrate sources to stimulate denitrification.

	Dalby				Narrabri				Dirranbandi			
	Treatment[1]											
	CON	C	N	C+N	CON	C	N	C+N	CON	C	N	C+N
	N emitted (g/ha)											
WF[2]	N_2O				N_2O				N_2O			
75	26	23	24	31	105	108	77	175	33	24	33	1809
90	23	29	22	107	86	337	76	2300	29	34	48	1599
	N_2				N_2				N_2			
75	3	4	8	10	322	55	38	7	25	213	98	30
90	34	92	40	160	62	1864	91	2117	219	485	59	413
	N_20/N_2				N_20/N_2				N_20/N_2			
75	8.82	1.70	2.94	3.19	0.33	2.0	2.0	26.2	1.32	0.11	0.33	60.2
90	0.69	0.32	0.56	0.67	1.40	0.18	0.84	1.1	0.13	0.07	0.80	3.9

[1]CON = unamended control, C = + glucose only, N= + nitrate only, C+N = both glucose & nitrate
[2]WF = Water Filled Pore Space (%)

c. Simulations

The simulated results for N_2O emissions during the 2002 study period are outlined in Table 5. The model generally under-predicted emissions in the 0 N treatments, was reasonably accurate in estimating total emissions from the cotton grown in the WVC and WC rotations receiving 100 kg N/ha urea, but generally over-predicted emissions in the 200N treatments for all rotations. The model was able to predict emisisons from the WVC treatments better than others, including the high N rate of 300 kg. The large emissions simulated in the CC treatment were generated in response to the fertiliser addition and possibly due to the relatively higher soil moisture content in this cropping system after the fallow period between cotton crops. The large discrepancy between observed and simulated results for the higher N CC treatments may also be an artifact of our gas sampling schedule during 2002. It appears from the simulations that if soil conditions are suitable, large emissions may be apparent during fertilisation. In our case we do not have sampling data to support this simulated output, but these losses were relatively high when we examined the DAYCENT simulations in detail. On the other hand, DAYCENT does not allow (at this stage) deep placement of N fertilisers, so simulated losses from fertiliser application may be exaggerated.

The total emissions for the cotton growing season as simulated by DAYCENT are outlined in Table 6. Considering the accuracy between the simulated and observed results for the WVC treatment (Table 5), losses of N_2O in the range of 3% of total applied N

(Table 7) are considered a good indication of reality. These emissions are well in excess of the IPCC default emission factor of 1.25% of applied N. In the WC rotation, simulated emissions for the whole season also exceeded the IPCC default, but there appears to be too much discrepancy between the model and observed results during the 10 week study period to draw a definitive conclusion.

Table 5. Simulated vs observed N_2O-N emissions from cotton production systems in ACRI F6 West at Narrabri (from 18 September to 6 December 2002) using the DAYCENT model.

	Treatment[1]					
N rate	CC		WVC		WC	
	N_2O-N (kg/ha)					
	Obs	Sim	Obs	Sim	Obs	Sim
0	0.75	0.51	1.05	.75	0.46	0.17
100	0.96	2.53	1.52	2.32	0.67	1.33
200	1.62	6.12	2.22	4.20	0.89	2.92
300	n.a.	n.a.	5.65	6.05		n.a.

[1](C)otton, (V)etch, (W)heat

Table 6. Season totals for N_2O-N emissions from soils under cotton in the ACRI F6 West treatments near Narrabri, using the DAYCENT simulation model. The period is from the day of N fertiliser (4 September) to beyond harvest (1 April).

	Treatment[1]		
N rate	CC	WVC	WC
	N_2O-N (kg/ha)		
0	0.84	1.65	0.47
100	4.65	4.39	2.12
200	10.52	7.46	4.30
300	n.a.	10.52	n.a.

[1](C)otton, (V)etch, (W)heat

Table 7. Total N_2O-N emitted from soils under cotton during the 2002/03 season in ACRI F6 West near Narrabri, as a proportion of added N fertiliser as estimated using the DAYCENT simulation model. The period is from the day of N fertiliser (4 September) to beyond harvest (1 April).

	Treatment[1]		
N rate	CC	WVC	WC
	N_2O-N / Fert N (%)		
0			
100	3.81	2.74	1.65

200	4.84	2.91	1.92
300	n.a.	2.96	n.a.

[1](C)otton, (V)etch, (W)heat

The simulated pattern of N_2O-N loss from cotton in the 200N treatments in the WVC and WC rotations for the 2002 growing season are depicted in Figure 1. Note the potentially large emissions in WVC in response to fertilisation. As mentioned earlier, this may possibly be a problem with the model in accommodating deep placement of N. However it is clear that irrigation events do play a major role in providing the suitable soil conditions for increased emissions.

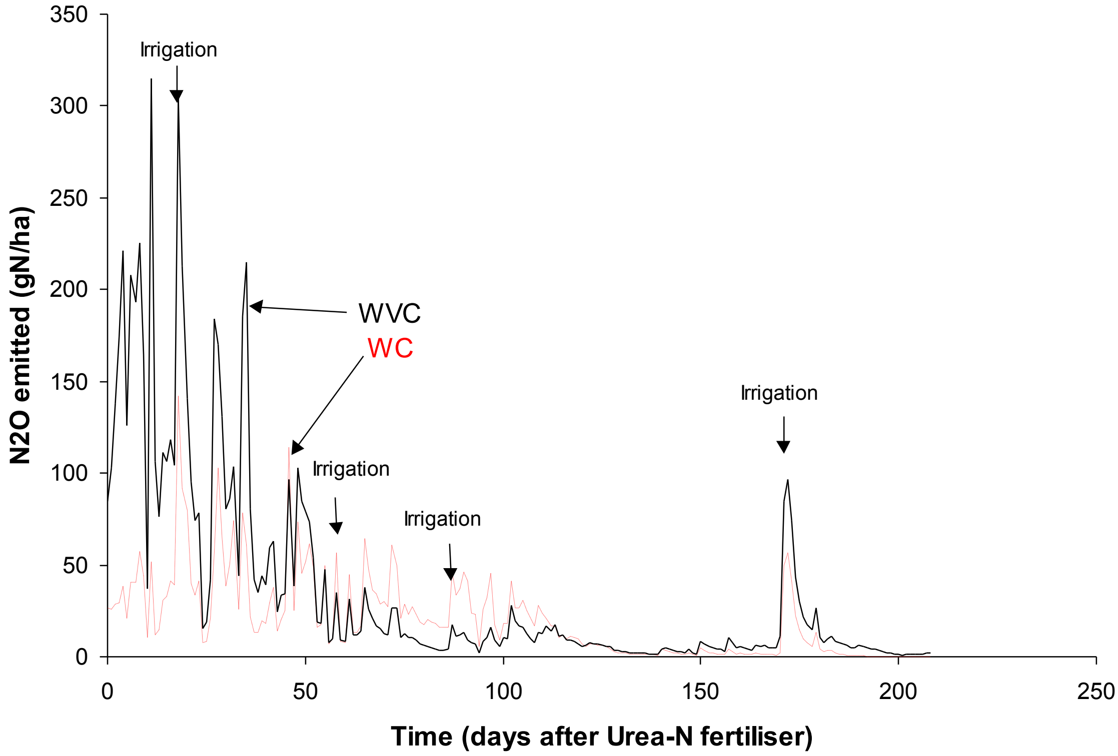

Figure 1. Simulated N_2O emission pattern for the 200N treatments in the WVC and WC rotations for the 2002 growing season at ACRI Field 6 West near Narrabri.

A daily simulation emissions output for the 0 and 100N rates in the WVC treatment is depicted in Figure 2. Wheat had only received 30 kg N/ha. Note the "spikes" in emissions after irrigation and in response to prolonged rainfall events. Again, large emissions are simulated in response to fertilisation. In the 950 day simulation period for one complete cropping cycle, the 0 N treatment emitted 7.5 kg N/ha with the 100N treatment 11.1 kg

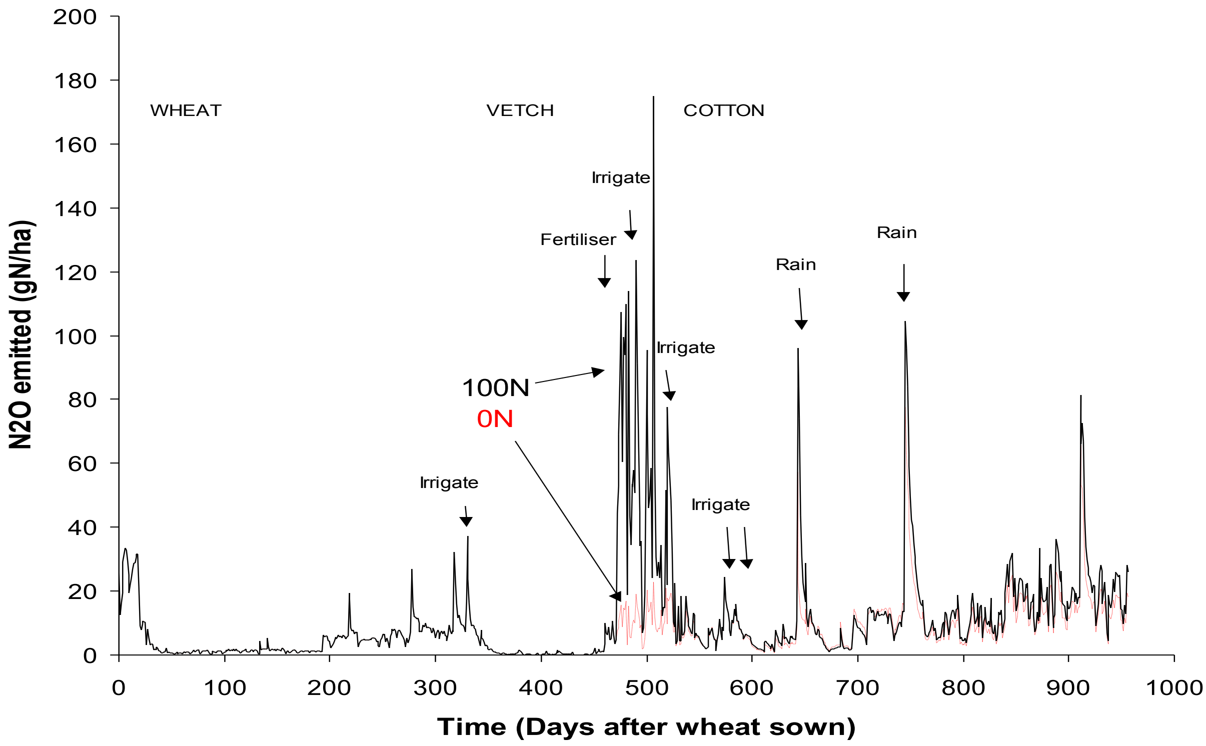

Figure 2. Figure 1. Simulated N_2O emission pattern for the 0 and 100N treatments in the WVC system for the 2001-2003 growing season at ACRI Field 6 West near Narrabri.

The DAYCENT model also outputs N_2-N losses during the season (Table 8) as this gas is the end-product of denitrification whilst N_2O is an intermediary. Losses of N_2 from the WVC treament were consistently about 5% of applied N fertiliser (Table 9). If in fact the simulated results for CC are closer to the truth, total losses (N_2O+N_2) of applied N from the CC treatments were approximately 38%, which is of an order of magnitude reported by Freney et al. (1993) as estimated from field studies.

Estimated seasonal N losses (N_2O + N_2) cotton in the WC rotation range from 3.1 to 3.9% of applied N when 100 and 200 kg N respectively is applied. In WVC rotations, total N losses of 8.1% are consistent across all fertiliser rates (100-300 kg N).

Table 8. Simulated seasonal N_2-N emissions from cotton in the ACRI F6 West treatments as estimated using the DAYCENT simulation model. The period is from the day of N fertiliser (4 September) to beyond harvest (1 April).

	Treatment[1]		
N rate	CC	WVC	WC
		N_2-N (kg/ha)	
0	6.97	6.26	0.80
100	38.6	11.41	2.29
200	72.73	17.29	3.01
300	n.a.	21.37	n.a.

[1](C)otton, (V)etch, (W)heat

Table 9. Total N_2-N emitted from cotton in the ACRI F6 West treatments as a proportion of added N fertiliser as estimated using the DAYCENT simulation model. The period is from the day of N fertiliser (4 September) to beyond harvest (1 April).

	Treatment[1]		
N rate	CC	WVC	WC
		N_2-N / Fert N (%)	
0			
100	34.13	5.15	2.22
200	33.88	5.52	1.11
300	n.a.	5.04	n.a.

[1](C)otton, (V)etch, (W)heat

5. Provide a conclusion as to research outcomes compared with objectives. What are the "take home messages"?

a. Estimates of N_2O-N emissions from an alkaline grey clay under cotton in a variety of rotations range from 0.5-5.7 kg N/ha over a 10 week period after the first irrigation. The largest emissions were found in WVC cropping systems receiving 300 kg N/ha, with 1.53% of applied fertiliser lost as N_2O-N, slightly higher than the estimated N loss using the IPCC guidelines for calculating emissions. For soils receiving less than 200 kg N/ha, N_2O emissions were on average, 0.35% of the fertiliser applied.

b. Laboratory data collected on a range of alkaline soils under cotton (Dalby, Narrabri and Dirranbandi) indicate losses of N_2O-N to be equivalent to 3% of applied N under prolonged water-logging. Whilst there is definite supporting evidence that the predominant N loss is N_2 and not N_2O in heavy clays, the sandier texture soils may have a tendency for greater N_2O emissions relative to N_2.

c. Simulation models are capable of providing reasonably accurate estimates of seasonal emissions, particularly in cropping systems which do not include long fallow periods (e.g. continuous cotton). The DAYCENT model generally over-predicted emissions in treatments receiving N fertiliser of 100 kg N/ha or more over the critical 10 week period after the first irrigation event The large emissions simulated in continuous cotton receiving 200 kg N/ha may be due to the slightly higher subsoil moisture at the time of fertilisation and excess nitrogen available due to mineralisation between crops.

d. Simulated N_2O emissions from an alkaline grey clay under cotton in a variety of rotations range from 0.5 –10.4 kg N/ha over the growing season. In the cropping systems receiving N fertiliser, the losses are equivalent to 1.7-4.9% of applied N.

e. Simulated seasonal N losses from cotton through denitrification average 3.5% of applied N in wheat-cotton rotations, and 8.1% in wheat-vetch-cotton. In continuous cotton, the total N loss is equivalent to 38% of applied N, but this may be an overestimate as the model requires further testing for Australian conditions, especially where fallow phases are in the rotation.

f. Both field and simulated data indicate seasonal losses of up to 3% of applied N (to cotton) as N_2O in wheat-vetch-cotton rotations.

g. Simulation models for N_2O and N_2 emissions require more testing with more complete data sets, specifically with data collected immediately after fertiliser is applied.

h. There is a critical need for more detailed field based data of N_2O emissions from cotton growing soils from across all of the industry. Without this information to develop guidelines and calibrate models, policy makers will rely on poorly developed models to make environmental decisions which will greatly affect profitability.

i. Detailed gas sampling experiments with specialised equipment must be given a high priority to ensure adequate data is available and undeveloped models are not used for making incorrect or inflated estimates of greenhouse gas emissions from cotton based systems.

6. Detail how your research has addressed the Corporation's three Outputs - Economic, Environmental and Social?

Economic – The simplest strategy to reduce greenhouse gas losses, specifically N_2O, is to incorporate management practices that maximise both nitrogen and water use as these are the essential ingredients for increasing yields for less cost.

Environmental – Reducing greenhouse gas emissions has a major impact on mitigating the effects of future climate change and improving the environment.

Social – Combining the environmental benefits of reducing greenhouse gas emissions whilst increasing profitability and developing sustainable farming systems for long-term productivity is much more acceptable to the community than farming solely for short-term profit.

7. Provide a summary of the project ensuring the following areas are addressed:

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

Alkaline soils in cotton based farming systems receiving up to 200 kg N/ha of fertiliser generally emit low levels of greenhouse gases relative to the fertiliser applied.

Nitrous oxide emissions as a proportion of applied fertiliser significantly increase if 300 kg N/ha is applied.

Nitrogen from fertiliser sources may be more susceptible to rapid N_2O losses compared to nitrogen from green manure sources.

Reducing fallow periods will reduce greenhouse gas emissions to the atmosphere.

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

A simple closed chamber procedure is now available which could easily be used by growers for taking gas samples for nitrogen loss assessment on their own farms and provide an industry inventory of N_2O losses. This will aid in developing management strategies for reducing both N_2O and N_2 emissions from fertiliser and green manures and lead to more sustainable and profitable farming.

Simulation models specifically designed for predicting greenhouse gas emissions (e.g. DAYCENT) are applicable for cotton based farming systems in Australia provided more detailed data is made available for calibration and validation. Some modifications are also possible in concert with the original developers

c) are changes to the Intellectual Property register required?

No

8. Detail a plan for the activities or other steps that may be taken:

(a) to further develop or to exploit the project technology.

Growers need to be made aware of the dual advantages that maximising nitrogen and water use efficiency have in developing sustainable systems and reducing greenhouse gas emissions and overall nitrogen losses. Whilst N_2O emissions may seem small, they usually indicate much larger losses of nitrogen from the cropping system that need to be addressed. Sustainable, profitable farming strategies will lead to reduced greenhouse gas emissions and stop N leakage from these systems. Extension activities need to be geared towards educating farmers of the potentially safe and profitable road to reducing greenhouse gas emissions.

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

An article in the Australian Cottongrower is being developed for wider dissemination. Two journal papers are planned, one on the field data the other on the laboratory data. This information will also be disseminated in cooperation with the CRC for Greenhouse Accounting who have employed extension personnel to work across industries. The project also has enormous public relations value, particularly its positiveness re the many environmental and social issues related to climate change.

(c) for future research.

More detailed field data on N_2O emissions in response to nitrogen and water management is urgently required – this is actually underway through a subsequent CRDC project in cooperation with the CRC for Greenhouse Accounting, however this new project relies heavily on borrowed equipment and a dedicated mobile field sampling unit is essential for cost-effectively collecting N_2O data across the industry. Without specialised field experiments and data collection, the estimates will be inaccurate and possibly provide inflated emission results which could be easily manipulated by policy makers. An increased effort in field work should be focused on both alkaline and acidic cotton growing soils north of Narrabri and into Qld.

9. List the publications arising from the research project and/or a publication plan.

Grace, P.R., Rochester, I, Hulugalle, N., Weier, K., Kiese, R., Butterbach-Bahl, K, Chen, D & Eckard, R. (2003) Full greenhouse gas profiling from irrigated soils in the cotton growing region of Australia, 2nd Joint Australia and New Zealand Forum on Non-CO_2 greenhouse emissions from agriculture, Australian Greenhouse Office, 20-22 October 2003, Melbourne, Australia.

Eckard, R, Rodriguez, D., Chen, D., White, R., Yong, L., Wang,Y-P., Grace, P., Bentley, S. & Bennett, A. (2003) Farming systems to reduce non-CO2 greenhouse gas emissions in Australian agro-ecosystems, 2nd Joint Australia and New Zealand Forum on Non-CO_2 greenhouse emissions from agriculture, Australian Greenhouse Office, 20-22 October 2003, Melbourne, Australia.

Galbally, I., Kelly, K., Baigent, R., Barker-Reid, F., Grace, P., Meyer, M., Denmead, T., & Griffith, D. (2003) Environmental and management Drivers of non-CO_2 greenhouse gas emissions in Australian agro-ecosystems, 2nd Joint Australia and New Zealand Forum on Non-CO_2 greenhouse emissions from agriculture, Australian Greenhouse Office, 20-22 October 2003, Melbourne, Australia.

An article in the Australian Cottongrower is being developed for wider dissemination. Two journal papers are planned, one on the field data the other on the laboratory data.

10. Provide an assessment of the likely impact of the results and conclusions of the research project for the cotton industry. Where possible include a statement of the costs and potential benefits to the Australian cotton industry or the Australian community.

Preliminary estimates of greenhouse gas emissions, specifically nitrous oxide, from cotton growing soils are in the low range of global emissions when fertiliser is used judiciously, however more field data is urgently needed to ensure current and future management practices are tailored to minimise emissions and maximise nitrogen and water use efficiency. A continued shift to sustainable farming practices, reductions in fallow periods and rotation crops will provide a win-win situation to the cotton and associated industries through enhanced soil carbon sequestration (and fertility) and a significant reduction in the amount of nitrogen fertiliser which is left unused in the soil profile and potentially lost to the atmosphere as nitrous oxide. More efficient nitrogen management will reduce emissions and increase profitability whilst reducing the potentially damaging effects of climate change on Australia in general.

LITERATURE CITED

Del Grosso, S.J., Parton, W.J., Mosier, A.R., Ojima, D.S., Kulmala, A.E. & Phongpan, S. (2000). General model of N_2O and N_2 gas emissions from soils due to denitrification. Global Biogeochemical Cycles, 14, 1045-1060.
Freney, J.R., Chen, D.L., Mosier, A.R., Rochester, I.J., Constable, G.A. & Chalk, P.M. (1993). Use of nitrification inhibitors to increase fertiliser N recovery and lint yield in irrigated cotton. Fert Res. 34, 37-44.
Rochester, I. (2003) estimating nitrous oxide emissions from flood-irrigated alkaline grey clays. Aust. J Soil Res. 41, 197-206.

POSTGRADUATE SCHOLARSHIPS are not required to submit a final report. Recipients are to send a statement from their supervisor confirming that their thesis has been submitted for assessment. Following examination and any necessary correction, a single copy of the thesis is to be forwarded to CRDC, along with an electronic copy of the Plain English Summary.

Part 4 – Final Report Executive Summary

Provide a one page Summary of your research that is not commercial in confidence, and that can be published on the World Wide Web. Explain the main outcomes of the research and provide contact details for more information. It is important that the Executive Summary highlights concisely the key outputs from the project and, when they are adopted, what this will mean to the cotton industry.

The greenhouse effect is widely considered one of the major threats to Australia agriculture. There is increasing evidence that carbon dioxide, methane and nitrous oxide concentrations are reaching levels that will cause a significant warming of the earth's atmosphere over the next 10 to 100 years causing great changes in seasonal weather patterns. Forecasts in Australia suggest a reduction in rainfall in the interior regions and increased incidence of drought. If a concerted effort is made to reduce global greenhouse gas emissions, these changes can possibly be avoided.

Cotton is one of many agricultural industries heavily reliant on nitrogenous fertilizers to maintain high levels of production. The inclusion of legumes also provides a boost to the nitrogen economy of the system. Surplus nitrogen is a direct contributor to nitrous oxide (N_2O) emissions which has a Global Warming Potential (GWP) approximately 300 times that of a single molecule of carbon dioxide (CO_2). Reducing N_2O emissions from cropping systems has been widely identified as the highest priority in greenhouse gas abatement in crop production and for ensuring profitability through enhance N and water use efficiency.

The project is the first dedicated analysis of greenhouse gas emissions from soils in cotton based farming systems and its relationship to sustainable cropping practices. Field based estimates of greenhouse gas emissions, specifically nitrous oxide, from an alkaline grey clay under cotton receiving up to 200 kg N/ha of fertiliser, ranged from 0.5 – 2.2 kg N/ha during the 10 week period after the first irrigation. On average only 0.35% of the nitrogen applied as fertiliser was emitted as N_2O, which is low compared to global estimates of emissions from fertilisers. Emissions increased to over 1.5% of applied nitrogen when 300 kg N/ha was added, which surpasses the IPCC's estimated value of 1.25% for deriving N_2O emissions from fertiliser sources. Laboratory and simulation studies carried out within this project indicate N_2O emissions equivalent to 3% of applied fertiliser nitrogen for a range of clay soils from across the industry.

More field data is urgently needed to ensure current and future management practices are tailored to minimise emissions and maximise nitrogen and water use efficiency. A continued shift to sustainable farming practices, reductions in fallow periods and rotation crops will provide a win-win situation to the cotton and associated industries. This wll include enhanced carbon sequestration (and fertility) of soils and a significant reduction in the amount of nitrogen fertiliser which is left unused in the soil profile and potentially lost to the atmosphere as nitrous oxide. More efficient nitrogen management will reduce emissions and increase profitability whilst contributing to the abatement of climate change and its impact on Australian agricultural systems.

TRAVEL REPORTS

1. A brief description of the purpose of the travel.

2. What were the:
   a) major findings and outcomes
   b) other highlights

3. Detail the persons and institutions visited, giving full title, position details, location, duration of visit and purpose of visit to these people/places. (Note - please provide full names of institutions, not just acronyms.)

4. a) Are there any potential areas worth following up as a result of the travel?
   b) Any relevance or possible impact on the Australian Cotton Industry?

5. How do you intend to share the knowledge you have gained with other people in the cotton industry?