Cotton Catchment Communities CRC

FINAL REPORT

Part 1 - Summary Details

Cotton CRC Project Number: 1.04.16

Project Title: **Maintaining profitability and soil quality in cotton farming systems III**

Project Commencement Date: 01/07/2008 **Project Completion Date:** 30/06/2011

Cotton CRC Program: The Farm

Part 2 – Contact Details

Administrator: G. Denney
Organisation: NSW Department of Primary Industries
Postal Address: Locked Bag 21, Orange, NSW 2800
Ph: 02 63913219 **Fax:** 02 63913527 **E-mail:** graham.denney@industry.nsw.gov.au

Principal Researcher: Dr. N.R. Hulugalle, Senior Research Scientist
Organisation: NSW Department of Primary Industries
Postal Address: ACRI, Locked bag 1000, Narrabri, NSW 2390
Ph: 02 67991533 **Fax:** 02 67991503 **E-mail:** Nilantha.hulugalle@industry.nsw.gov.au

Supervisor: Dr. P. Slavich
Organisation: NSW Department of Primary Industries
Postal Address: Wollongbar Agricultural Research Institute, 1243 Bruxner Highway, Wollongbar, NSW 2477
Ph: 02 6626-1352 **Fax:** 02 6628-1744 **E-mail:** peter.slavich@industry.nsw.gov.au

Signature of Research Provider Representative:

Peter Slavich

Cotton Catchment Communities CRC

FINAL REPORT

Maintaining profitability and soil quality in cotton farming systems III

July 2008 to June 2011

N.R. Hulugalle, Australian Cotton Research Institute, Narrabri, NSW 2390
T.B. Weaver, Australian Cotton Research Institute, Narrabri, NSW 2390
S. Kimber, Wollongbar Agricultural Institute, Wollongbar, NSW 2477
J. Powell, Australian Cotton Research Institute, Narrabri, NSW 2390
F. Scott, Tamworth Agricultural Research Centre, Tamworth, NSW 2340

NSW GOVERNMENT
Primary Industries

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1 Project objectives and achievements

Objective	**Status**
Determine the effect of selected crop and soil management practices (rotation crops; soil amendments; *in situ* stubble retention; treated sewage effluent as a source of irrigation water) on carbon sequestration, soil quality, drainage soil water storage, water use efficiency, greenhouse gas emissions, crop growth, yield and profitability.	Most achieved. See sections 6.1, 6.2, 6.3, 6.4, 6.5, and 6.6. In-field water use with “Irrimate” use not assessed as technical officer for WUE project of Mr Jackson was not appointed due to funding constraints.
Investigate whether system characteristics such as water use efficiency and carbon sequestration could be related to qualitative indicators, which could be measured by cotton growers and consultants, such as ground cover, rotation frequency and tillage intensity. We hypothesized that these qualitative indicators could be used as surrogate indices of soil carbon sequestration, N and WUE.	Achieved for irrigated sites in NSW. See sections 6.1.5 and 6.6.5.
Complete modifications to "Mulch manager", a machinery system developed to manage vetch in cotton-vetch systems on permanent beds.	Achieved. See sections 5.4 and 6.7. Provisional patent awarded. Full patent not pursued.
Determine drainage & leaching under selected cropping systems and management practices. Compare drainage estimated with CMB with that measured with the tension lysimeter funded by Cotton CRC/CRDC	Achieved. See sections 6.5.1, 6.5.2 and 6.5.3
Communicate research outcomes to the National Priority Teams for extension throughout the industry	Information provided to individual extension staff via copies of publications, conference papers and reports and at industry workshops. See section 14.

2 Executive Summary

The aims of the project were to determine the effect of selected management practices on carbon sequestration, soil quality and hydrology, crop agronomy and profitability in irrigated and dryland Vertosols using a combination of field and laboratory experiments, and desktop studies. Management practices were tillage systems, rotation crops, soil amendments, irrigation and stubble management. Measurements included environmental variables such as soil quality, carbon storage and sequestration, greenhouse gas emissions, deep drainage and soil water storage, and agronomic variables such as above- and below-ground crop growth and cotton lint yield. Economic returns in irrigated sites at ACRI were evaluated by comparing seasonal and cumulative gross margins. Partial life cycle analyses of greenhouse gas emissions were made using a desktop approach. The "Mulch Manager", a machinery attachment which was able to kill vetch while reducing herbicide application rates and trafficking was completed and assessed.

In general, SOC stocks in the 0-60 cm depth ranged between 50 and 70 t/ha. Legumes, although contributing large amounts of carbon to the soil were unable to retain it because their low C/N ratio facilitated rapid microbial decomposition. Carbon inputs of C4 crops such as sorghum and corn were much larger than those of C3 crops such as wheat. A major proportion of that carbon came from their root systems. Increasing water availability and reducing tillage improved root growth. SOC sequestration rates were generally negative or neutral, except where a stressed soil (disease, sodicity, salinity) was in the process of recovering. Estimates of carbon inputs, based on above-ground and root dry matter, together with measured sequestration rates indicated that large losses of carbon were occurring, probably due to a combination of accelerated erosion, runoff and microbial decomposition. SOC storage was positively related to dry matter inputs, average maximum temperature, soil aeration and water availability but was negatively associated with N fertiliser inputs. Except for temperature, the other variables can be manipulated by cotton growers. Average maximum temperature and soil organic carbon in the 0-60 cm depth had a curvilinear relationship. The temperature optima were higher in the Namoi valley (27-28 ^{o}C) than in the Macquarie (25.5 ^{o}C). Farming practises that could reduce emissions include eliminating inversion tillage, minimising use of groundwater, sowing winter crops in rotation with cotton, reducing/optimising mineral N fertiliser rates, substituting a legume an thus, fixed N for mineral N fertiliser. Long-term cropping-related K depletion may be minimised by regular application of cattle manure. Gypsum application did not improve subsoil structure under dryland conditions, probably because of the erratic rainfall pattern.

Water losses through drainage can be reduced and soil water storage increased (i.e. water conservation improved) by including a wheat crop in the rotation with in situ stubble retention under less frequent irrigation. Management systems that conserve all rainfall received in situ, thereby reducing irrigation water requirements can contribute greatly to the sustainability of irrigated cropping. Deep drainage in cropped plots under normal or low rainfall conditions was many times higher than that in fallow plots, and reflects the higher water inputs in the former. When rainfall was frequent and no irrigation was required, drainage was higher under fallow, with fallow length being positively correlated to drainage. A model was developed that used rainfall and potential evaporation to estimate soil evaporation from beds where stubble was either incorporated or retained in situ. A model that used EM38 measurements, soil water storage and sodicity (ESP) was able to accurately estimate chloride in non-saline soils. These values could then be used to estimate drainage using chloride mass balance models.

Cotton yields and gross margin/ML were generally higher when wheat was included in the rotation with highest values occurring on permanent beds. Amendments such as gypsum or manure did not improve crop yields under dryland conditions, even though soil quality was

improved. Including vetch in the rotation did not result in sufficient improvements in cotton yield to compensate for the increase in production costs. In years of plentiful water (or when crop area is the limiting factor) reducing water application rates on a continuous cotton crop was a false economy.

Cotton lint yields, in general, were positively related to water and N inputs, soil aeration in some sites and average annual daily maximum temperature in cooler or poorly-drained sites but were lowered by higher average annual daily minimum temperature. In a sodic soil, a high frequency of the tillage practices intended to aerate the soil may have caused yield decreases, presumably due to exposure of more sodic soils. Depth and frequency of tillage, average annual maximum and minimum temperature, N and SOC directly affected WUE of cotton. Except for SOC, which had no effect, all of the above variables directly affected NUE of cotton, particularly N fertiliser rate, which was negatively related, and legumes, which were positively related. The relative importance of individual variable differed among sites for yield, WUE and NUE.

The “Mulch manager” reduced use of herbicides, decreased labour, lowered risk to operators and had a lower carbon footprint. In comparison to spraying with an 8-row boom sprayer, depth of compaction was more when this 4-row implement was used, although the former resulted in more intense and shallower compaction.

Between 2008 and 2011, two postgraduate students, two honours student and a visiting fellow from Pakistan were hosted by the project. Project outputs were: 7 journal articles, 11 conference papers and 5 cotton industry and extension. A total of 16 public presentations were given by project and associated staff.

Key outcomes included:

- Identifying soil and crop management practices, and climatic variables that had direct impacts on soil carbon stocks, yield, water and nitrogen use efficiency in irrigated cotton soils.
- Quantifying rainfall harvested, and associated drainage and evaporation, and thus, water saved by retaining rotation crop stubble as in situ mulch.
- Identifying practices that could reduce carbon footprint of cotton farming systems with life cycle analysis.
- A machinery attachment for managing prostrate cover crops bed-furrow systems.
- Simplified field methods to estimate soil evaporation and deep drainage.
- A whole-farm model of profitability for cotton farming systems that can be used as an analytical research tool.

3 Introduction

A major proportion (~75%) of Australian cotton is grown on Vertosols (Vertisols, Usterts), of which almost 80% is irrigated. Typically, they have a self-mulching layer 2 to 5 cm deep, overlying a zone of blocky peds to depths of 30 to 50 cm. These soils have high clay contents (40-80 g/100g) and strong shrink-swell capacities such that they form deep soil cracks which close when wetting occurs due to swelling of the soil, but are frequently sodic at depth and prone to deterioration in soil physical quality if incorrectly managed. In addition, soil pores and stable aggregates attributable to the interacting activities of soil organic matter, exchangeable cations, plant root systems and microbes occur in these soils.

Resiliency and sustainability in cotton farming systems are dependent upon a number of interacting factors which include climate, soil quality, plant nutrition, farm management, weed and disease incidence, and economic factors. Frequently, when external constraints such as drought and economic factors impose on farming systems, growers who manage their soils to optimise quality are able to respond more rapidly, thereby sustaining profits. Indices of soil quality include soil porosity, organic carbon and available nutrients.

Management systems whereby soil quality can be modified and managed include tillage and stubble management systems, and crop rotations. Wheat rotation crops sown after cotton can improve soil quality indicators such as subsoil structure, salinity and sodicity, while legumes such as vetch and faba bean can increase available nitrogen by fixing atmospheric nitrogen, and by reducing leaching losses. Furthermore stubble management systems which avoid burning such as *in situ* stubble retention in combination with suitable soil amendments can also improve soil quality. As comparative studies on these systems (wheat and vetch rotations, standing stubble) had not been conducted, measurements commenced in 2002 in several on-station experiments at ACRI and in 2005 in several on-farm trials in Moree, Brigalow and Narrabri. These observations were continued during this phase of this project focussing on water conservation, carbon sequestration, economic profitability and drainage. Management practices (e.g. fertiliser rates, irrigation, rotation sequences, stubble management, depth of tillage etc.) and climatic factors (e.g. rainfall, temperature etc.) that influence C sequestration, N and Water use efficiency in either a positive or negative way were also assessed.

This report focuses on results obtained over the period 2008-2011 from seven experiments (six irrigated, one dryland) in New South Wales and Queensland on rotation crop management. Where long-term trends are discussed, data collected since 1993 were also included. In addition, management practices from several past long-term experiments were evaluated as potential surrogate indices for soil carbon sequestration, water and N use efficiency using a multiple linear regression approach.

4 Aims and Objectives

The general aims of the project were to determine the effect of selected crop and soil management practices on carbon sequestration, soil quality, drainage, soil water storage, crop growth, yield and profitability.

The specific objectives were to:

a) Determine the effect of selected crop and soil management practices (rotation crops; soil amendments; *in situ* stubble retention; treated sewage effluent as a source of irrigation water) on carbon sequestration, soil quality, drainage soil water storage, water use efficiency, greenhouse gas emissions, crop growth, yield and profitability.

b) Investigate whether system characteristics such as water use efficiency and carbon sequestration could be related to qualitative indicators, which could be measured by cotton growers and consultants, such as ground cover, rotation frequency and tillage intensity.

We hypothesized that these qualitative indicators could be used as surrogate indices of soil carbon sequestration, N and WUE.

c) Complete modifications to "Mulch manager", a machinery system developed to manage vetch in cotton-vetch systems on permanent beds.

d) Determine drainage & leaching under selected cropping systems and management practices. Compare drainage estimated with CMB with that measured with the tension lysimeter funded by Cotton CRC/CRDC (CRC Project 1.2.01).

e) Communicate research outcomes to the National Priority Teams for extension throughout the industry

5 Methodology

The methodology consisted of several field experiments located in the Namoi (Narrabri), Gwydir (Ashleigh), Macquarie (Narromine) and Lachlan (Hillston) valleys (section 5.1), laboratory experiments and linear regression model development using results from the experiments described below and from several long-term experiments conducted between 1993 and 2005[1] that were located in the Namoi and Macquarie valleys of NSW.

5.1 Field Experiments

5.1.1 **Effects of sowing cotton into standing rotation crop stubble on soil quality, carbon sequestration, gas emissions, soil hydrology[2], crop growth and profitability**

Soil quality, carbon sequestration in soil, drainage, water storage, evaporation, greenhouse gas emissions and cotton and rotation crop growth were monitored in two on-going on-station experiments on rotation crop management located at ACRI (long-term rotation/tillage system experiment established in 1985 and a cotton/wheat/vetch rotation experiment established in 2002); and three on-farm experiments (“Federation Farm”, near Narrabri, “Windmill Farm” near Ashleigh via Moree and “New Haven”, near Narromine). Measurements on the on-farm sites were limited to soil quality and carbon sequestration, with additional measured of greenhouse gas emissions being conducted on the site at “Federation Farm”. The details of the individual experiments are as follows:

5.1.1.1 Tillage/rotation experiment in Field C1 at ACRI, near Narrabri

Treatments were continuous cotton sown after either conventional or on “permanent beds” with most tillage operations being restricted to the bed after cotton picking), and cotton-wheat rotation sown after minimum tillage into standing wheat stubble[3]. The trial was initially established in 1985 with the wheat stubble being incorporated before sowing cotton. Since 2000 the wheat stubble was retained as standing stubble and Round-up Ready cotton (SICALA V2-RR) sown until the 2005-06 season, and “Bollgard-Roundup Ready Flex” varieties thereafter (43BRF during the 2006-07 season and its successors 60BRF during the 2007-08 and 2008-09 seasons, and 71BRF during the 2009-10 and 2010-11 seasons). From 2005, the experiment was re-designed such that two irrigation regimes, “frequent” (~7-14 day

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[1] Hulugalle, N.R., and Cooper, J.L. (1996). "Final report to Cotton Research and Development Corporation on CRDC Project no. DAN 83C (Management Systems for Cotton on Permanent Beds - Maximizing the benefits of Rotation Crops)", 10 pp.
Hulugalle, N.R., Cooper, J.L., and Scott, F. (1999). "Final report to Cotton Research and Development Corporation on CRDC Project no. DAN 108C (Long-term effects of cotton rotations on the sustainability of cotton soils)", 14 pp.
Hulugalle, N.R., Weaver, T.B., and Scott, F. (2002). "Final report to Cotton Research and Development Corporation on CRDC Project no. CRC 12C (Long-term effects of cotton rotations on the sustainability of cotton soils II)", 44 pp.
Hulugalle, N.R., Weaver, T.B., and Scott, F. (2005). "Final report to Cotton Research and Development Corporation on CRDC Project no. CRC 45C (Maintaining profitability and soil quality in cotton farming systems)”, 70 pp.
Hulugalle, N.R., Weaver, T.B., and Scott, F. (2008). “Final Report to Cotton Catchment Communities Co-operative Research Centre on CRC Project 1.04.13 (Maintaining profitability and soil quality in cotton farming systems II)”, 70 pp.

[2] Limited to drainage, soil water storage and evaporation

[3] The terms “standing stubble” and “*in situ* mulch” are used synonymously in this report.

cycle) and "infrequent" (14-21 day cycle), were superimposed on the tillage/rotation treatments to assess the role of different soil cracking patterns caused by imposition of contrasting irrigation frequencies on deep drainage and its pathways. The experimental design was a split plot design where tillage/rotation system was designated as the main plot treatments and irrigation frequency as sub-plot treatment, replicated twice in plots 190 m long and 36 rows wide. Cotton crops received 160-180 kg N/ha during August of each year as anhydrous ammonia before sowing cotton until the 2008-09 season, and as urea after sowing cotton thereafter. An additional 60 kg N/ha of urea was applied to cotton crops in January 2011 due to excessively wet conditions from November 2010 to January 2011 as it was assumed that N losses through volatilisation and leaching were high during this period. Urea was applied to wheat before sowing at a rate of 20 kg N/ha, and 60-80 kg N/ha subsequently during later July or early August. Cotton and rotation crops were irrigated at an average rate of 1 ML/ha subject to water availability, rainfall and soil water content. Soil quality was evaluated in samples taken during September 2008. Six 5-cm diameter soil cores were extracted from each plot with a tractor-mounted soil corer from the 0-10 cm, 10-30 cm, 30-60 cm and 60-120 cm depths. A supplementary sampling was conducted during May 2009 to evaluate post-season soil chloride concentration. Additional samples (6 cores to a depth of 2 m) were taken near the tension lysimeter that is located in this experiment[1]. Due to extended and heavy rainfall, and consequent waterlogging of the field during the last quarter of 2010, soil could not be sampled. Soil water content in the 20 to 120 cm depth was measured with a neutron moisture meter, and that in the surface by gravimetric sampling. Agronomic measurements included cotton plant mapping, root growth of cotton (2008-09 season) in the surface 10 cm with the core-break method and that in the 10-100 cm depth with a I-CAP image capture system and minirhizotrons, lint yield and fibre quality of cotton, wheat grain yield and quality, and dry matter yield. Static chambers were used to sample greenhouse gas emissions after operations such as tillage, slashing, stubble incorporation, irrigation and fertiliser application.

5.1.1.2 <u>Cotton-wheat and cotton-vetch cropping systems experiment in Field D1 at ACRI, near Narrabri</u>

The experiment commenced in 2002, and crop rotations and their chronosequences from 2005 to 2008 are summarised in Table 1). The experiment is expected to run for a period of 12 years (until 2014). The rotations studied were: cotton-vetch-cotton (Rotation 1), cotton-winter fallow-cotton (Rotation 2), cotton-wheat-summer and winter fallow-cotton, wheat stubble incorporated (Rotation 3), and cotton-wheat-summer fallow-vetch-cotton, wheat stubble retained as standing stubble (Rotation 4). Vetch in the cotton-vetch sequence was sown immediately after cotton picking and bed renovation in May and slashed/sprayed out in mid to late September whereas that in the cotton-wheat-vetch sequences was sown after suitable rainfall events during late February and slashed/sprayed out in July or August. This practice differs from management earlier in the experiment, when vetch was killed in September. The objective of early vetch termination was to maximise the fallow period between vetch and sowing cotton, thus conserving spring rains for use by the subsequent cotton crop. The vetch stubble was retained as surface mulch into which the following cotton crop was sown. Land preparation was with minimum tillage ("permanent beds") with tillage operations (disc-hilling, commonly known as "go-devilling") being restricted to the bed after cotton picking. When cotton was sown, a "Roundup Ready" cotton variety (SICALA V2-RR) was used until the 2005-06 season, and "Bollgard-Roundup Ready Flex" varieties thereafter (43BRF during the 2006-07 season and its successors 60BRF during the 2007-08 and 2008-09 seasons, and 71BRF during the 2009-10 and 2010-11 seasons). The experiment was laid out in 3 RCB, with individual plots being 20 1-m rows wide and 165-m long. Within the more complex

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[1] Ringrose-Voase, A.J., and Nadelko, A.J. (2006). Quantifying Deep Drainage Using Lysimetry, Cotton Catchment Communities Cooperative Research Centre (Final report for Cotton CRC Project 1.2.01), 21 pp.

rotations, both rotation and cotton phases were sown in the same year to allow evaluation of climatic variability. Cotton in rotations which did not include a vetch component (Rotations 2 and 3) received 160-180 kg N/ha before sowing cotton until the 2008-09 season, and as urea after sowing cotton thereafter. An additional 60 kg N/ha of urea was applied to cotton crops in January 2011 due to excessively wet conditions from November 2010 to January 2011. Cotton in rotation that did not include vetch were not fertilised before sowing cotton but received supplementary N as urea in December or January. Application rates were dependant on N fixation by the vetch and estimated losses. Between 2008 and 2011, they were 60 (2008-09), 70 (2009-2010) and 120 (2010-11) kg N/ha for Rotation 4 and 80 (2008-09) and 120 (2009-2010, 2010-2011) kg N/ha for Rotation 1. In addition, 60 kg N/ha of urea was applied to cotton crops in January 2011 due to excessively wet conditions from November 2010 to January 2011 as it was assumed that N losses through volatilisation and leaching were high during this period. Urea was applied to wheat before sowing at a rate of 20 kg N/ha, and 60-80 kg N/ha subsequently during late July or early August. Phosphorus was applied only during September 2010 to all plots at a rate of 25 kg P/ha as single superphosphate. Cotton and rotation crops were irrigated at an average rate of 1 ML/ha subject to water availability, rainfall and soil water content.

Soil quality was evaluated in samples taken during late September or early October of each year. Chloride was also measured in soil sampled after cotton picking in May and drainage estimated with the chloride mass balance method. Soil sampled during September 2010 was also analysed for exchangeable cations. Four 5-cm diameter soil cores were extracted from each plot with a tractor-mounted soil corer from the 0-10 cm, 10-30 cm, 30-60 cm and 60-120 cm depths. A supplementary sampling to evaluate post-season soil chloride concentration was conducted during May of each year. These results were used to estimate drainage using the chloride mass balance method. Soil water content in the 20 to 120 cm depth was measured with a neutron moisture meter, and that in the surface by gravimetric sampling.

Agronomic measurements included plant mapping, root growth of cotton (2008-09 season) rotation crops (2008, 2009 and 2010 winters) in the surface 10 cm with the core-break method and that in the 10-100 cm depth with a I-CAP image capture system and minirhizotrons, lint and DM yield and fibre quality of cotton, wheat grain and DM yield, and vetch DM yield, C and N concentrations. During the 2010 winter, vetch in replicate one of treatment 4 was severely affected damaged by aphids (Fig. 1). The aphid damaged plot was analysed as a separate treatment using a mixed models approach quantify the effect of the aphids on root growth. Static chambers were used to sample greenhouse gas emissions after operations such as tillage, slashing, stubble incorporation, irrigation and fertiliser application.

Fig 1. Aphid-damaged vetch, June 2010, Field D1, ACRI

Table 1. Crop rotations and chronosequences in cotton/vetch/wheat experiment in Field D1, ACRI, 2008-011. (The letters a and b denote different phases of the same rotation. Vetch$_{GM}$ = green-manured /stubble mulched vetch)

Rotation	2008 winter	2008-09 summer	2009 winter	2009-10 summer	2010 winter	2010-11 summer	2011 winter
1	Vetch$_{GM}$	Cotton	Vetch$_{GM}$	Cotton	Vetch$_{GM}$	Cotton	Vetch$_{GM}$
2	Fallow	Cotton	Fallow	Cotton	Fallow	Cotton	Fallow
3a	Wheat stubble incorporated/ Fallow	Cotton	Wheat	Wheat stubble incorporated/ Fallow		Cotton	Wheat
3b	Wheat	Wheat stubble incorporated/ Fallow		Cotton	Wheat	Wheat stubble incorporated/ Fallow	
4a	Vetch$_{GM}$	Cotton	Wheat	Standing wheat stubble/ Fallow/ Vetch$_{GM}$		Cotton	Wheat
4b	Wheat	Standing wheat stubble/ Fallow/ Vetch$_{GM}$		Cotton	Wheat	Standing wheat stubble/ Fallow/ Vetch$_{GM}$	

5.1.1.3 Gypsum x standing wheat stubble experiment at "Federation Farm", near Narrabri

Treatments were cotton sown into wheat stubble incorporated with an aer-way cultivator to a depth of ~15 cm which had either 2.5 t/ha gypsum applied in 2000 or standing wheat stubble with no gypsum applied. The plots were 400 m long x 12 rows wide, and were arranged in a 3 RCB design. The experiment was irrigated with treated sewage effluent which is high in exchangeable Na and K, soluble Cl and has a moderately high EC. Statistical precision was improved by establishing 5 sampling plots within each individual treatment plot. Soil was sampled during June 2000 (baseline sampling), September 2001, January 2002, September 2003, April 2004, September 2005, April 2006, October 2007, April 2008, September 2009 and May 2010. Results presented in this report relate to samples taken from 2009 to 2010. At each time of sampling, 5-cm diameter soil cores were extracted from each plot with a tractor-mounted soil corer from the 0-10 cm, 10-30 cm, 30-60 cm, 60-120 cm and 120-180 cm depths. The previously-described static chambers were used to sample greenhouse gas emissions after operations such as tillage/stubble incorporation and irrigation during the 2009-10 cotton-growing season.

5.1.1.4 Gypsum x standing wheat stubble experiment at "Windmill Farm", near Ashley

Treatments were intended to be cotton sown into standing or incorporated wheat stubble, which had either 2.5 t/ha gypsum applied during March 2006 or remained untreated in a 2 RCB design. Due to a combination of drought/lack of irrigation water, poor wheat establishment and changing grower priorities, the full wheat stubble management treatments had not been implemented by December 2008. Even though soil sampling had been conducted from 2005 to 2008 on the assumption that the experiment would be implemented as this had not occurred by the end of 2008, no further sampling took place.

5.1.1.5 Comparison of cotton-corn (stubble burnt/incorporated) with cotton-wheat (standing wheat stubble/no-tillage "New Haven", Narromine

A split-field trial under sprinkler irrigation had been established by the collaborating grower since 2006. An EM-38 survey was conducted during 2009 to determine spatial variability, and soil (clods and disturbed bulk soil) sampled using a paired sites design (10 pairs) from the 0-10 cm and 10-30 cm depths during September 2009 and September 2010. Cotton was sown during the 2009-10 cotton season, wheat during the winter of 2010 and sorghum during summer 2011. Both wheat and sorghum were sown with no-tillage. Plant dry matter was sampled at crop maturity, and grain/lint yields hand-picked at harvest.

5.1.2 Application of organic and inorganic amendments to dryland Vertosols and their effects on soil quality and crop yield

5.1.2.1 On-farm experiment on soil amendment x application depth near Brigalow, Qld.:

Dryland cotton soils in the southern Darling Downs are frequently characterised by sub-optimal K availability, and high subsoil salinity and sodicity. Following a request by Mr. Wade Bidstrup, an experiment was established during 2005 in one of his fields at Brigalow (near Dalby) to evaluate the effects of some selected management practices and amendments on soil quality, and crop growth and yield. Although replicated, a formal experimental design was not used. Exchangeable K concentration in the surface 0.10 m of this field was < 1 cmol (+)/kg, and declined exponentially with increasing depth, average chloride concentration in the 0.6-1.2 m depth was of the order of 550 mg/kg OD soil and ESP 22. The experimental treatments, imposed after zero-tillage on individual plots 50 m x 24 m and replicated three times, were as follows: (1) Ripping alone to an average depth of 0.5 m; (2) Deep application (0.5 m) of P, Zn and K; (3) Deep application (0.5 m) of P and Zn; (4) Surface application and incorporation (no ripping) of cattle manure at a rate of 16 t/ha; (5) Gypsum at a rate of 9 t/ha followed by ripping; (6) Gypsum at a rate of 9 t/ha followed by ripping, and deep application of P, Zn and K. In all treatments P was applied at a rate of 11 kg P/ha in the form of mono-ammonium phosphate (MAP), K at a rate of 55 kg K/ha as potassium sulphate, and Zn at a rate of 3.5 kg Zn/ha as zinc sulphate. Wheat was sown during winter 2005, cotton during 2006-07 summer and sorghum during 2007-08 summer. Due to poor rainfall during 2005 the wheat crop failed but cotton and sorghum yielded well due to good in-crop rainfall in subsequent years. The treatments were imposed during April-May 2005, and soil sampled from the experiment during July 2005, and June 2006 and 2007, and July 2008. Two 5-cm diameter soil cores were extracted from each plot with a utility-mounted soil corer from the 0-10 cm, 10-30 cm, 30-60 cm and 60-120 cm depths. The experiment was terminated after harvest of the 2007-08 sorghum crop in June 2008. Cotton lint, and wheat and sorghum grain yields were determined by hand-picking. Soil and data analyses were completed by February 2009.

5.1.3 Sowing two cereal rotation crops (winter cereal fb. summer cereal) after cotton

5.1.3.1. Comparing a cotton-wheat-sorghum sequence with a cotton-wheat sequence on soil carbon

An experiment was established at “Merrowie” near Hillston during October 2008 using 3RCB design, comparing two cropping sequences, *viz*. cotton-wheat-sorghum vs. cotton-wheat on soil carbon stocks. Individual plots were 530 m long and 48 1-m rows wide. The experiment was planned to run for 6 years. Cotton was sown during October 2008 and wheat the following winter. Unfortunately due to the collaborating agronomist departing on leave during December 2009, the summer sorghum crop was not sown, and hence, the experiment was sown to a wheat crop that was sprayed out and followed by cotton in 2010 summer. The originally intended cropping sequence will be implemented form now on. An EM-38 survey was conducted during 2008 to determine spatial variability, and soil sampled from the 0-10 cm and 10-30 cm depths during 2008 and 2010. Plant dry matter was sampled at crop maturity, and grain/lint yields hand-picked at harvest. Concurrently unreplicated observation plots of both cotton and rotation phases of a cotton-wheat-sorghum sequence were established in Field D1, adjacent to the experiment described in section 4.1.1.2, and soil sampled from the 0-10 cm and 10-30 cm depths during September 2008, 2009 and 2010.

5.1.4 Ancillary experiments

5.1.4.1 Carbon contribution by sorghum roots

The contribution of carbon by sorghum roots grown under conventional tillage and no-tillage (sown into standing wheat stubble) was measured during the summer of 2011 in adjacent plots in Field C1, adjacent to the experiment described in section 4.1.1.1. The experiment was sown after good spring and summer rains, but were furrow irrigated with 100 mm of water when in-crop rainfall was insufficient to meet evaporative demand. The rows (beds) were spaced at 1-m intervals with vehicular traffic being restricted to the furrows. Measurements were made of root growth in the surface 10 cm with the core-break method and that in the 10-100 cm depth with an I-CAP image capture system and a minirhizotron, and C and N concentrations in roots. DM and grain was measured at crop maturity. Root images were analysed with RooTracker 2.03.

5.1.4.2 Carbon contribution by corn roots

Corn root growth was measured in an experiment at the Australian Cotton Research Institute, near Narrabri during the summers of 2007-08 and 2008-09 in Field C1, adjacent to the experiment described in section 4.1.1.1. The experiment consisted of four cropping systems: continuous cotton, continuous corn, cotton-wheat and cotton-corn rotations sown in plots 20 m long and 8 rows wide. The experiment was designed such that both phases of the rotation were sown every year in the rotation treatments. The experiment was sown after good spring rains, but were furrow irrigated with 100 mm of water when in-crop rainfall was insufficient to meet evaporative demand. The rows (beds) were spaced at 1-m intervals with vehicular traffic being restricted to the furrows. Corn root growth was measured only in the corn monoculture and cotton-corn rotation. Cotton roots were not monitored in this experiment. Measurements were made of root growth in the surface 10 cm with the core-break method and that in the 10-100 cm depth with a minirhizotron and an I-CAP image capture systems, and C and N concentrations in roots. DM and grain was measured at crop maturity. Root images were analysed with RooTracker 2.03.

5.2 Laboratory experiments

5.2.1 <u>Modelling soil evaporation from beds where wheat stubble was either incorporated or retained *in-situ*</u>

The objective of this study was to develop a model with easily determined input variables that could be used by cotton consultants, extension staff and growers to predict evaporative water losses from wet or moist bed surfaces (e.g. after a shower of rain), thus facilitating planning for sowing cotton crops.

Cores with a diameter of seven cm were extracted from the surface of beds in cotton-wheat and cotton-wheat-vetch rotations in the experiment in field D1 (section 4.1.1.2) during December 2008, February 2009 and March 2010. Five cores were extracted from each of these treatment plots in every replication, thus totalling 15 cores per treatment. In addition, five cores were extracted from an adjacent buffer zone bare fallow within the experimental area. The cores were saturated and excess water allowed to drain. The cores were then allowed to dry our by evaporation under varying drying condition, *viz*. laboratory bench, open air, combination of the two). The cores sampled in February 2009 were subjected to 2 wetting/drying cycles, whereas the cores sampled at other times were subjected to a singe wetting drying cycle. During each drying cycle, evaporation from a free water surface was measured with an evaporimeter, radiation obtained from meteorological records and ambient temperature measured with a 10K NTC thermistor datalogger (TinyTag® TG-4080). After completion of each drying cycle, the cores were oven-dried at 110^{o} C, weighed, and the stubble separated from the soil by washing over a 4-mm sieve. The washed stubble was then dried and weighed. The results (cumulative evaporation) were fitted to a 3-parameter power function. Empirical models were developed using best subset and stepwise linear multiple regression analysis using independent variables such as field bulk density, initial soil water content, stubble amounts and their management (surface mulch or incorporated), radiation and potential evaporation from a free water surface. The model was field validated during February 2011 by comparing samples taken from fields where wheat stubble had either been incorporated or retained *in situ* with values derived from the model. Data was analysed using regression analyses and Student's T-test.

5.3 Measurements and data analyses

5.3.1 Soil quality (physical and chemical properties)

Air-dried soil was passed through 2 mm-sieve and the following tests carried out: pH (in 0.01M $CaCl_2$); electrical conductivity, $EC_{1:5}$ (in a 1:5 soil:water suspension); nitrate-N[1] (with a nitrate electrode pre-calibrated with the Kjehldahl method and from 2007 onwards with the Kjeldahl method alone after extraction with 0.02M K_2SO_4); and exchangeable Ca, Mg, K and Na (after extraction with alcoholic 1M NH_4Cl at a pH of 8.5; commonly described as the "Tucker" method). These data were used to derive several sodicity indices: exchangeable sodium percentage, ESP [= (exchangeable Na/Σexchangeable cations) x100], electrochemical sodicity index, ESI (= $EC_{1:5}$/ESP) and $EC_{1:5}$/ESC ratio (ESC, exchangeable sodium content). Total soil organic carbon (SOC) was determined by the wet oxidation method of Walkley and Black on soil which had been passed through a 0.5 mm-sieve. All chemical analyses are those described in the "Australian Laboratory Handbook of Soil and Water Methods"[2]. The SOC was expressed in t/ha, by multiplying their concentration in each depth interval by the bulk density and the depth increment, followed by summing up all the depth intervals. Soil Cl was determined by measuring its concentration by titration with $AgNO_3$ of a saturated paste extract using a chloridometer[3].

Surface bulk density was measured on both soil clods after coating with paraffin wax[4] and on air-dried aggregates (1-10 mm diameter) with the kerosene saturation method[5], and the bulk density expressed as a weighted mean (33:67 aggregates: clods). Bulk density in other depths was determined on soil clods (experiments at ACRI, Narromine and Hillston, sections 5.1.3.1 and 5.1.1.5) or 5-cm diameter cores extracted as previously described after oven-drying at 110 ^oC (Field D1 at ACRI, section 5.1.1.2) after coating with paraffin wax. Complete shrinkage curves were determined only where clods were used. Soil water retention was determined with the filter paper method[4].

5.3.2 Field measurements

Surface soil water content was determined gravimetrically whereas that in depths > 20 cm was measured with neutron moisture meter (CPN-503 DR Hydroprobe®) that had been calibrated *in situ*[6].

Root growth in the surface 10 cm m was measured with the core-break method[7]. The live roots in a sub-sample of the cores were separated from the dead material after washing. Washing root samples involved soaking them in warm water containing a solution containing a 2:1 10% sodium hexametaphosphate: 1 M sodium hydroxide for a period of 4-6 hours. Once dispersed, the suspension was washed through a 0.2 mm sieve. The remaining silt and sand material were separated from the root and other organic material by flotation and decantation. The remaining organic material (including roots) were then stained with a 0.1% congo red

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[1] Nitrate-N was measured only in ACRI's cotton-wheat-vetch experiment (see section 5.1.1.2). Due to malfunctioning of the nitrate analyser (managed by CSIRO at ACRI) results for 2009 were discarded.

[2] Rayment, G.E., and Higginson, F.R. 1992. *Australian Laboratory Handbook of Soil and Water Methods, 1st edition.* Inkata, Melbourne and Sydney.

[3] Beatty, H.J., and Loveday, J. 1974. Soluble cations and anions. In '*Methods for analysis of irrigated soils*'. *Technical Communication No. 54*. (Ed J Loveday) pp. 108-117. Commonwealth Bureau of Soils, Commonwealth Agricultural Bureau: Farmham Royal, Bucks, UK.

[4] McKenzie, N., Coughlan, K., and Cresswell. 2005. *Soil Physical Measurement and Interpretation for Land Evaluation,* 1st edition. CSIRO publishing, Collingwood.

[5] McIntyre, D.S., and Stirk, G.B., 1954. A method for determination of apparent density of soil aggregates. *Aust. J. Agric. Res*. **5**, 291-296.

[6] Greacen, E.L. 1981. S*oil water assessment by the neutron method.* CSIRO publishing, East Melbourne.

[7] Smit, A.L., Bengough, A.G., van Noordjwijk, M., Pellerin, S., van de Geijin, S.C. (Eds). *Root methods: A Handbook.* Springer-Verlag, Berlin, Heidelberg & New York.

solution for a period 4-8 hours (depending on age of crop), followed by washing in absolute alcohol (supermarket grade). The congo red stains the live roots in the sample a bright red colour, whereas the dead organic material remain black. The live roots were separated from the dead material using a forceps under a bright light. Root separation was done by spreading the sample in a shallow white, plastic tray. The trays were filled with ~5 mm of water. Once the live roots were separated from the dead material, they were stored in a 25% alcohol solution until the length was measured using a modified Newman's line interception method or scanned and measured with WINRHIZO® software. The root samples were then oven-dried, weighed and nitrogen and carbon concentration measured by combustion with a LECO CHN 2000 analyser. Relationships were derived between root number, root length and root weight, and the root length and weight in each core estimated. Relative root length (root weight /root length) was also calculated. Root growth in the 0.10 to 1.0 m depth was measured at 10 cm depth intervals with a "Bartz" BTC-2 I-CAP image capture system®. The video camera part of the image capture system was inserted into clear, plastic acrylic minirhizotron tubes (50 mm diameter) installed within each plot, 30^o from the vertical. Measurements of roots were made 4-5 times during the crop growing season, at approximately 3-4 week intervals. Root images were captured in two orientations, left and right side of each tube, at each time of measurement and analysed with RooTracker 2.03® to estimate selected root growth indices. The data for each orientation and over the entire measured profile were summed to assess root growth over a 360^o plane of vision. The indices evaluated were the length and number of live roots at each time of measurement, number and length of roots which died (i.e. disappeared between times of measurement) and net change in root numbers and length. The above, together with the previously-described relative root lengths and root C concentrations were used to calculate several other indices of root growth; viz. (1) Root length per unit area to a depth of 1 m, L_A; (2) Root carbon at end of season, C_{root} = Sum of net changes in root carbon between times of measurement in all depths where, for individual depths and between times of measurement, the net change in root carbon was calculated as: Net change in root length x Relative root length x Root carbon concentration) (3) Root carbon added to the soil during season, C_{lost} = Sum of root carbon added to soil due to root death between times of measurement in all depths where, for individual depths and between times of measurement, root carbon added to soil was calculated as: Length of roots which died x Relative root length x Root carbon concentration; (4) Root carbon which could be potentially added to SOC, $C_{total} = C_{root}$ (2) + C_{lost} (3).

Penetrometer resistance was measured only in the experiment in D1 with the objective of assessing trafficking effects of the "Mulch manager". Penetrometer resistance to depth of 0.45 m was measured before and after trafficking at 15 mm depth increments in 6 sites (3 insertions per site) selected at random in each plot in wheel-tracked furrows with a Rimik® CP10 recording cone penetrometer fitted with a standard 30o circular stainless steel cone of 12.83 mm diameter and a 9.83 mm diameter shaft. Gravimetric water content was measured at 0.10 m depth intervals in soil sampled at the same time from the same locations with a tractor-mounted soil corer. Penetrometer readings were adjusted to a standard water content of 0.275 g/g (~field capacity)[1] and pre- and post-trafficking values compared with a Students t-test.

Green house gas monitoring was conducted at regular intervals, triggered by key events in the system, such as slashing/incorporation, irrigation and fertiliser application. Emissions were measured in Fields C1, D1 and "Federation Farm" 150mm diameter static chambers, with a 150mm head-space. These were capped for 2 hours prior to atmospheric sampling. A 25mL air sample was taken in an Exetainer vial and analysed by multi-column GHG GC: N_2O, CO_2, CO and CH_4. This methodology is suitable for detecting differences between treatments, but makes emission accounting difficult due to the sporadic nature of the sampling program. Lids

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[1] Busscher, W.J., Bauer, P.J., Camp, C.R., and Sojka, R.E. 1997. Correction of cone index for soil water content differences in a coastal plain soil. *Soil Till. Res.* **43**, 205-217.

were removable to allow semi-permanent installation, and could be fitted with septa for one-off sampling or septa and Tedlar® baffle combination to allow for multiple samplings from a single chamber with Exetainer® sampling tubes and gas-tight syringes. Due to the highly labour-intensive nature of their operation, sampling was limited to emissions associated with events such as tillage, irrigation, laser-levelling and fertiliser application.

Black root-rot incidence in the rotation experiment in Field D1 was assessed by Mr. P. Lonergan of the Plant Pathology unit at ACRI by sampling two transects in each cotton plot, one at the head ditch end and the other at the tail ditch end. From each plot 160 plants were dug up and the tap root assessed. Severity of the disease was established by rating the percentage length of the tap root with characteristic blackening using a scale of 0-10, where 0 = no blackening, 1 was >0 and ≤10%, 2 was >10% and ≤20%, 3 was >20% and ≤30%, 4 was >30% and ≤40%, 5 was >40% and ≤50%, 6 was >50% and ≤60%, 7 was >60% and ≤70%, 8 was >70% and ≤80%, 9 was >80% and ≤90% and 10 was >90% and ≤100% of the tap root affected.

Agronomic measurements included plant mapping, plant dry weight and crop yields. In all sites multiple locations (3/plot in on-station experiments and 10-15/plot in on-farm sites) of 1 m^2 were sampled. Yield in on-station experiments was assessed by mechanically-picking cotton or harvesting grain from the entire plot. Nitrogen and carbon concentration in vetch dry matter was measured by combustion with a LECO CHN 2000 analyser.

Cotton fibre quality parameters assessed (by the CSIRO fibre quality laboratory) were fibre length, strength, short fibre index, uniformity, elongation and micronaire. Wheat grain quality parameters were protein concentration, falling numbers and screenings.

5.3.3 Desktop assessment of greenhouse gas emissions associated with farming practices

Greenhouse gas emissions (as carbon dioxide equivalents, CO_2-e) associated with farming operations, herbicide and fuel production and transport were estimated from available sources[1] by relating them to diesel and electricity consumed. Estimates were made for the two long-term experiments at ACRI and the dryland experiment at Brigalow (sections 5.1.1.1, 5.1.1.2, 5.1.2.1). Nitrous oxide emissions from N fertiliser and legume cover crops were based on the average figure 0f of 0.3% of N inputs reported by Grace (2006)[2]. Assuming that 60% of soil carbon losses were attributable to those due to erosion (in sediments) and runoff (as dissolved organic carbon)[3], carbon dioxide emissions from soil were calculated from the net sequestration rates for the above mentioned sites reported in Table 4.

Detailed records were maintained of labour requirements associated with both setting up and in-field operation of the "mulch manager" in its early and final versions. Detailed records were also kept of fuel use, herbicide application rates and costs. Fuel use and greenhouse gas emissions (as carbon dioxide equivalents, CO_2-e) associated with vetch management, herbicide and fuel production and transport were estimated from available sources. The above information was used to assess labour requirements, and greenhouse gas emissions associated with herbicide and fuel production for three developmental stages of the "Mulch manager".

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[1] (i) Chen, G., and Baillie, C. 2007. Development of EnergyCalc – *A tool to assess cotton on-farm energy uses* (NCEA Publication 1002565/1). University of Southern Queensland,Toowoomba, Qld.
(ii) Audsley, E., Stacey, K., Parsons, D.J., and Williams, A.G. 2009. *Estimation of the greenhouse gas emissions from agricultural pesticide manufacture and use*. Cranfield University, Cranfield, UK.
(iii) Scott, F. 2009. Personal Communication.

[2] Grace, P. 2006. *Reducing nitrogen losses from cotton rotation systems*. Final report for project no. GCRC4C, 24 pp. CRDC, Narrabri, NSW.

[3] (a) Gregorich, E. G., *et al*. 1998. Carbon distribution and losses: erosion and deposition effects. *Soil & Till*. Res. **47**, 291-302. (b) King, A. P., *et al.* 2009. Annual carbon and nitrogen loadings for a furrow-irrigated field. *Agric. Water Manage.* **96**, 925-930.

5.3.4 Estimating soil organic carbon storage and sequestration

Soil organic carbon (SOC) concentration (%) in each depth interval was converted to carbon content (t/ha) as:

SOC content = SOC concentration x oven-dried bulk density (Mg/m^3) x depth interval (m).

SOC concentration is usually reported on an oven-dried basis. Soil carbon storage at any one time was determined by summing carbon contents of specified depth intervals in a profile.

A potential source of error when evaluating soil carbon storage and sequestration is the use of a fixed depth in the calculation rather than an equivalent soil mass[1] as the former does not account for possible changes in bulk density either over time or between treatments and when the entire profile is not sampled. In other words, carbon storage should be reported on an equal mass of soil between the times being compared. Methodology for this is described by Ellert and Bettany (1995)[2]. Carbon contents were calculated with the fixed depth method (FD) and Ellert and Bettany's method (ESM) for a subset of the results from the experiments in Field D1 and C1 (sections 4.1.1.1 and 4.1.1.2) for the period 2002 to 2009 to ascertain the magnitude of differences, if any between the previously-mentioned methods, and values compared using linear regression analysis.

SOC sequestration is defined as the rate of change in SOC storage with time, and is usually determined by fitting a linear regression model (y = mx + c) between time (in years) and SOC storage measured at intervals of 1-3 years or more (Powlson *et al*., 2011)[2].

5.3.5 Drainage estimation with the chloride mass balance method

Drainage was measured with the chloride mass balance method in all treatments in the tillage/rotation experiment and cotton/wheat/vetch rotations experiment at ACRI; gypsum x standing wheat stubble trial at "Federation Farm"; and the soil amendment experiment at Brigalow. Water samples were taken from the head-ditch during each irrigation at each experimental site. The water samples were analysed for pH_w, EC_w (salinity), Cl by titrating with $AgNO_3$, nitrate-N (with the Kjeldahl method), and Ca, Mg, K and Na with an atomic absorption spectrophotometer[3]. At each sampling site soil water content in the 20-120 cm depth interval was measured with a neutron moisture meter (CPN 503-DR Hydroprobe) which had been calibrated *in-situ*. Soil water content in the soil surface was measured gravimetrically.

Previously published models[4,5] were used to estimate deep drainage assuming steady state conditions (Eqn. 1) and transient state conditions (Eqn. 2). Assuming steady state conditions, deep drainage was calculated as:

$$DP_z = I\left(\frac{C_i}{\overline{C_z}}\right) \tag{1}$$

where DP_z is the deep drainage (mm/wk) at soil depth z (mm); I is infiltration of irrigation and rain application rate (mm/wk); C_i is average chloride concentration of irrigation water (mmol/l); $\overline{C_z}$ is the concentration of chloride in the drainage water at depth z (mmol/l),

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[1] Ellert, B.H. and Bettany, J.R. 1995. Calculation of organic matter and nutrients stored in soils under contrasting management regimes. *Can. J. Soil Sci*. **75**, 529-538.

[2] Powlson, D. S., Whitmore, A. P., Goulding, K. W. T. 2011. Soil carbon sequestration to mitigate climate change: a critical re-examination to identify the true and the false. *European J. Soil Sci*. **62**, 42-55.

[3] Rayment, G.E., and Higginson, F.R. 1992. *Australian Laboratory Handbook of Soil and Water Methods, 1st edition*. Inkata, Melbourne and Sydney

[4] USSL (United States Salinity Laboratory) 1954. *Diagnosis and improvement of saline and alkali soils*. Agriculture handbook No. 60. USDA, Washington DC

[5] Slavich, P.G., Petterson, G.H., and Griffin, D. 2002. Effects of irrigation water salinity and sodicity on infiltration and lucerne growth over a shallow watertable. *Aust. J. Exp. Agric*. **42**, 281-290.

calculated from the mean of the soil chloride concentrations pre- and post-crop. Assuming transient state conditions, deep drainage was calculated as:

$$\frac{S_2 - C_i/(L_f\lambda) - S_{im}}{S_1 - C_i/(L_f\lambda) - S_{im}} = exp\left(\frac{-D\lambda}{z}\right) \qquad (2)$$

Where S_1 and S_2 are the masses of chloride stored per unit volume of soil in the (0-z) layer (kg/m^3) at the start and end of the desired monitoring period; C_i is the weighted average chloride concentration of the irrigation water and rainfall (kg/m^3); L_f is the net leaching fraction [i.e. D/(I+R)] where I is the depth of applied irrigation water and R is the depth of rainfall; $-1<L_f<1$; dimensionless); D is the net amount of drainage (m, positive downwards); z is the depth at which net drainage is assessed. λ and S_{im} are defined by the assumption that the relationship between the chloride concentration of the drainage water at depth z (C_z, kg/m^3) and the mass of chloride per unit volume of soil stored in the (0-z) layer S(0-z) is linear, ie. $C_z = \lambda\ (S_{(0\text{-}z)}\text{-}S_{im})$. The λ term (m^3 soil/m^3 water) can be interpreted as the inverse of the transport pore space of the (0-z) layer and S_{im} (kg/m^3) can be interpreted as the mass of chloride per unit volume of soil in the (0-z) layer which is occluded from the transport pore space. The λ and S_{im} terms are calculated from the soil sampling data at the start and end of the assessment period.

The chloride concentration of drainage water (C_z) for each sampling time was calculated as:

$$C_z = \frac{C_{SP(z)}\theta_{SP(z)}}{\theta_{g(z)}} \qquad (3)$$

where $C_{SP(z)}$ is chloride concentration in the saturation extract at depth z (mmol/l); $\theta_{SP(z)}$ is the water content of the saturation paste at depth z (kg/kg); $\theta_{g(z)}$ is the water content at depth z (mm) at which drainage is assumed to occur (kg/kg).

The field saturated water content was estimated as 93% (a correction factor for entrapped air of 7%) of the total porosity, which was calculated from the bulk density. The mean soluble chloride content per unit volume of the 0-z layer for each sampling time was calculated as:

$$\overline{S}_{(0-z)} = 0.814 C_{SP(z)}\theta_{SP(z)}\rho_b \qquad (4)$$

where ρ_b is soil bulk density (kg/m^3); 0.814 accounts for anion exclusion (m^3/kg) and has been defined as the distribution factor[1].

The amount of irrigation water that infiltrated the profile (I) to a depth of 1.2 m was calculated as $I = \theta_{(0\text{-}1.2\ m)}\, t_2 - \theta_{(0\text{-}1.2\ m)}\, t_1 + ET_C$ where the difference in volumetric soil water content before ($\theta_{(0\text{-}1.2m)}\, t_1$ in mm) and after ($\theta_{(0\text{-}1.2\ m)}\, t_2$ in mm) sampling events (intervals of 7-14 days) plus any evapotranspiration (ET_C (mm)) was calculated for each site. The volumetric soil water content was measured with a neutron moisture meter (CPN 503-DR Hydroprobe) which had been calibrated *in situ*. The ET_c for each site was calculated as $ET_c = K_c \times (K_p \times E_{pan})$ where K_c is crop factor, K_p is pan coefficient, E_{pan} is evaporation from class A pan with green fetch (mm/day).

The total rainfall that occurred during the monitoring period was used to adjust the chloride concentration of the irrigation water (C_i) in equation 1 and 2 to account for dilution due to rainfall. Rainfall was collected and analysed for chloride concentration and was shown to be negligible, thus reducing the effective chloride concentration of the infiltrating water when combined with irrigation. If there was no rainfall during the monitoring period, no adjustment was made.

The deep drainage estimates from both models were tested for differences using regression analysis and Student's t-test to determine if chloride flux was in steady or transient state.

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[1] Slavich, P.G., Petterson, G.H., and Griffin, D. 2002. Effects of irrigation water salinity and sodicity on infiltration and lucerne growth over a shallow watertable. Aust. J. Exp. Agric. 42, 281-290.

Model accuracy was cross checked by comparing pre- and post-cropping season soil chloride concentrations with a paired t-test. If they differed significantly at the 95% probability level, then the chloride flux was assumed to have occurred under transient state conditions. If not, then they were assumed to have occurred under steady state conditions.

5.3.6 Estimating deep drainage using an EM38 in horizontal mode

An EM38 is an electromagnetic induction instrument that comprises of two electrical coils one metre apart - a transmitter at one end and a receiver at the other. A time varying magnetic field induces eddy currents in the soil and the magnitude is proportional to the electrical conductivity of the soil. Secondary magnetic fields are generated from these current loops in proportion to the current flowing in the loop. The receiver coil intercepts the secondary magnetic fields and the sum of the signals is amplified producing an output voltage that is converted to a reading on the display. An EM38 can be used to measure and map soil parameters such as salinity, water content and clay concentration.

The experimental sites were located at the Australian Cotton Research Institute (ACRI) near Narrabri, 'Glenarvon' near Wee Waa and 'Beechworth' near Merah North, NSW. The ACRI sites were a plot sown with a cotton-wheat rotation on permanent beds where wheat stubble was retained as *in situ* mulch (site 1) and the rotation experiment in Field D1 (experiment 5.1.1.2, site 2). The 'Glenarvon' site consisted of a plot sown with a cotton-wheat rotation where stubble was incorporated. At the 'Beechworth' site, there were three cropping sequences, continuous cotton, cotton-wheat, and cotton-dolichos sown between 1993 and 2000. The three treatments were sown with cotton during the 2000-01 and 2002-03 growing seasons, wheat during 2001 winter and sorghum during the 2001-02 growing season with stubble being incorporated.

Soil cores (0-120 cm) were taken from 2000 to 2003 in six sampling sites established in a diagonal transect at ACRI (site 1), Wee Waa and Merah North from the tail-drain to the head-ditch. Four cores were also taken from the same depth in each plot in the rotation experiment in Field D1 at ACRI during 2010 and 2011. Sampling was conducted immediately before sowing and after picking cotton. Air-dried soil was passed through a 2 mm-sieve and chloride concentration determined by $AgNO_3$ titration[1]. Soil water content in the 20-120 cm depth interval was measured at 7-10 day intervals during the cotton season with a neutron moisture meter which had been calibrated *in situ*, whereas that in the soil surface was measured gravimetrically. Drainage was estimated with the chloride mass balance method assuming either steady or transient state conditions as described previously. Measurements using an EM38 in the horizontal mode were made prior to sowing and after harvest for the 2000-01, 2002-03 and 2010-11 cotton growing seasons. The readings were taken at the same locations where soil was removed for chloride analysis.

A linear multiple regression model was derived between selected independent variables such as electromagnetic readings in the horizontal mode (EMH), soil parameters such as profile water content and exchangeable sodium percentage and the dependent variable, soil chloride concentration using data collected during the 2002-03 cotton growing season. The model was used to estimate soil chloride concentrations for the 2000-01 and 2010-11 cotton seasons and validated with actual soil chloride concentration. The estimated chloride concentrations were used in a chloride mass balance model to estimate deep drainage for 2000-01 and 2010-11 seasons. Measured values of Cl were also used to estimate deep drainage.

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[1] Beatty, H.J., and Loveday, J. (1974). Soluble cations and anions. In '*Methods for analysis of irrigated soils*'. *Technical Communication No. 54*. (Ed J Loveday) pp. 108-117. Commonwealth Bureau of Soils, Commonwealth Agricultural Bureau: Farmham Royal, Bucks, UK.

Table 2. Dataset from 2002-03 cotton season used in the stepwise linear multiple regression model. ESP, exchangeable sodium percentage; EM_H, electromagnetic induction measured in the horizontal mode; S**,** soil water storage in the 0-120 cm depth, pre, pre-season values; post, post-season values

		Chloride		ESP	EM_H		S	
Experimental Locations	Sites	meq/l			mS/m		mm	
		pre	post		pre	post	pre	post
ACRI (site 1)	1	1	1	4	58	50	491	391
	2	1	1	4	61	47	456	354
	3	1	1	4	71	44	445	355
	4	1	1	3	66	46	453	385
	5	1	1	3	55	43	440	341
	6	1	2	5	49	45	434	355
“Glenarvon”	1	1	1	6	79	67	251	208
	2	1	1	3	78	56	260	223
	3	1	1	3	79	63	268	218
	4	1	1	3	79	64	266	220
	5	1	1	3	78	63	305	239
	6	1	1	4	82	63	286	250
“Beechworth”	1	3	5	12	112	106	366	285
ex-Continuous Cotton	2	1	2	10	108	101	385	325
	3	9	7	16	114	124	381	313
	4	4	2	11	116	105	391	323
	5	5	6	14	103	113	349	302
	6	2	3	11	109	105	390	326
ex-Cotton-Wheat	1	6	5	12	119	110	367	295
	2	2	3	11	110	103	364	290
	3	3	4	13	114	112	355	281
	4	4	3	11	118	98	380	294
	5	5	4	13	115	101	369	290
	6	1	1	10	112	94	365	310
ex-Cotton-Dolichos	1	15	14	16	118	124	366	309
	2	7	10	17	110	116	392	316
	3	8	7	13	118	113	373	313
	4	5	4	13	118	103	390	311
	5	15	15	19	118	118	374	314
	6	3	4	15	119	106	384	318

5.3.7 Data analyses

In replicated experiments, all data were analysed with analysis of variance appropriate for the specified experimental design. In unreplicated split plot experiments (e.g. Narromine), where soil was sampled in paired transects, the results were analysed using Student’s t-test.

The results from the site at Brigalow, in which a formal experimental design was not used, were analysed using Generalised Linear Models (GLMs)[1]. Where possible, a fixed model consisting of treatment, year, depth and their interactions was used, with a random model of replications, plots and depth within plots. These models were restricted for some variables, as appropriate. Spatial correlations for plot and depth were fitted for exchangeable magnesium percentage (EMP), exchangeable sodium percentage (ESP) and $EC_{1:5}$/ESC only. Spatial correlations for other variables were too small to be resolved by this model, and were dropped.

The relationship between management practices such as tillage depth, rotation crop, dry matter inputs, N fertiliser and irrigation amounts, and climatic factors such as temperature,

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[1] McCullagh P., and Nelder, J.A. (1989). *Generalized Linear Models.* Chapman and Hall, London

rainfall (in-crop, fallow etc.), on lint yield, soil organic carbon sequestration, N use efficiency (yield/N in fertiliser) and water use efficiency (yield/total water) were evaluated with multiple linear regression analysis using results from past and on-going irrigated experiments on crop rotations and tillage systems conducted between 1993 and 2011 in the Lachlan, Namoi and Macquarie valleys of NSW. Analyses were conducted within each individual site and among all sites. The among site analysis was restricted to a single common treatment *viz*. cotton-wheat rotation due to confounding by the different treatments in each site. The influence of temperature within and between sites was further investigated with non-linear regression analysis.

5.3.8 Profitability

Profitability: Financial returns and profitability for each rotation were evaluated for the tillage/rotation (C1) and rotation (D1) experiments at ACRI by comparing cumulative gross margins per hectare and per ML of irrigation water applied. A gross margin is the gross income from an enterprise less the variable costs (costs directly attributed to the enterprise). Fixed costs such as depreciation, permanent labour and overhead costs are not included. Gross margin results were calculated using a cotton price of $450/bale and a seed price of $300/tonne and costing of all operations conducted on each treatment, including fallow management. The wheat price used was ‘Feed’ and ‘ASW’ $195/tonne, ‘AH’ $202/tonne and ‘PH14’ $235/tonne with the current discount system for low protein and bonuses for low screenings included. Where possible, 2011 prices have been used for inputs such as fuel, fertiliser, herbicides (including defoliants) and pesticides. The same output and input prices are used for each season’s results, in order to determine the rotation effects. Alteration of prices from year to year would confuse the rotation effect. Cotton price sensitivity testing was conducted using lint prices ranging from $350 to $550 per bale.

5.4 Development of the “Mulch Manager”

The objective of this study was to develop an economically and environmentally-acceptable management system which minimised trafficking and reduced the use of the more toxic herbicides for killing a prostrate cover crop in furrow-irrigated permanent beds in a Vertosol. The cropping system tested was one in which vetch (*Vicia villosa* L. Roth, *Vicia benghalensis* L.), a prostrate leguminous cover crop, was followed by row-cropped cotton. Our ultimate objective was to retain the vetch residues killed by the herbicides as *in situ* mulch into which the following cotton could be sown (Fig. 2). This report includes a summary of the development of an implement (“Mulch manager”) to manage vetch cover crops. Vetch has several issues and constraints which need to be addressed when its termination is under consideration:

- Vetch is a prostrate crop which forms adventitious roots through its lateral stems (also referred to as stolons or runners) and produces dry matter in the range of ~5-7 t/ha. The bulk can be reduced by mowing with a slasher mower. Depending on climatic conditions, this kills about 20-50% of the vetch. The remainder can be killed either by incorporation or by application of a knockdown herbicide such as Spray.Seed®. Mature vetch is tolerant of Glyphosate.
- Spray.Seed® is highly toxic and more costly than Glyphosate. A 20 L drum of Spray.Seed® is of the order of $A 215 and Glyphosate (Roundup®) $A 80.
- Survival of the prostrate vetch cover is enhanced through adventitious roots formed by the lateral stems. Personal observations by the authors suggest that adventitious root formation by the laterals is stimulated by mowing. Cutting the lateral stems can, however, minimise proliferation of adventitious roots.

The implement described in this report addresses the above constraints and issues in a single pass subsequent to mowing.

Fig. 2. Sprayed out vetch stubble

The initial design (Fig. 3a) consisted of a toolbar to which paired sets of parallel coulter discs were rigidly attached. The pairs of discs were located such that they ran on either side of the vetch plant line to a depth of ~2-4 cm, thus cutting off any lateral stems (Fig 3b). It was assumed that the discs would follow the bed contours, thus ensuring a uniform cutting depth. A set of nozzles that applied herbicide (Spray.Seed®) to the vetch plant line on bed surfaces was located between individual disc pairs (Fig. 3c). The nozzles were attached to a tank that contained the herbicide. The discs also minimised herbicide drift. While this design was successful in reducing Spray.Seed® application amounts and killing the vetch, it also resulted in winter weeds such as wild Phalaris (*Phalaris paradoxa* L.), milk thistle (*Sonchus oleraceus* L.), dead nettle (*Lamium amplexicaule* L.) and wild turnip (*Brassica tournefortii* L.,

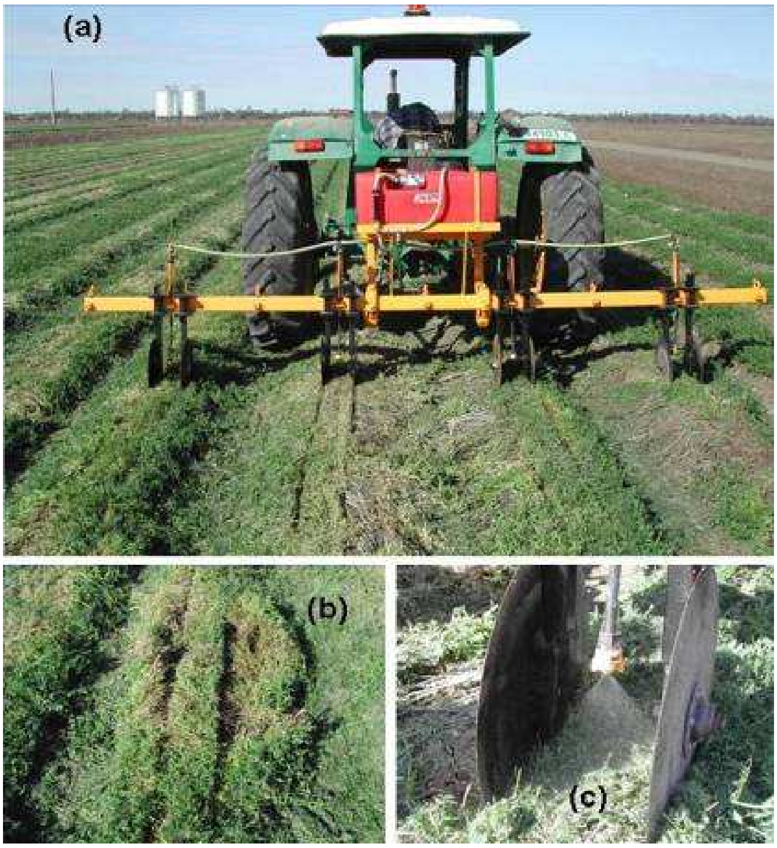

Fig. 3. Later design of mulching implement (Stage 2”). (a) Complete implement under field conditions (b) Close-up of strip cut by coulter discs (c) Close up of coulter-discs and nozzle

Raphanus raphanistrum L., *Rapistrum rugosum* L.) proliferating in the furrows, thus necessitating an additional application of a herbicide such as Roundup® with a boom sprayer. The implement was subsequently modified to include a second tank and a second set of nozzles that directed an appropriate herbicide such as Roundup® to the furrows to control winter weeds. In addition, the rigidly attached coulters discs were replaced with spring-loaded coulter discs as the cutting depth of the former was variable. Thus, the final design consisted of a toolbar to which were attached four sets of spring-loaded pairs of parallel coulter discs, one set of nozzles that applied herbicide (Spray.Seed®) to the bed surfaces located between individual discs, and a second set of nozzles located to directed Roundup® to the furrow (Figs. 4 and 5). The two groups of nozzles were attached to separate tanks which contained the two different herbicides. Limiting Spray.Seed® application to a narrow band between two coulter discs ensures that herbicide drift is greatly reduced, thus minimising non-target crop damage, and reducing exposure of farm workers to Spray.Seed®. Commercially available, "off-the-shelf" components (nozzles, coulter discs, tanks etc.) were used at all times. In summary, the three developmental stages of the vetch termination system were:

- Stage 1 – Mowing followed by applying Spray.Seed® with 2 passes of an 8-row boom sprayer ("No implement"). Occasionally, an additional application of Roundup® with a single pass of a boom sprayer was required.
- Stage 2 - Mowing followed by applying Spray.Seed® in a single pass with an intermediate stage of the implement (Fig. 3a) and Roundup® with a single pass of an 8-row boom sprayer ("Later stage");
- Stage 3 - Mowing followed by applying Spray.Seed® and Roundup® with the final version of the implement in a single pass (Fig. 4) ("Final design")

Fig. 4. Final design ("Stage 3") of mulching implement

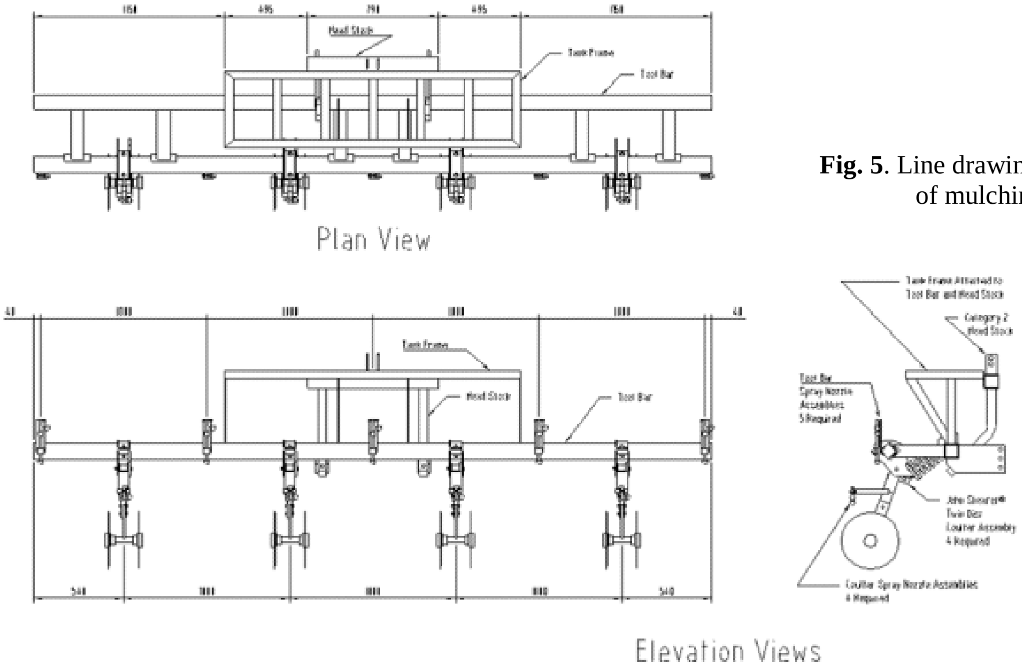

Fig. 5. Line drawing of final design of mulching implement

6. Key Results and Discussion

6.1 Cropping systems and soil organic carbon

6.1.1 <u>Estimating soil organic carbon (SOC) using the equivalent soil mass (ESM) method</u>

Comparison of a subset of SOC values (2000-2009) determined with both the ESM and fixed depth (FD) methods for the 0-30 cm, 0-60 cm and 0-120 cm depths for the experiments described in sections 5.1.1.1 (Field C1, ACRI) and 5.1.1.2 (Field D1, ACRI) with Student's t-test indicated although statistically significant differences were present (P < 0.001), these differences were very small (Fig. 6). In Field D1, for example, relative to the FD method, values determined using the ESM method differed by an average of 0% (range of -4% to +2%) in the 0-30 cm depth, 3% (range of 1% to 4%) in the 0-60 cm depth and 2% (range of 1% to 3%) in the 0-120 cm depth. Similarly, in Field C1 in comparison with the FD method,

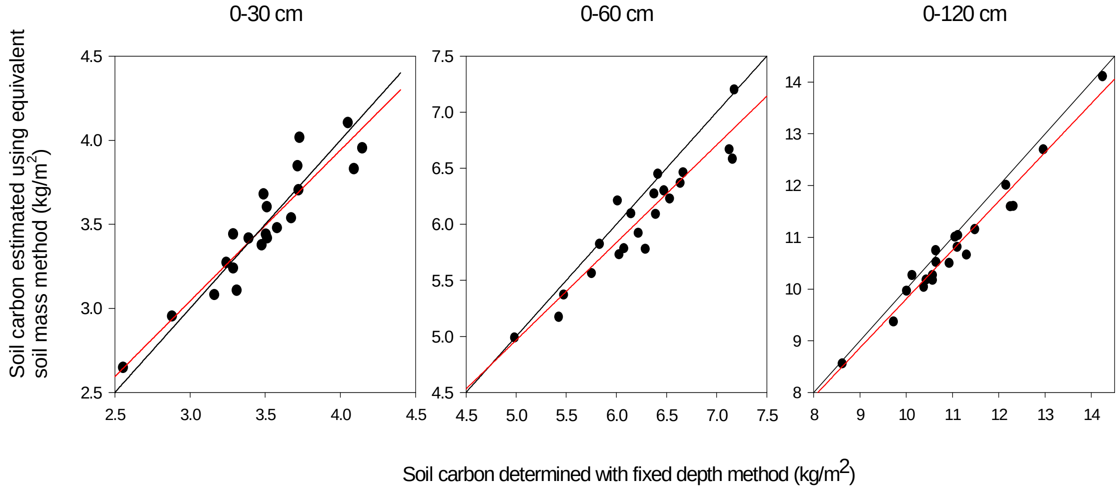

Fig. 6. SOC stocks in the 0-30 cm, 0-60 cm and 0-120 cm depths determined using the fixed depth (FD) and equivalent soil mass (ESM) methods in Field D1, ACRI (2002-2009)

values determined using the ESM method differed by an average of -4% (range of -20% to +22%) in the 0-30 cm depth, -3% (range of -8% to 8%) in the 0-60 cm depth and -3% (range of -5% to 5%) in the 0-120 cm depth, with the greatest variability occurring in the 0-30 cm depth where deeper tillage operations had taken place. The relatively small differences in Field D1 may be due to the fact that all treatments were sown on permanent beds. The low average differences suggest although it is justifiable to use the FD method, soil carbon stocks for shallow depths (e.g. surface 30 cm) where conventional tillage is practised may be more accurately determined with the ESM method. Soil carbon stocks can, however, be accurately determined with the FD method for depths deeper than the maximum depth of tillage (e.g. 0-60 cm or 0-120 cm depths).

6.1.2 Soil organic carbon stocks 2008-2010

Soil organic carbon stocks generally ranged between 50 and 70 t/ha in the 0-60 cm depth, although higher values were present in the tillage/rotation experiment and where a cotton-wheat-sorghum sequence was sown at ACRI (Table 3). The latter sequence resulted in a higher SOC than with cotton-wheat and was probably caused by the higher amounts of plant material that were retained in the field. Significant differences among treatments in the cotton/vetch/wheat rotation experiment at ACRI only occurred when a wet winter and spring

Table 3. Effect of cropping system on SOC stocks, 2008-2010

Site	**Cropping system**	**Soil organic C in the 0-60 cm depth (t/ha)**		
		2008	**2009**	**2010**
ACRI, Narrabri[1], NSW (Tillage/rotation experiment)	Conventional tillage/continuous cotton	69	-	-
	Permanent beds/continuous cotton	73	-	-
	Permanent beds/cotton-wheat (*in situ* mulch)	80	-	-
	P <	0.05	-	-
	SEM	2.2	-	-
ACRI, Narrabri, NSW (Cotton/vetch/ wheat rotations experiment)	Continuous cotton	58	62	52
	Cotton-vetch	66	60	54
	Cotton-wheat (incorporated), cotton phase	64	70	52
	Cotton-wheat (incorporated), rotation phase	57	69	62
	Cotton-wheat (*in situ* mulch)-vetch, cotton phase	59	67	54
	Cotton-wheat (*in situ* mulch)-vetch, rotation phase	62	63	59
	P <	ns	ns	0.001
	SEM	3.7	3.3	1.1
"Federation Farm" , Narrabri, NSW	The site had been laser-levelled during the 2009 winter. Treatments were, thus, not imposed and a baseline measurement taken during 2009 from all plots	- - -	69	- - -
"New Haven", Narromine, NSW[2]	Corn (burnt) fb. cotton-wheat (*in situ* mulch)	-	52	49
	Cotton-wheat (*in situ* mulch)	-	61	60
	t-value	-	-2.89	2.48
	P <	-	0.05	0.05
"Merrowie", Hillston NSW	Treatments only partially imposed due to absence of collaborator. Only values averaged among all treatment plots are reported	48	-	56
ACRI, Narrabri, NSW (Cotton/wheat/ sorghum rotation experiment)	Cotton-wheat-sorghum (mean of 3 years)	71.5		
	Cotton-wheat (mean of 3 years)	57.4		
	t-value	-2.41		
	P <	0.05		

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[1] Irrigation frequency did not significantly affect SOC storage and averaged 73 t/ha with "infrequent" irrigation and 76 t/ha with "frequent" irrigation. The site was not sampled in 2010 due to excessively wet conditions.

[2] Sampled only from 0-30 cm depth. Values for 2010 adjusted using ESM method.

coincided with a wheat crop in 2010. The additional dry matter associated with the vetch (Tables 7 and 9) did not contribute to soil carbon stocks, and may due to its low C/N ratio facilitating rapid microbial decomposition and consequent loss of C and N through a combination of plant uptake and gaseous emission.

Irrigation frequency in the tillage/rotation experiment at ACRI did not result in a significant difference in soil carbon stocks although there was a higher non-significant response with frequent irrigation. The absence of a significant response may be due to the fact as these sub-treatments had been implemented only since 2005-06 only two points in time (2006, 2008) had been sampled. The values of SOC in the 0-30 cm depth at “New Haven” (sprinkler-irrigated) were comparable to those in the 0-60 cm depths in the other sites, which were all furrow-irrigated. This may be caused by a higher concentration of SOC in the surface (range of 1.2-2.1 g/100g) with sprinkler-irrigation. In comparison with retaining stubble as *in-situ* mulch, SOC stocks were lower where stubble had been burnt.

6.1.3 Soil organic carbon sequestration 1993-2010

SOC sequestration rates were, generally, negative for extended periods in many sites (Table 4). In other words, there was a net loss of carbon each year. In some sites such as Field D1, Federation Farm and “Glenarvon”, the low R^2 (≤ 0.15) values suggest that SOC sequestration rates, although negative, were effectively similar to a situation where there was no net change with time (i.e. the line was horizontal). It is notable that in these sites, cotton was sown for much of the time either into standing crop stubble or after minimum tillage (e.g. aer-way cultivator).

Table 4. SOC sequestration rates (t C/ha/year) in the 0-60 cm depth in the Lachlan, Macquarie and Namoi valleys of New South Wales. A single average value is given for sites where there were no significant differences among treatments. Only sites where measurements were made for 6 years or more are included in this table.

Site	Years	SOC sequestration rate	R^2
Field C1, ACRI, Narrabri, NSW	1993-2008	-1.25	0.61***
(Tillage/rotation experiment)	1993-2000	-1.54	0.34**
	2000-2008	-2.38	0.45*
Field D1, ACRI, Narrabri, NSW	2002-2010	-0.05	0.0004ns
(Cotton/vetch/wheat rotations experiment)			
“Federation Farm” , Narrabri, NSW:	2000-2009		
Gypsum (stubble incorporated)		-0.81	0.04ns
No gypsum (*in situ* mulch)		-1.50	0.12**
“Beechworth”, Merah North, NSW	1993-1999	-4.67	0.55***
	1999-2004	2.10	0.23**
“Glenarvon”, Wee Waa	1993-2001	-1.60	0.04ns
“Auscott”, Warren	1993-2009	-1.74	0.16***
	1993-1998	-5.24	0.37***
	1998-2009	0.04	0.01ns

In other sites (“Beechworth”, “Auscott-Warren”), carbon losses were followed by a stabilisation or increase in sequestration rates. The causes of these decreases, however, differed. At “Beechworth”, a very sodic soil was irrigated with bore water that became increasingly saline with time leading to a reduction in crop growth, and thus, carbon sequestration. By 2000, the soil condition had deteriorated to the extent that the 2000-01 cotton crop was a failure. The grower responded by irrigating with good quality river water, and substituted an irrigated/fertilised wheat-irrigated/fertilised sorghum sequence from 2000-2002 followed by a cotton-wheat sequence thereafter. The wheat-sorghum sequence returned above and below-ground dry matter amounts of the order of 36 t/ha. The net result was an increase in sequestration rate from 2000 to 2004. At “Auscott-Warren”, the sharp decline in SOC stocks during the 1990’s may have been due to crop stubble being burnt during the initial stages of the experiment. In addition, root-borne diseases such as black-root rot was prevalent in the cotton crops. After termination of the trial in 2001, the combination of sowing cotton in to cereal stubble and permanent beds appears to have resulted in the decline in SOC being arrested.

6.1.4 Temperature and soil organic carbon

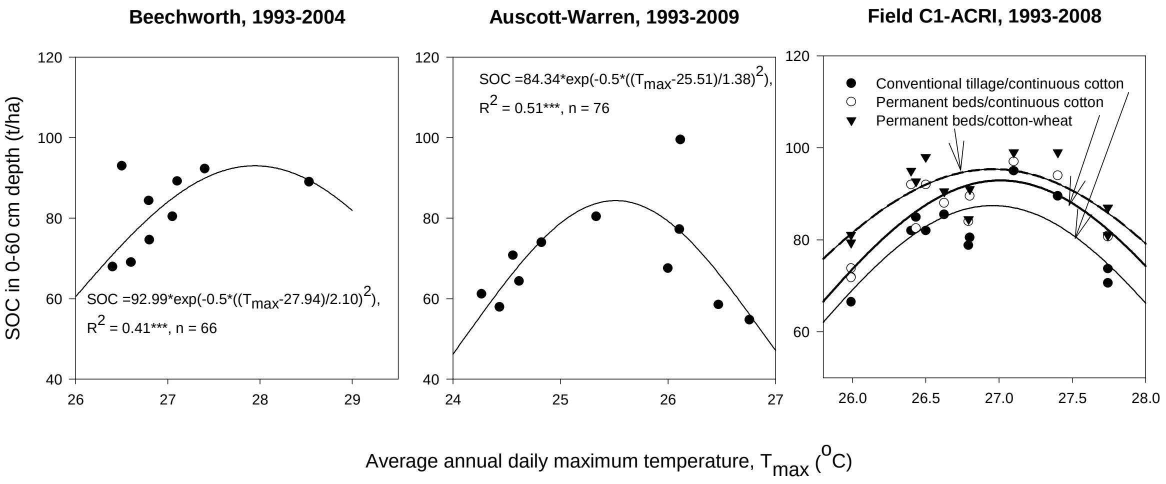

Fig. 7. Effect of annual average daily maximum temperature, T_{max}, on soil organic carbon stocks in the 0-60 cm depth at "Beechworth", "Auscott-Warren" and Field C1, ACRI. Fitted equations for Field C1 at ACRI are as follows: Conventional tillage/continuous cotton: $SOC = 87.43*exp(-0.5*((T_{max}-1.40)/27.0)^2)$, $R^2 = 0.66^{**}$; Permanent beds//continuous cotton: $SOC = 92.90*exp(-0.5*((T_{max}-1.48)/27.0)^2)$ $R^2 = 0.72^{**}$; Permanent beds/cotton-wheat : $SOC = 93.33*exp(-0.5*((T_{max}-1.71)/27.0)^2)$ $R^2 = 0.51^{**}$.

The decrease in SOC stocks at "Beechworth" during the 1990's may partly be due to sub-optimal temperatures (Fig. 7). At "Auscott-Warren" a combination of sub- and supra-optimal temperatures (Fig. 7) and black-root rot during the 1990's resulted in a period of decreasing SOC followed by a period when they appeared to stabilise. In field C1 at ACRI due to supra-optimal temperatures' during the 2000's in combination with deteriorating water quality[1] there was more rapid loss of SOC relative to the 1990's, although the cotton-wheat rotation appears to be less sensitive to temperature than either of the continuous cotton treatments. The data for the three sites suggest that there may be an optimal temperature with respect to SOC sequestration; *viz*. 27.9 °C at "Beechworth", 25.5 °C at "Auscott-Warren" and 27 °C at ACRI (Fig. 7).

The impact of temperature on SOC stocks was further investigated by comparing SOC under the same cropping system (cotton-wheat rotation sown on 1-m permanent beds) at several different locations in which cotton is grown in Australia; *viz*. Hillston (latitude -33.4, longitude 145.4), NSW, Warren (latitude -31.8, longitude 147.8), NSW, Narrabri, NSW (latitude -30.2, longitude 147.8) and Emerald, Queensland (latitude -23.5, longitude 148.1). Details of the Emerald experiment (terminated in 2002) have been reported previously[2]. Briefly, it consisted of four cotton-based cropping systems (early cotton sown between August and October; wheat sown in May, sprayed out and followed by early cotton; wheat allowed to mature, harvested and followed by late cotton sown between October and December; and grain sorghum followed by cotton) sown on 1-m and 2-m wide permanent beds.

SOC storage increased on moving northwards from Hillston in southern NSW to Narrabri in northern NSW (Fig. 8). Moving further north to Emerald in central Queensland resulted in only a small (non-significant) increase in SOC storage. These changes in SOC with latitude were closely related to changes in annual average daily maximum temperature, which in turn

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[1] Hulugalle, N.R., Weaver, T.B., and Scott, F. (2005). "Final report to Cotton Research and Development Corporation on CRDC Project no. CRC 45C (Maintaining profitability and soil quality in cotton farming systems)", 70 pp. See also section 6.4 in this report.

[2] Hulugalle, N.R., Weaver, T.B., and Scott, F. (2002). "Final report to Cotton Research and Development Corporation on CRDC Project no. CRC 12C (Long-term effects of cotton rotations on the sustainability of cotton soils II)", 44 pp.

is closely related to the length of a growing season (commonly measured as day-degrees) in each year.

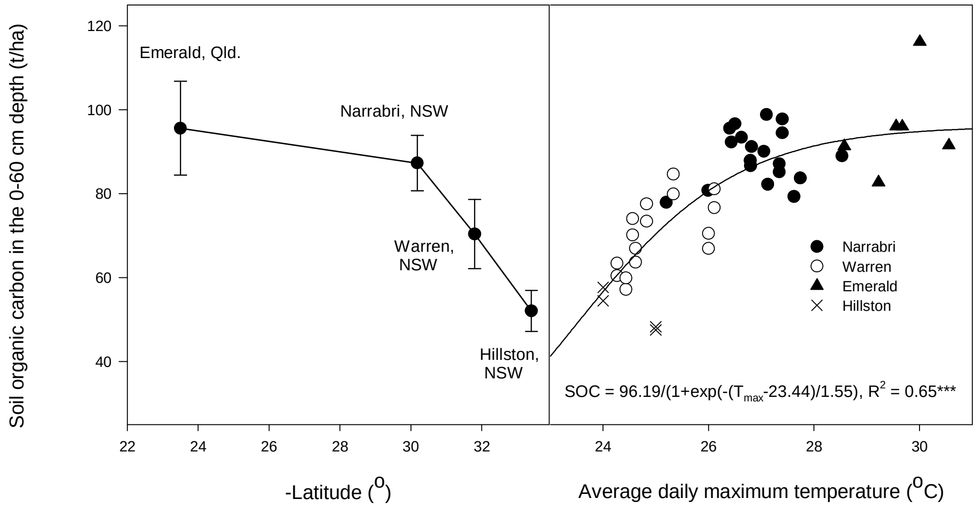

Fig. 8. Variation of latitude and annual average daily maximum temperature, T_{max}, on soil organic carbon stocks in the 0-60 cm depth. Vertical bars are SEM's.

We propose that there are two inter-related factors that determine how temperature affects soil carbon stocks. (Note that dry matter production in all sites was similar). Firstly, increasing length of the growing season ensures that there is an increasing frequency of wet/dry cycles. At the same time higher temperatures result in higher evaporative demand. Thus the intensity of the wet/dry cycles are also likely to be greater. In swelling soils such as Vertosols, frequent and intense wet/dry cycles ensures that large numbers of stable aggregates are formed, usually encompassing soil organic matter. Within these aggregates, the organic matter is protected from microbial decomposition, and thus, sequestered. Secondly, aggregation is also enhanced by microbial activity, which increases with increasing temperatures. A simplified diagrammatic representation of both these processes is shown below (Fig. 9)..

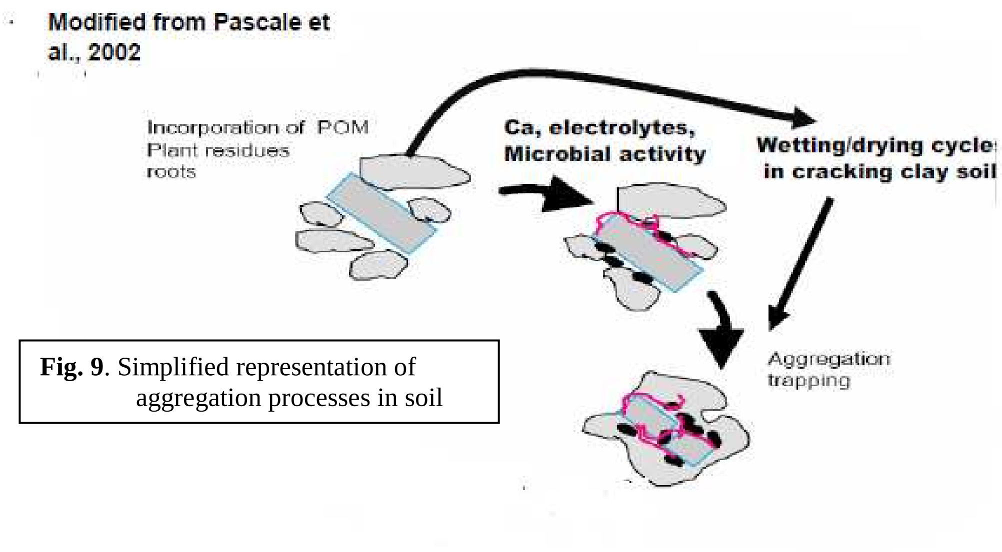
- **Modified from Pascale et al., 2002**

Fig. 9. Simplified representation of aggregation processes in soil

As temperatures increase, there is an increase in aggregation until a maximum values is reached. Thereafter, the microbial decomposition overtakes the aggregation process, leading to decreasing SOC with further increases in temperature (Fig. 7). The end result is a "bell-shaped" curve. Figure 7 suggests that the "maximum value" may also be site dependent with factors such as management, crop types, soil condition and quality, and eco-climatic zone exerting significant effects. In addition, high temperatures cause inhibition of plant growth through enhanced respiration and reduced photosynthesis, and thus, reduction in plant dry matter available for addition to soil carbon stocks.

6.1.5 Management inputs and soil organic carbon stocks

Within site multiple linear regression of management and climatic variables with soil organic carbon stocks for Field C1 and D1 at ACRI, “Glenarvon”, “Beechworth” and “Auscott-Warren” produced somewhat variable results (Table 5). In Field C1 the number of tillage operations irrespective of tillage depth had a negative effect on SOC whereas at “Glenarvon” and “Beechworth” it was positive. This may be due to the fact that in the latter two sites “deep tillage” was primarily associated with pupae-busting and rarely exceeded 15 cm but in Field C1 it was more aggressive and associated with chisel- and disc-ploughing, listering and preparation of land for laser-levelling. The number of shallow tillage (< 10 cm depth) operations had positive and negative effects on SOC at “Glenarvon” and “Auscott-Warren”, respectively . Increasing N fertiliser rates had a negative effect on SOC in Field C1 and “Glenarvon”, no effect at “Auscott-Warren” but a positive response was observed at “Beechworth”. The sodic/saline conditions in the latter may have contributed to this response. This was also the only site where dry matter inputs had a positive effect on SOC. Average daily maximum temperature had a positive effect on SOC at Field C1, “Auscott-Warren” and

Table 5. Results of multiple linear regression analyses of management and climatic variables on SOC sequestration. Max till, number of tillage operations > 10 cm deep; Min till, number of tillage operations < 10 cm deep; N, N fertiliser applied (kg N/ha); Water, total water inputs, irrigation and rainfall (mm); T_{max}, annual average daily maximum temperature (^{o}C); T_{min}, annual average daily minimum temperature (^{o}C); DM, total plant dry matter (t/ha); VIF, variance inflation factor.

Site	Variable	Coefficient	VIF	P <	R^2	n
Field C1, ACRI, Narrabri, NSW	Max till	-2.34	1.2	0.001	0.69^{***}	57
	Min till	-3.02	1.2	0.001		
	N	-0.110	1.7	0.001		
	Water	0.015	1.4	0.001		
	T_{max}	4.80	1.8	0.001		
	T_{min}	-5.64	1.2	0.001		
Field D1, ACRI, Narrabri, NSW	Max till x N x Water	-1.180E-05	1.0	0.05	0.12*	48
“Glenarvon”, Wee Waa, NSW	Max till	2.07	1.1	0.01	0.60^{***}	32
	Min till	2.77	1.6	0.001		
	N	-0.039	1.6	0.05		
“Beechworth”, Merah North, NSW	DM	-0.55	1.3	0.01	0.66^{***}	72
	Max till	9.86	1.3	0.001		
	N	0.022	1.2	0.01		
	T_{max}	6.22	1.2	0.001		
“Auscott-Warren”, Warren, NSW	T_{max}	4.46	1.3	0.001	0.52***	56
	Min till	-2.50	1.2	0.001		
	T_{min}	5.71	1.2	0.05		
Pooled results[1] for cotton-wheat rotations on permanent beds	DM	1.76	1.3	0.001	0.41^{***}	96
	Water	0.009	1.9	0.05		
	N	-0.077	1.9	0.01		
	T_{max}	5.96	1.1	0.001		
	Max till	2.17	1.3	0.05		

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[1] Fields C1 and D1, ACRI, Narrabri; “Glenarvon”, Wee Waa; “Auscott-Warren”, Warren, NSW; “Merrowie”, Hillston, NSW

"Beechworth" but had no effect on SOC at "Glenarvon". Average daily minimum temperature was positively related to SOC at "Auscott-Warren" but had a negative effect at Field C1. The variations in SOC stocks in Field D1 were poorly explained by management and climatic variables (Table 5). Presumably a non-linear approach may have had more success, although model complexity may have been significantly enhanced.

Pooling of results for cotton-wheat rotations on permanent beds from Fields C1 and D1, ACRI, Narrabri; "Glenarvon", Wee Waa; "Auscott-Warren", Warren, NSW; and "Merrowie", Hillston, NSW indicated that increasing amounts of dry matter inputs, water (irrigation and rainfall), average daily maximum temperature and the number of tillage operations greater then 10 cm deep increased SOC stocks in the 0-60 cm depth whereas increasing N fertiliser rate had a negative effect (Table 5). Except for the impact of tillage, the other responses are not surprising. The positive impact of tillage > 10 cm deep is at variance with the widely-held belief that tillage results in depletion of SOC stocks. It should be noted that these claims have been made with respect to carbon concentrations in shallow depths whereas the present study was based on SOC stocks in the 0-60 cm depth. In addition many of the tillage operations conducted in this study, did not include inversion tillage,did not exceed 15-20 cm, and were mainly associated with pupae-busting and thus conducted under dry conditions after picking cotton. The clods formed by tillage were coarse, and thus aggregate disruption was minimal. Examples of such tillage practices were cultivation with the aer-way cultivator, "centre-busting" or "go-devils" (disc-hiller). The end result is an aeration of the soil after the compactive effects of trafficking associated with picking (Fig. 10). In contrast, if an implement such as a rotary-harrow had been used significant disruption of soil aggregates would have been likely.

Fig. 10. Aer-way cultivator and associated land preparation at "Federation Farm", Narrabri

6.1.6 Carbon inputs into soil

The major sources of carbon inputs into soil in agricultural systems are plant materials, *viz*. above and below-ground residues, root exudates etc. However, much of the carbon in crop residues is returned to the atmosphere as carbon dioxide through microbial respiration. The literature suggests that the proportion of carbon in crop residues that is ultimately sequestered in soil can range from 2-20%, although most authors concur that the values are more likely to be at the lower end of this range. In this report we have used two values, 5% and 15%, to estimate the amounts of carbon that can potentially be sequestered in soil. Furthermore no assessments were made of root exudates in soil. This assessment does not account for the subsequent losses of carbon due to microbial decomposition, soil erosion and runoff.

Cotton and rotation crops above-ground residues for the period 2008-11 are summarised in Tables 6, 7 and 8. The amounts of sequestered carbon estimated for the cotton-wheat-vetch rotation and C_4 crops such as corn and sorghum using a 5% sequestration rate (Tables 9 and 10) are similar to those reported for Vertosols under annual cropping systems in Texas, USA (Potter, 2010[1]). The above and other sources in the literature[2] suggest that the using a value of 5% to estimate potential sequestration rates is a reasonable assumption.

The estimated sequestration value for the cotton-wheat-vetch sequence (Table 9) is similar to the value reported by Potter (2010)[1] for pasture systems. This is largely due to the higher below ground contributions by the vetch crop (which was sown in later summer/early autumn) (Table 9, Fig. 11). Assuming a 5% sequestration rate, cotton, wheat and vetch roots totalled 0.5 t C/ha/year of which vetch contributed 0.3 t C/ha/year. In spite of this higher value, however, significant differences among SOC stocks in this experiment were only observed during the 2010 winter (Table 2), when values in treatments with a wheat crop were higher than those without. This implies that even though higher amounts of carbon are potentially available for sequestration with the cotton-wheat-vetch sequence, the high N concentration, and thus, low C/N ratios of both above- (12.9) and below-ground (18.7) vetch materials results in enhanced microbial decomposition of soil organic matter resulting from vetch residues. This casts doubt on the efficacy of leguminous crops in soil carbon sequestration in environments where microbial activity is high such as in irrigated summer-cropping systems. A further cause of SOC losses from a field are those associated with erosion and as dissolved carbon in runoff water. No long-term results are available for cotton soils under furrow irrigation but data from Canada suggests that up to 70% of SOC losses are due to erosion and only 30% were caused by microbial decomposition. Under the warm, wet conditions of northern NSW and southern Queensland, however, the proportion of SOC lost

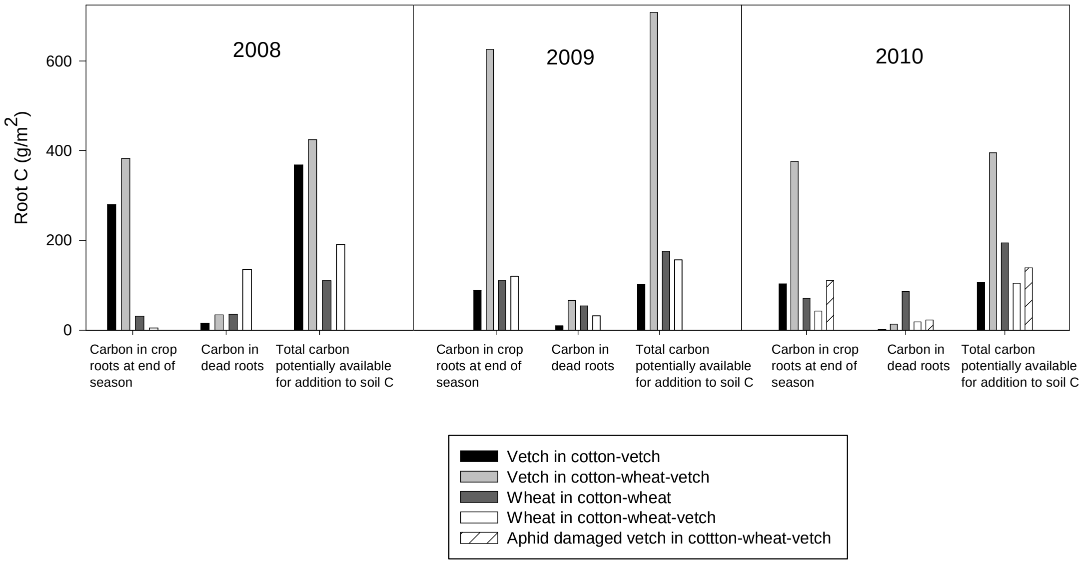

Fig. 11. Effect of crop rotation on root C indices, Field D1, ACRI, Narrabri. C_{root}, carbon in roots at end of season; C_{lost}, carbon added to the soil during season through root death; C_{total}, carbon which could be potentially added to soil organic carbon stocks = C_{root} + C_{lost}. Significant differences between cropping systems at the 95% probability level were present for all root indices (Table 20)

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[1] Potter, K.N. (2010). Building soil carbon content of Texas Vertisols. In: *Soil Solutions for a Changing World, Eds. R. J. Gilkes and N. Prakongkep, Proc. 19th World Congress of Soil Science, 1 – 6 August 2010, Brisbane, Australia [DVD].* http://www.iuss.org/19th%20WCSS/symposium/pdf/0222.pdf

[2] Environment and Natural Resources Committee of the Parliament of Victoria (2010). Report of Inquiry into Soil Carbon Sequestration in Victoria, Parliamentary Paper No. 362, Session 2006-10. http://www.parliament.vic.gov.au/publications/committee-reports/817-final-report-of-the-inquiry-into-soil-carbon-sequestration-in-victoria/download

by microbial decomposition is probably higher. Extrapolating from published data of SOC concentration in eroded sediments and sediment concentration in runoff water[1], for a typical cotton season estimated values of SOC lost with erosion ranged from 0.4 to 1.2 t C/ha. These values, for the most part, are greater than those reported in Tables 6-10. It is not surprising, therefore, that net carbon sequestration measured in this study was either negative or neutral.

In comparison with C_3 crops such as wheat, the estimated potential C sequestration values of the C_4 crops corn and sorghum are much higher (Table 10) and are comparable to those reported for pastures. This is largely due to high above- and in particular, below-ground biomass. With respect to below-ground contributions by corn, C_{total} and C_{root} of corn differed significantly ($P < 0.05$) between rotations and seasons (Fig. 12). Significant ($P < 0.05$) interactions also occurred between years and seasons. C_{lost} of corn was not significantly affected by seasons or years. C_{total} and C_{root} were higher ($P < 0.05$) with corn monoculture (Fig. 12). Average corn C_{total} with monoculture was 9.3 t/ha and with cotton-corn was 5.0 t/ha, and average C_{root} with corn monoculture was 7.7 t/ha and with cotton-corn was 4.1 t/ha. C_{total} averaged between both treatments was, thus, of the order of 7.7 t C/ha/year. Assuming a 5% sequestration rate, this suggests that corn roots could contribute 0.4 t/ha/year to SOC stocks whereas above-ground dry matter is expected to contribute 0.2 t/ha/year. Averaged between both cropping systems mean C_{lost} was of the order 0.8 t/ha. These data also suggest that carbon addition to soil through C_{lost} was small with corn; *viz*. averaging 11% of C_{total} in both years. This is much lower than that of cotton, which ranged from 25-29% in the same field. The differences in root carbon between the two rotations may be related to the greater amount water stored in the soil after corn than with cotton[2]. The shorter growing season of the corn (5-6 months) results in a longer fallow period between corn crops whereas the longer growing season of the cotton (~6 months) results in a shorter fallow. Subject to late summer, autumn and winter rainfall, more water is therefore, likely to be stored under a corn monoculture than with a cotton-corn rotation.

Sorghum roots contributed less carbon with conventional tillage than with no-tillage ($P < 0.05$) (Fig. 13). Values for C_{total}, C_{root} and C_{lost} were higher than those of corn. A large proportion of the carbon inputs from sorghum roots came from depths > 60 cm. Averaged between both treatments, during flowering and grain filling, 65% of the total root mass was located in the 60-1.0 m depth (Fig. 47). This pattern of root distribution is unusual in irrigated soils where the majority of roots are located in the surface regions. As noted in previous sections, heavy and frequent rainfall during December resulted in near saturated soil profiles, and thus no irrigation was applied until February. The high root densities and proliferation in the deep subsoil may have been caused by the wet subsoils and low soil strength stimulating root growth at depth. It is unlikely that this "bulge" of roots in the deep subsoil would be present in a season when rainfall distribution was more typical of this region and where frequent irrigation occurred. Extrapolation of these values to other sites and years should, therefore, be done with some caution.

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[1] (a) Carroll C. *et al* (1999). A simulation study of erosion in the Emerald Irrigation Area. *Aust. J. Soil Res.* **37**, 479-494; (b) Silburn, D.M. and Glanville, S.F. (2002). Management practices for control of runoff losses from cotton furrows under storm rainfall. I. Runoff and sediment on a black Vertosol. *Aust. J. Soil Res.* **40**, 1-20. (c) Silburn, D. M., *et a*l. (2009). Management practices for control of runoff losses from cotton furrows under storm rainfall.III.Cover and wheel traffic effects on nutrients (N and P) in runoff from a black Vertosol. *Aust. J. Soil Res.* **47,** 221-233.

[2] Devereux AF, Fukai S, Hulugalle NR (2008) The effects of maize rotation on soil quality and nutrient availability in cotton based cropping. In '*Global Issues – Paddock Action, Proceedings 14th Australian Agronomy Conference, 21-25 September 2008, Adelaide, SA (Unkovich M, Ed).' Australian Society of Agronomy, Adelaide, SA. [CD-ROM]*

Table 6. Dry matter production of wheat and cotton in tillage/rotation experiment, Field C1, ACRI. DM, dry matter. Wheat dry matter yields are those from previous winter; thus for 2008-09 season, wheat dry matter yields shown are from 2007 winter. *, ** and *** indicate that treatments differ significantly at $P < 0.05$, $P < 0.01$ and $P < 0.001$, levels, respectively. 40% of plant dry matter was assumed to consist of carbon.

Irrigation frequency	**Rotation**	**Tillage system**	**2008-09**				**2009-10**				**2010-11**			
			Wheat	**Cotton**	**Total DM**	**Total carbon**	**Wheat**	**Cotton**	**Total DM**	**Total carbon**	**Wheat**	**Cotton**	**Total DM**	**Total carbon**
Frequent	Cotton-cotton	Conventional	-	5.2	5.2	2.1	-	4.2	4.1	1.6	-	3.2	3.2	1.3
	Cotton-cotton	Permanent beds	-	6.3	6.3	2.5	-	3.2	3.2	1.3	-	4.0	4.0	1.6
	Cotton-wheat	Permanent beds	1.2	4.9	6.0	2.4	-	-	-	-	3.9	5.9	9.8	3.9
Infrequent	Cotton-cotton	Conventional		3.8	3.8	1.5	-	3.7	3.7	1.5	-	2.3	2.3	0.9
	Cotton-cotton	Permanent beds	-	3.2	3.2	1.3	-	3.5	3.5	1.4	-	2.3	2.3	0.9
	Cotton-wheat	Permanent beds	1.1	5.0	6.1	2.4	-	-	-	-	4.0	3.8	7.8	3.1

SEM:

Parameter	**Cropping systems (CS)**			**Irrigation frequency (IF)**			**CS x IF**		
	2008-09	**2009-10**	**2010-11**	**2008-09**	**2009-10**	**2010-11**	**2008-09**	**2009-10**	**2010-11**
Cotton DM	0.27	0.16*	0.22***	0.06*	0.02	0.06*	0.38***	0.23	0.31
Wheat DM	-	-	-	0.09		-	-	-	-

Table 7. Dry matter production (t/ha) of vetch, wheat and cotton in rotation experiment, Field D1, ACRI. Wheat dry matter yields are those from previous winter; thus for 2008-09 season, wheat dry matter yields shown are from 2007 winter. Values in parentheses are $\log_e$ transformed values. DM, dry matter. *, ** and *** indicate that treatments differ significantly at $P < 0.05$, $P < 0.01$ and $P < 0.001$, levels, respectively. 40% of plant dry matter was assumed to consist of carbon.

Rotation	**Rotation stubble management**	**2008-09**					**2009-10**					**2010-11**				
		Vetch	**Wheat**	**Cotton**	**Total DM**	**Total carbon**	**Vetch**	**Wheat**	**Cotton**	**Total DM**	**Total carbon**	**Vetch**	**Wheat**	**Cotton**	**Total DM**	**Total carbon**
Cotton-vetch	Mulched	3.4	-	4.5	7.7	3.1	2.7	-	4.0	6.7	2.7	2.9	-	4.7	7.6	3.0
Cotton-cotton	-	-	-	5.4	5.4	2.2	-	-	4.8	4.8	1.9	-	-	4.5	4.5	1.8
Cotton-wheat	Incorporated	-	1.0	6.2	7.2	2.9	-	2.7	5.4	8.1	3.2	-	3.0	5.3	8.3	3.3
Cotton-wheat-vetch	Mulched	4.2	1.1	4.7	10.0	4.0	6.4	2.6	3.9	12.9	5.2	4.4	2.8	5.1	12.3	4.9
SEM		0.21	0.15	0.36			0.23	0.09	0.35			0.27	0.23	0.38		
P <		0.01	ns	0.05			0.001	ns	ns			0.01	ns	ns		

Table 8. Dry matter production of rotation crops and cotton in experiments at "Federation Farm", Narrabri; "New Haven", Narromine; "Merrowie", Hillston; and the cotton-wheat-sorghum rotation experiment, Field D1, ACRI, Narrabri.

Site	**Cropping system**	**2008-09**				**2009-10**				**2010-11**			
		Rotation	**Cotton**	**Total DM**	**Carbon**	**Rotation**	**Cotton**	**Total DM**	**Carbon**	**Rotation**	**Cotton**	**Total DM**	**Carbon**
"Federation Farm", Narrabri[1]	Cotton-wheat (incorporated)	4.2	-	4.2	1.7		6.9	6.9	2.8	3.2	-	3.2	1.3
	Cotton-wheat (*in situ* mulch)		-				6.8	6.8	2.7	3.2	-	3.2	1.3
	SEM						0.34			0.22			
	P <						ns			ns			
"Merrowie", Hillston	Cotton-wheat					6.5		6.5	2.6	-	6.4	6.4	2.6
	Cotton-wheat-sorghum[2]					6.9		6.9	2.8	4.5	5.0	9.5	3.8
	SEM					0.18				-	0.25		
	P <					ns				-	0.001		
"New Haven", Narromine[3]	Corn (burnt) fb. Cotton-wheat					?	7.3	7.3	2.9	6.1	-	6.1	2.4
	Cotton-wheat (*in situ* mulch)					?	7.9	7.9	3.2	7.3	-	7.3	2.9
	t-value						-0.97			-2.05	-		
	P <						ns			0.01	-		
Field D1, ACRI, Narrabri	Cotton-wheat-sorghum[4] (*in situ* mulch)	19.6	5.9	25.5	10.2	9.4	6.3	15.7	6.3	10.3	6.5	16.8	6.7
	Cotton-wheat (*in situ* mulch)	-	6.1	6.1	2.4	2.9	6.0	8.9	3.6	3.5	5.6	9.1	3.6

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[1] Laser levelled in 2008 winter and sown to chickpea and wheat; values shown are an average of the two (treatments not imposed). Wheat sown in 2010 could not be harvested due to frequent, heavy rains and waterlogged conditions. The residue was burnt and soybean sown during summer 2010-11.

[2] Sorghum was not sown during 2009-10. Instead a wheat crop which was sprayed out was sown during 2010 winter, followed by cotton.

[3] Dry matter production by corn and wheat is unknown as measurements commenced in October 2009. Corn and wheat crops had been sown during the 2008-09 season.

[4] Forage sorghum was sown during 2008-09, and grain sorghum, thereafter. The experiment was designed such that both cotton and rotation phases were sown every year.

Table 9. Effect of cropping system on carbon inputs and sequestration averaged from 2008 to 2011

Tillage/rotation experiment, Field C1, ACRI:

Irrigation frequency	**Rotation**	**Tillage system**	**Average carbon inputs (t C/ha/year)**			**Amount sequestered (t C/ha/year)**	
			DM	Roots[1]	Total	5%	15%
Frequent	Cotton-cotton	Conventional	1.7	0.6	2.3	0.1	0.4
	Cotton-cotton	Permanent beds	1.8	0.6	2.4	0.1	0.4
	Cotton-wheat	Permanent beds	2.1	2.2	4.3	0.2	0.7
Infrequent	Cotton-cotton	Conventional	1.3	0.3	1.6	0.1	0.2
	Cotton-cotton	Permanent beds	1.2	0.3	1.5	0.1	0.2
	Cotton-wheat	Permanent beds	1.8	1.7	3.5	0.2	0.5

Rotation experiment, Field D1, ACRI:

Rotation	**Rotation crop stubble management**	**Average carbon inputs (t C/ha/year)**			**Amount sequestered (t C/ha/year)**	
		DM	**Roots[1]**	**Total**	5%	15%
Cotton-vetch	Mulched	2.9	2.9	5.8	0.3	0.9
Cotton-cotton	-	2.0	1.2	3.2	0.2	0.5
Cotton-wheat	Incorporated	3.1	3.1	6.2	0.3	0.9
Cotton-wheat-vetch	Mulched	4.7	9.0	13.7	0.7	2.1

Table 10. Carbon inputs and estimated sequestration by C4 crops (sorghum, corn, see experiments 5.1.4.1, 5.1.4.2, 5.1.3.1)

Site	**Crop**	**Years**	**Average carbon inputs (t C/ha/year)**			**Amount sequestered (t C/ha/year)**	
			DM	Roots[1]	Total	5%	15%
Field C1, ACRI	Corn	2007-08 & 2008-09	5.1	7.7	12.8	0.6	1.9
Field D1, ACRI	Grain sorghum	2009-10 & 2010-11	2.5	9.2	11.7	0.6	1.8
Field C1, ACRI	Grain sorghum	2010-11	3.4	12.5	15.9	0.8	2.4

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[1] Based on data in Figs. 11, 12 and 13

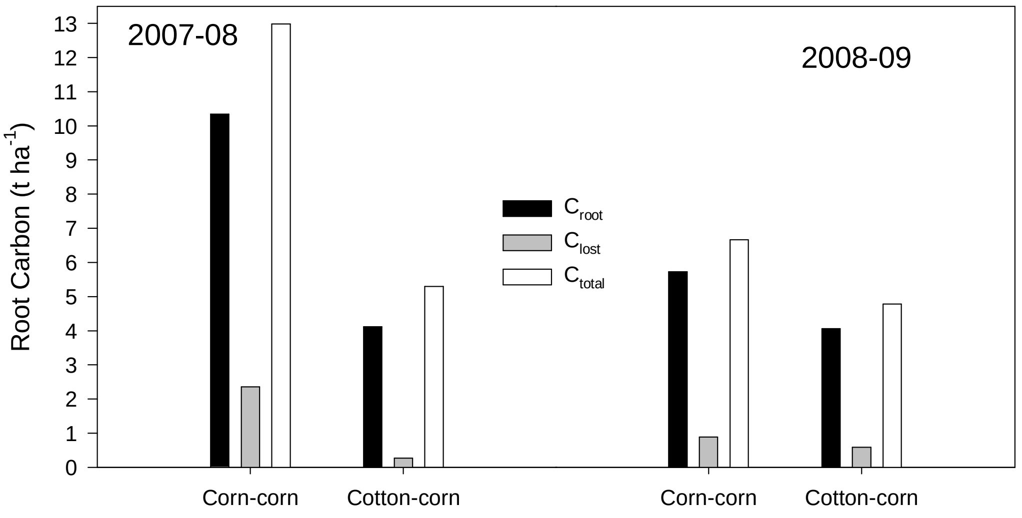

Fig. 12. Effect of corn-corn and cotton-corn rotation on corn root C indices. C_{root}, root carbon at end of season; C_{lost}, root carbon added to the soil during season; C_{total}, root carbon which could be potentially added to soil organic carbon stocks = C_{root} + C_{lost}. Significant differences between cropping systems at the 95% probability level were present only with respect to C_{root} and C_{total}

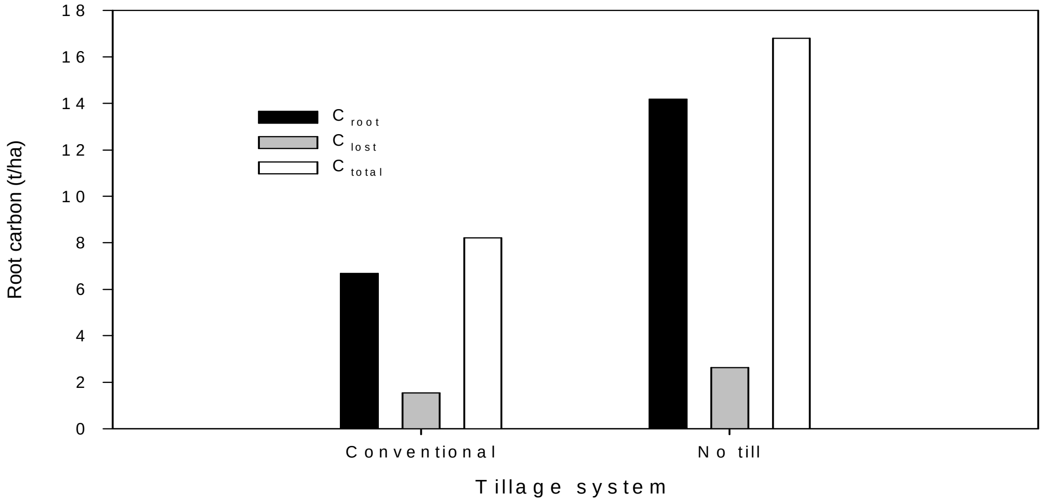

Fig. 13. Effect of tillage system on sorghum root C indices. C_{root}, root carbon at end of season; C_{lost}, root carbon added to the soil during season; C_{total}, root carbon which could be potentially added to soil organic carbon stocks = C_{root} + C_{lost}.

6.2 Greenhouse gas emissions

6.2.1 Greenhouse gas emissions associated with farming practices

A significant cause of greenhouse gas emissions in agriculture is claimed to be that produced by burning fossil fuel during various farming operations. Few long-term results exist, however, for Australian cotton farming systems. This section presents emissions estimated from fuel and electricity use (presented as carbon dioxide equivalents, CO2-e) from the experiments described in sections 5.1.1.1. 5.1.1.2 and 5.1.2.1. Treatments included tillage systems, stubble retention, rotations and soil amendments such as gypsum and cattle manure.

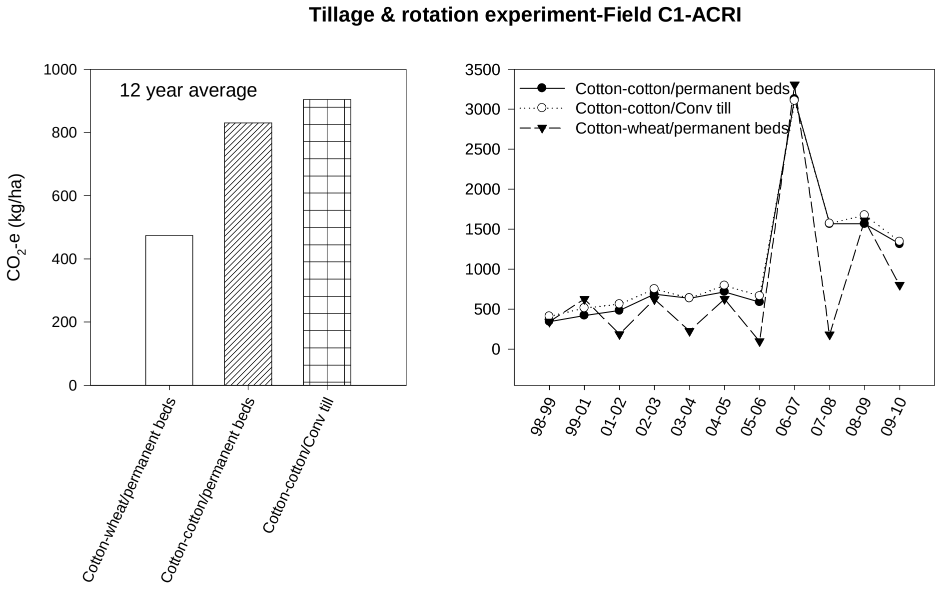

Fig. 14. Effect of tillage and cropping system on in-field greenhouse gas emissions, measured as carbon dioxide equivalent (CO_2-e), Field C1, ACRI, Narrabri

The key findings from these estimates are summarised as follows:

- Groundwater pumping can be a major contributor to greenhouse gas emissions. Emissions produced during irrigation with river water are relatively small whereas those produced by pumping groundwater are large; about 6 times higher, in fact. The sharp increases in CO_2-e after the 2005-06 cotton season shown in Fig. 14 indicate the point at which irrigation with river water was replaced by groundwater pumped from an average depth of 35 m. Energy use and emissions are high when pumping depths are high.
- Reducing tillage reduced in-field emissions whereas continuous cotton increased them. High emissions occurred when cotton was sown every year (i.e. summer cotton-winter fallow or rotation crop-summer cotton) (Figs. 14 and 15). Within such cropping systems, sowing cotton onto permanent beds resulted in the least amount of emissions, with increases taking place when conventional tillage was practiced or a vetch rotation crop was sown. Relative to permanent beds, conventional tillage produced about 3 times more CO_2-e (i.e. 3 times more diesel is consumed) during land preparation. Furthermore, sowing a vetch or any other rotation crop into dry soil immediately after cotton and when rainfall is insufficient for seed germination required irrigation, which produces emissions.

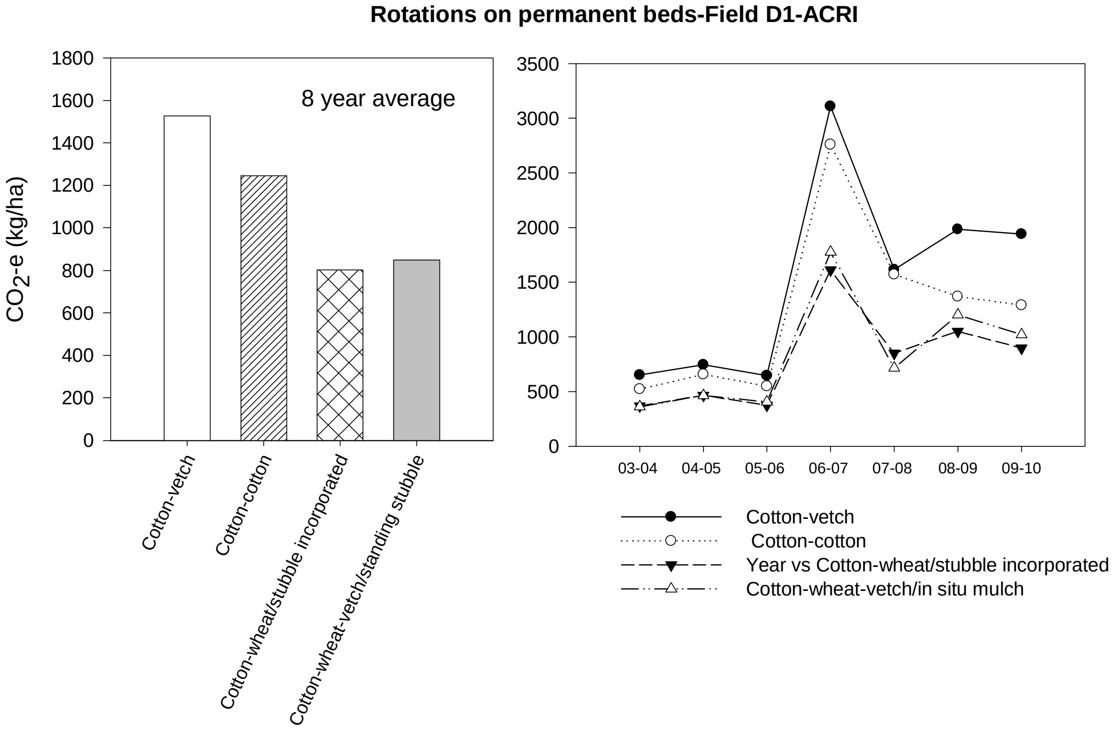

Fig. 15. Effect of tillage and cropping system on in-field greenhouse gas emissions, measured as carbon dioxide equivalent (CO_2-e), Field D1, ACRI, Narrabri

- Least in-field emissions were produced when wheat was part of the rotation (i.e. cotton-wheat-cotton; cotton-wheat- vetch-cotton). The lower emissions were due mainly to the inclusion of a fallow in these rotations. Including vetch in a cotton-wheat rotation had a negligible effect on CO_2-e emission because the former was grown mainly as a dryland crop with water used by vetch coming from stored soil water and in-crop rainfall.

- Partial life cycle analysis showed that most CO_2-e was produced by in-field activities and soil emissions (Figs. 16 and 17). Significant amounts of CO_2-e were also emitted during production of N fertiliser used in the field, herbicide production and transport to the field and fuel production and transport to the field. Partial substitution of mineral N fertiliser by legumes such as vetch was able to reduce emissions associated with N fertiliser production and transport by 65% when cotton was sown every year and 49% in a cotton-wheat rotation system (Fig.16). This is equivalent to a reduction of 256 and 135 kg CO_2-e/ha/year, respectively.

- Emissions were least when manure was applied as a soil amendment (Fig. 18). CO_2-e emissions in the experiment at Brigalow (experiment 5.1.2.1) reflected depth and frequency of tillage operations associated with application of the amendments at its commencement. In subsequent years, as zero-tillage was practiced, there were no differences among treatments.

In summary, reduction in in-field CO_2-e production ranged between 28% and 59% when management practices such as reduced or minimum tillage, permanent beds and wheat rotation crops were used in comparison with sowing cotton every year after conventional tillage. The inclusion of wheat was able to reduce emissions because it included a stubble-mulched fallow which facilitated harvesting of rain water, thereby reducing the number of irrigations. Past research has also shown that these are the very same practices which can improve soil health, cotton yield and fibre quality. Substitution of mineral N fertiliser with a leguminous crop was able to reduce the carbon footprint of cotton-based rotation systems.

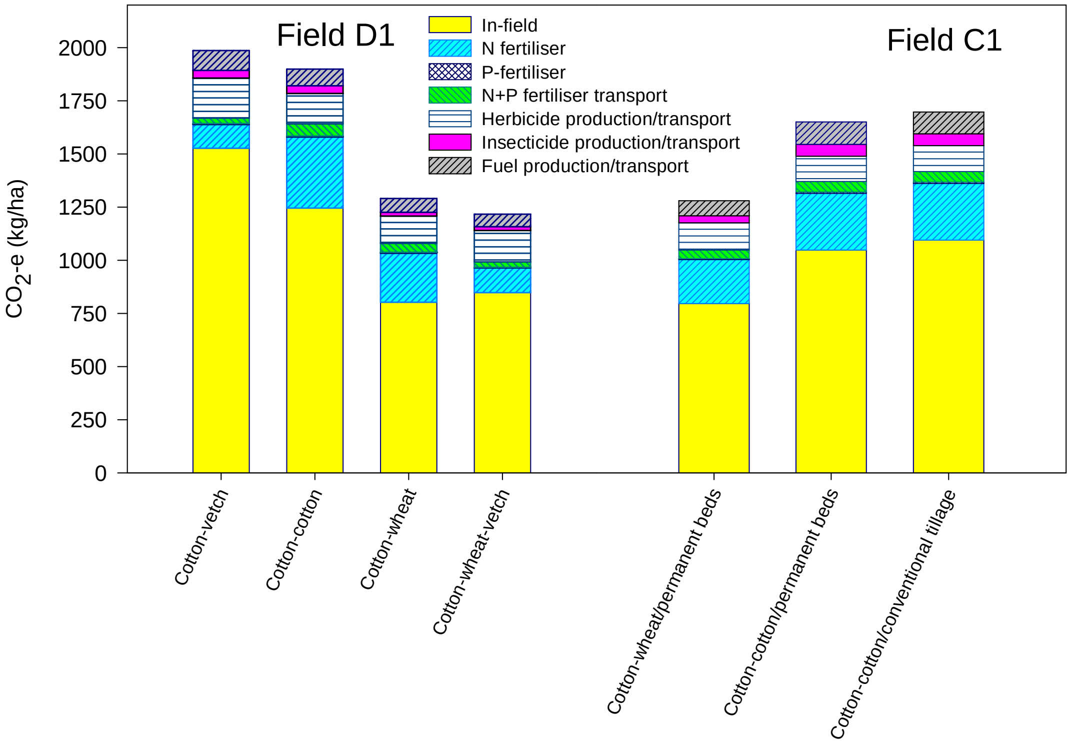

Fig. 16. Partial life-cycle analysis (in-field, transport and production of variable inputs) of greenhouse gas emissions from tillage and cropping systems in Fields C1 and D1, ACRI, Narrabri

The above analysis does not account for losses from the soil in the form of N_2O from fertiliser and decomposing leguminous crop residues, and CO_2 from mineralisation of soil organic matter. Inclusion of these factors, which is not usually addressed, suggests that soil emissions can be significant (Fig. 17). The estimated relatively high losses of CO_2 through soil organic matter mineralisation in Field C1 was probably due to the high level of soil disturbance

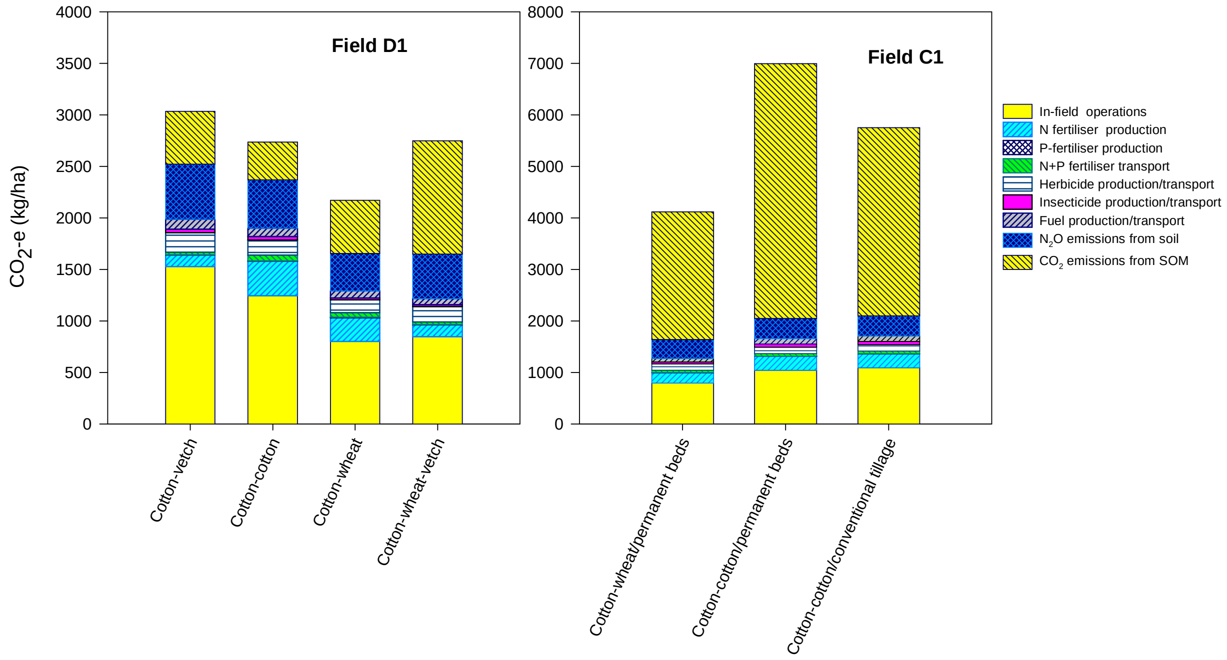

Fig. 17. Partial life-cycle analysis of greenhouse gas emissions from tillage and cropping systems in Fields C1 and D1, ACRI, Narrabri with emissions of N_2O and CO_2 accounted for

associated with bed re-alignment and laser levelling. Conversely, the absence of any such disturbance in Field D1 may have resulted in much lower values of emissions through organic matter mineralisation. It should be noted that estimates of CO_2 emissions from SOM were based on estimated C sequestration rates (Tables 3 and 9), and are thus, likely to be underestimates as they do not account for CO_2 emissions from decomposition of retained crop residues. Table 9 and Figs. 19-22 suggest that this may be the single largest component of CO_2 emissions in a farming system. Note that not all retained crop residues decompose completely within a single year.

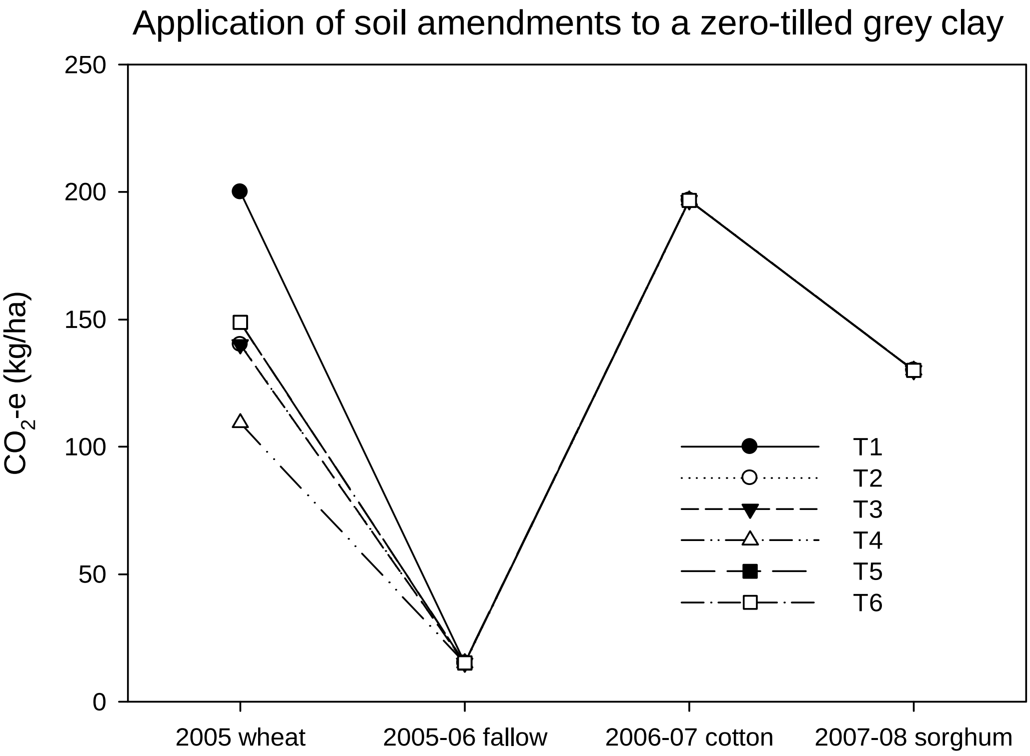

Fig. 18. Seasonal CO_2-e production from soil amendments trial, near Brigalow, Qld. T1, Ripping alone to an average depth of 0.5 m; T2, Deep application (0.5 m) of P, Zn and K; T3, Deep application of P and Zn; T4, Surface application and incorporation (no ripping) of cattle manure at a rate of 16 t/ha; T5, Gypsum at a rate of 9 t/ha followed by ripping; T6, Gypsum at a rate of 9 t/ha followed by ripping, and deep application of P, Zn and K.

6.2.2 Greenhouse gas emissions from soil

Green house gas samples were taken from 150mm diameter static chambers (0.24 m^2) over a two hour incubation period with monitoring conducted at regular intervals, triggered by key events in the system such as slashing/incorporation, irrigation and fertiliser application. Results for twenty four sampling events are depicted graphically in Figs. 19-22. Methane was not detected in significant quantities in any of the sampling events, and so results are not included. For reporting purposes, data is converted to emissions in kg CO_2-e/ha/year. In the case of nitrous oxide, the measured values of nitrogen gas in nitrous oxide is multiplied by (44/28)*298 to convert it to carbon dioxide equivalents

In spite of this reporting format, the reader is cautioned against extrapolating these values, as they are deliberately measured at targeted events, and only measured across two hours.

6.2.2.1 Cropping system effects

Fig. 19A shows emissions late in the 2008-09 season, for treatments 1, 2 and 3a in the rotation experiment in Field D1 at ACRI (Experiment 5.1.1.2). Treatment 1, cotton sown in the cotton-vetch rotation had more than double the emissions of cotton in continuous cotton (treatment 2) or cotton-wheat (treatment 3a). Emissions in systems that include legumes may occur throughout the season as crop residues and soil organic matter originating from the leguminous vetch decomposes, whereas in cropping systems where N was applied as mineral fertiliser, emissions may occur rapidly when the fertiliser is applied during the early part of the season. In other words, in the latter type of system the pattern of gas emissions is characterised by an early season peak that falls to very low emission rates whereas in systems that include a legume, emissions are associated with organic matter decomposition and occur continuously at moderate rates throughout the season. Fig. 19B shows emissions at the break in the cropping cycle after cotton. Notable are emissions of nitrous oxide during the go-devilling operation. Spikes of nitrous oxide or CO_2 were not detected during wheat planting, which can occur following hydrolysis and mineralisation of urea. Slashing of the vetch (Fig. 19C) resulted in significant amounts of N_2O emissions. One week later (Fig. 19D), these emissions had declined substantially.

Slashing vetch in the cotton-vetch rotation during September again resulted in significant CO_2 emissions but unlike with cotton-wheat vetch, emissions of N_2O were low (Fig. 20A).This may be related to differences in climatic conditions between the two times and lower amounts of vetch dry matter, and hence, lower available N in the cotton-vetch. N in above ground vetch dry matter was 187 kg/ha in the cotton-wheat vetch rotation and 97 kg/ha in the cotton-vetch rotation (Table 24), Similarly N in vetch roots was of the order of 308 kg/ha and 53 kg/ha in the cotton-wheat-vetch and cotton-vetch, respectively. Significant differences also occurred between vetch varieties with Rasina having less emissions relative to Popany. This can be partly attributed to differences in N content of the vetch dry matter; *viz.*105 kg N/ha with Popany and 82 kg N/ha with Rasina, although other unknown factors may also have been involved. Within the Rasina plots, incorporation released more emissions than slashing, and may be associated with soil disturbance during incorporation.

6.2.2.2 Irrigation and N fertiliser effects

Irrigation at “Federation Farm” in October 2009 resulted in significant emissions of nitrous oxide (Fig. 20C). At a subsequent irrigation (December) (Fig. 20D) emission returned to background levels. No pattern of emissions down the irrigation run was evident in either of these sampling events.

No immediate response was detected to urea application in December 2009 in Field D1 (Fig. 21A), but during irrigation later that month significant N_2O emissions and highly elevated CO_2 emissions occurred (Fig. 21B). These were the highest instantaneous carbon dioxide emissions measured in the project. By the following irrigation in January, however, the system had settled back to a more normal level. Sampling was carried out on the 6th, 9th and 20th April, following an irrigation event on 31/3/2010. Instrument failure in the laboratory resulted in the loss of the two earlier samplings. Due to this, assessment of the influence of drying has been lost. No nitrous oxide was detected in the emissions sampled on 20/4 (three weeks after irrigation) (Fig. 21C).

In comparison with retaining wheat stubble as *in situ* mulch in Field C1, “listering” (ridging or bedding) of the continuous cotton had no obvious impact when measured after urea application during December 2010 (Fig. 21D). Significant nitrous oxide was measured in both “listered” and standing stubble, and may be related to the very wet conditions in this field during December 2010. In Field D1, urea application again failed to detect a spike in either N_2O or CO_2. Irrigation events were monitored at both the Federation Farm and ACRI sites in January 2011 but little difference was evident within each irrigation at the ACRI sites. In

Field C1, however, an effect of irrigation frequency was evident, with the infrequent (14-21 day cycle) irrigation producing much less CO_2 (Fig. 22A) This may be related to lower dry matter, and hence, available carbon, in the infrequently irrigated treatments. A final monitored irrigation in February 2011, in Field D1 (Fig. 22B) revealed little of interest. N_2O emissions were extremely low in all treatments. No differences between treatments were evident. The final monitoring event during irrigation at C1 (Fig. 22C) failed to detect the effects of irrigation frequency observed during January.

In summary, carbon dioxide was the dominant green house gas generated in the system. Fertiliser application combined with high soil moisture is seen as the dominant driver of nitrous oxide generation. This is consistent with previous greenhouse experiments carried out at Wollongbar. It is likely that the high pH of these soils is responsible for the moderation of N_2O emissions compared to the rates of nitrogen fertilisers being used in the system. The largest instantaneous fluxes of carbon, measured as CO_2, were associated with either mechanical disturbance of residues (slashing/incorporation) or irrigation events. Other key drivers of greenhouse gas emissions were nitrogen fertiliser application and irrigation.

No evidence was found to suggest that nitrous oxide emissions are high from these production systems, bearing in mind the sporadic nature of the sampling program. Differences between rotations are weakly suggested throughout the data, but significance is masked by replicate variability. The problem of high spatial variability is one that is not addressed by the automated systems deployed around the country. They attempt to overcome variability problems by sampling from a larger soil surface area.

It should be noted that the static chamber method of greenhouse gas measurement is suitable for the comparison of treatments, but is not appropriate for quantifying total emissions. Inherent variability in greenhouse gas generation, in particular nitrous oxide, remains problematic, but this is real variability and cannot be avoided. The research team at Wollongbar are currently using an automated sampling and analysis system; however, current projects will not see it available in the next few years.

A lack of temporal replication, typical of manual green house gas sampling techniques makes interpretation of results difficult. Previous laboratory work by the author has shown that spikes in emissions, particularly of N_2O, (but also CO_2, such as during urea hydrolysis) can be very rapid, and brief. As such, these events can easily be missed with this sampling regime.

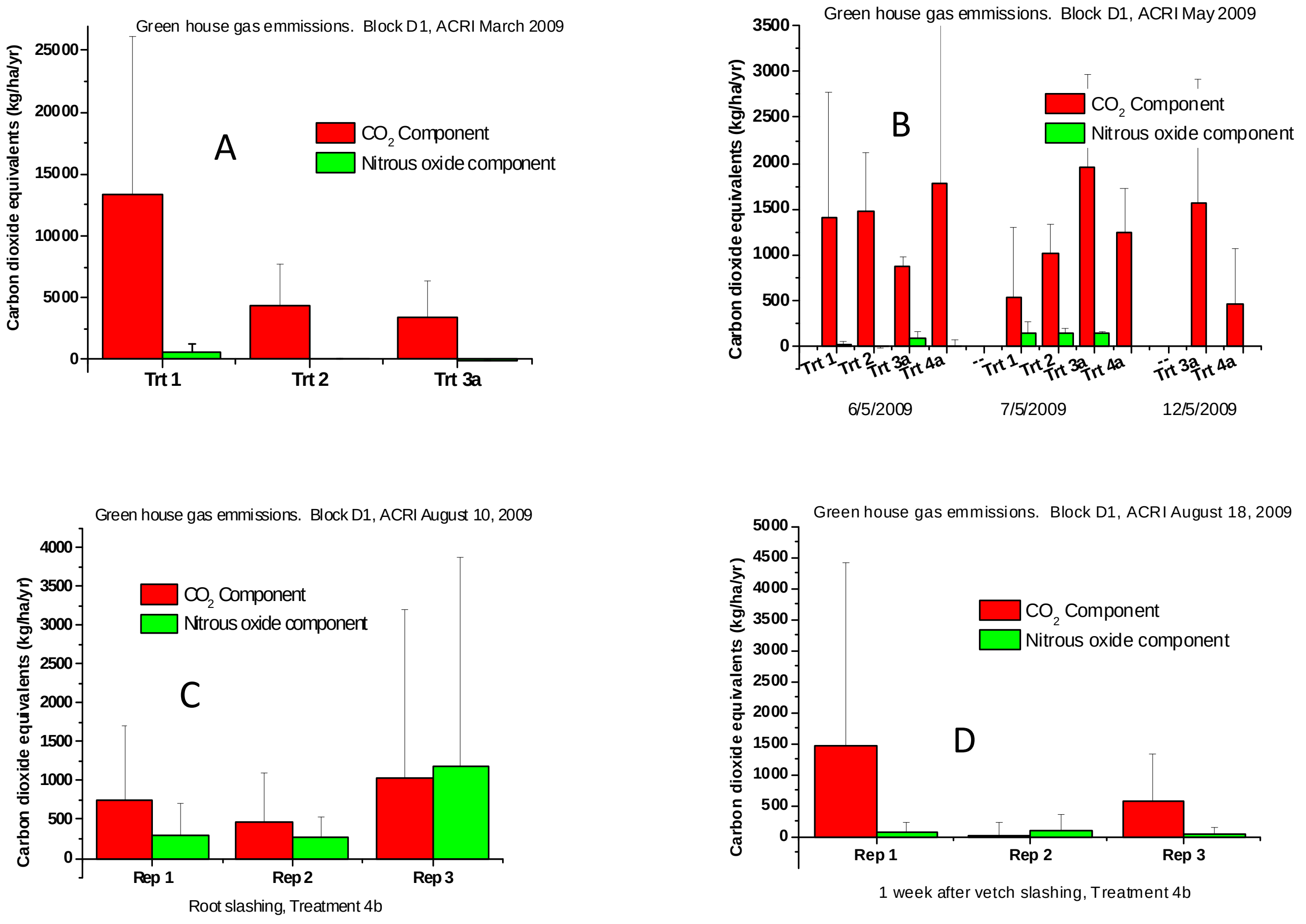

Fig. 19. Greenhouse gas emission in rotation experiment in Field D1 during selected events March-August 2009. Results converted to carbon dioxide equivalents (A) End of 2008-09 cotton season; (B) Root cutting was carried out on the 6th, Go-devilling on the 7th and wheat planted with 20 kg N/ha as urea on the 12th of May; (C) Slashing of vetch on 10 August in treatment 4b (cotton-wheat-vetch); (D) one week after vetch slashing on 18 August in treatment 4b (cotton-wheat-vetch). Treatment 1, Cotton-vetch; Treatment 2, Cotton-cotton; Treatment 3, Cotton-wheat ; Treatment 4, Cotton-wheat-vetch

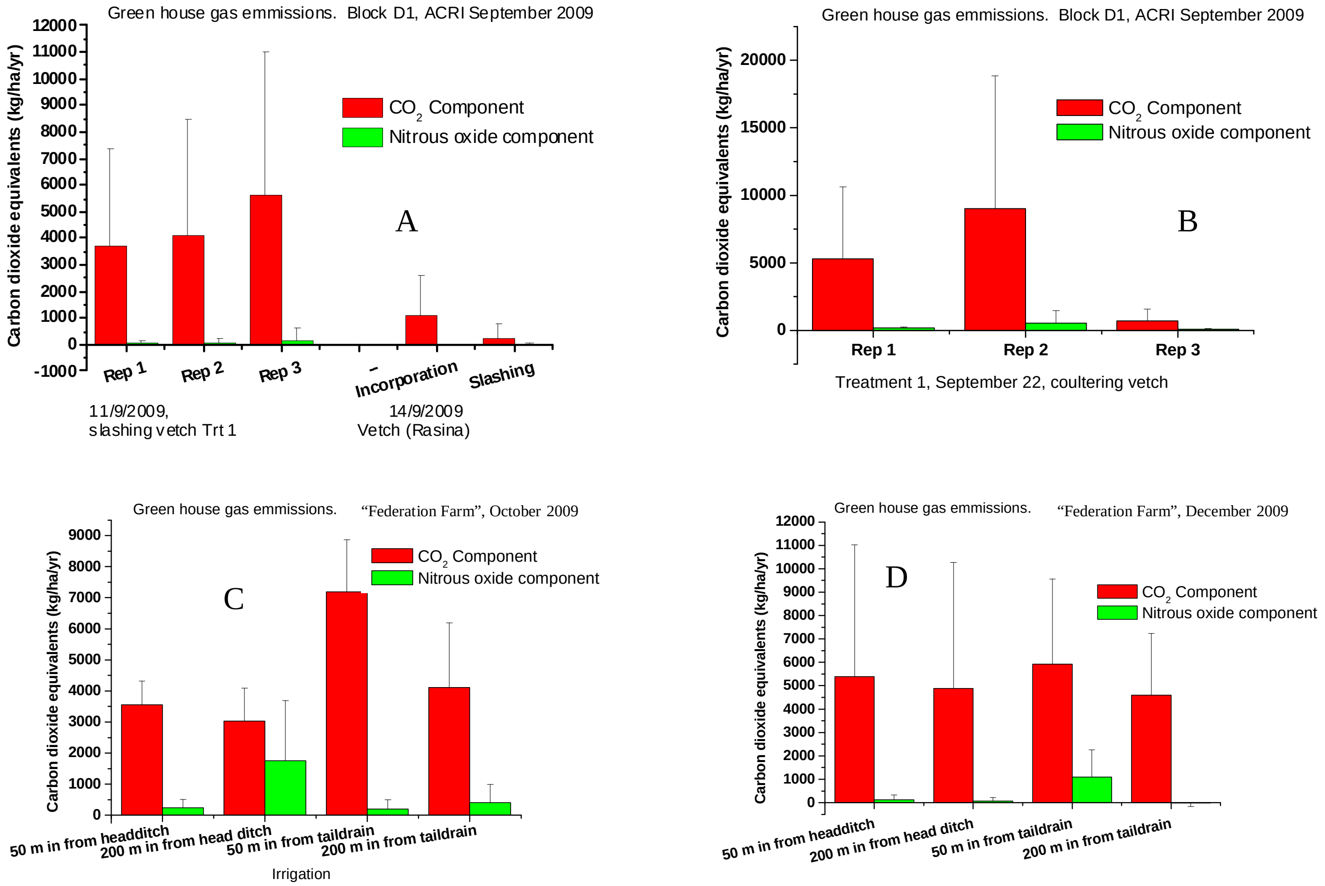

Fig. 20. Greenhouse gas emission in rotation experiment in Field D1 and "Federation Farm" during selected events September 2009-December 2009. Results converted to carbon dioxide equivalents (A) After vetch slashing and incorporation in Treatment 1 (cotton-vetch), September 2009. Results for 11 /9/2009 relate to the variety Popany and those for 14/9/2009 to the variety Rasina; (B) After cutting vetch laterals and applying herbicides with "Mulch Manager" in Treatment 1, September 2009; (C) Spatial distribution of emissions down the length of the field during irrigation, "Federation Farm", October 2009. Note no obvious pattern. (D) Spatial distribution of emissions down the length of the field during irrigation, "Federation Farm", December 2009. Again, no obvious pattern in emissions down the field.

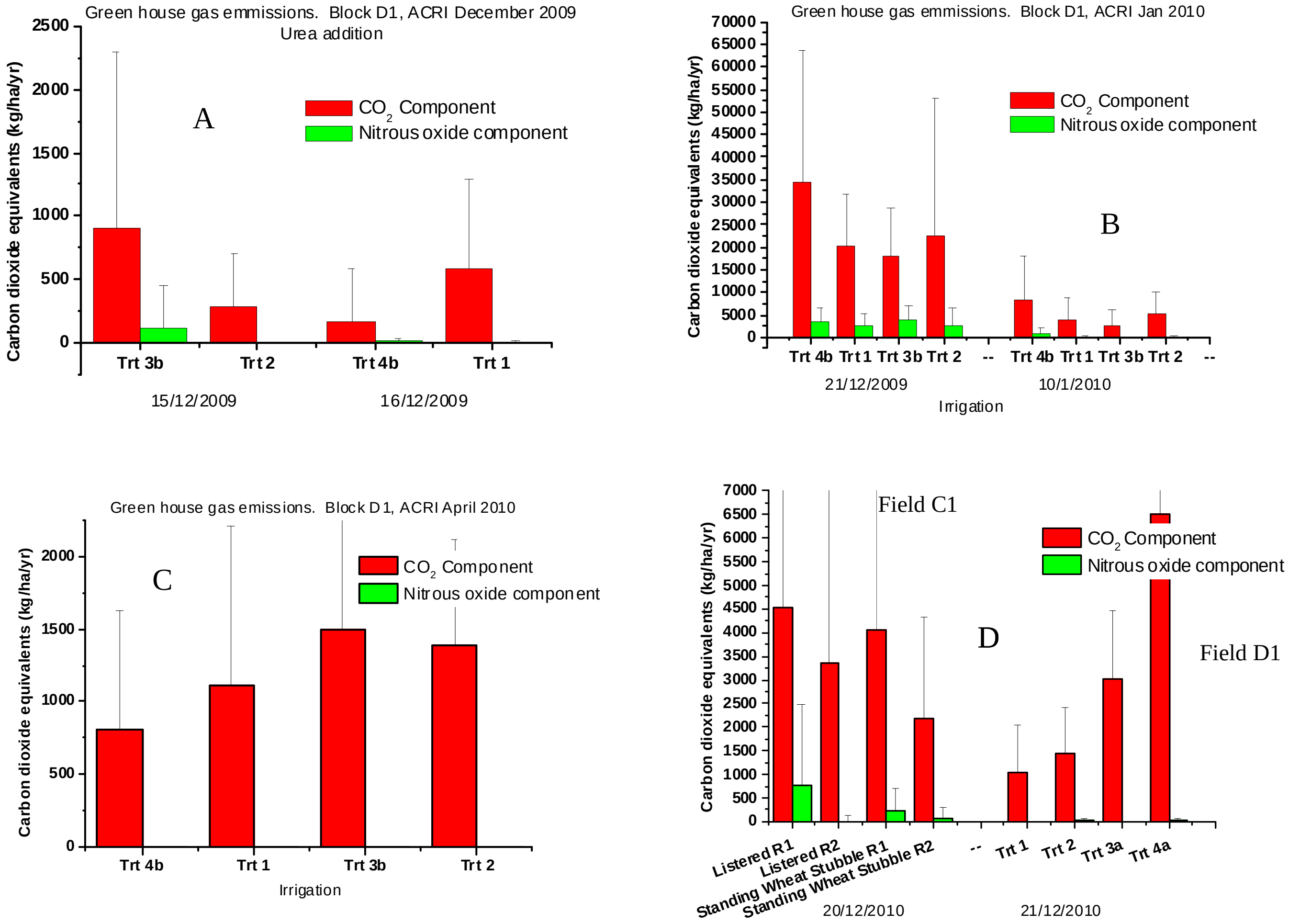

Fig. 21. Greenhouse gas emission in rotation experiment in Field D1 during selected events December 2009-December 2010. Results converted to carbon dioxide equivalents (A) Emissions after urea application on 14/12/2009. Note the absence of significant quantities of nitrous oxide; (B) Irrigations following urea application on 14/12/2009. More significant emissions of N_2O observed in the 1st irrigation.; (C) Emissions on 20/4/2010 during the drying cycle following irrigation on 31/3. Data for two previous samplings in the drying cycle lost due to instrument failure. (D) Field D1 ACRI during irrigation, and C1 after urea application, December 2010.

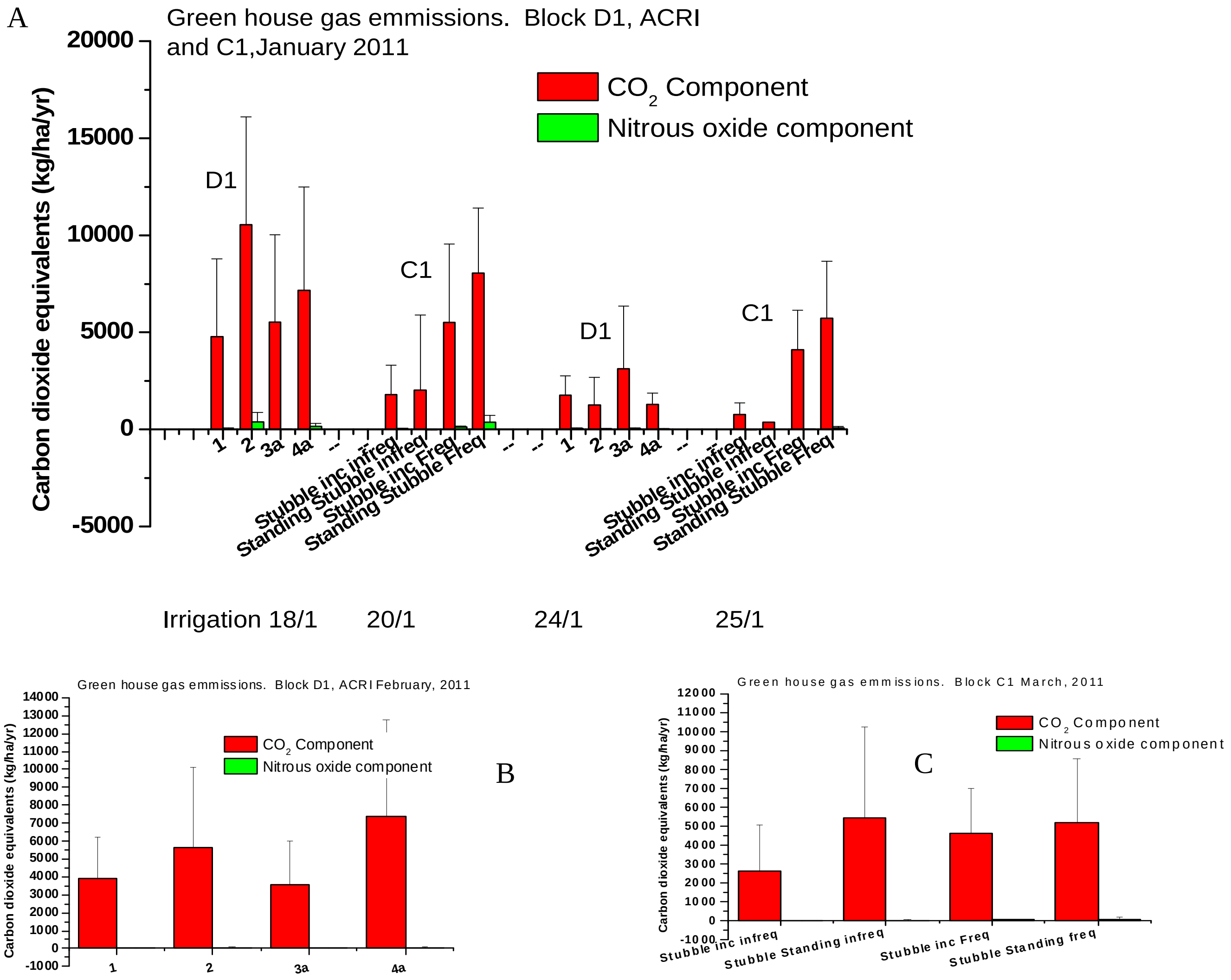

Fig. 22. Greenhouse gas emission in rotation Fields D1 and C1 during selected events January-March 2011. Results converted to carbon dioxide equivalents (A) During and 1 week after irrigations at field D1 and C1 at ACRI. Standing stubble is cotton-wheat rotation standing stubble, stubble incorporated is continuous cotton plots that had been laser levelled, incorporated and listered in Field C1; (B) 14 Block D1, ACRI, irrigation, 24th February 2011.˙; (C) 1 week after irrigation at Field C1, ACRI, March 2011. NB. Irrigated on 24/2, sampled on 1/3

6.3 Cropping systems and soil quality

"Soil quality" in this section refers primarily to soil physical and chemical properties including soil carbon concentration.

6.3.1 Including vetch in cotton-based crop rotations

Soil physical properties measured were soil shrinkage using paraffin wax-coated clods (2009) and kerosene-saturated aggregates (2008) in the 0-10 cm depth. Soil water retention was measured with a modified filter-paper method. The shrinkage data was fitted to a logistical 4 parameter model. Significant differences were not clearly evident due to the scatter of the data (Fig. 23, Table 11). Nonetheless some treatment related differences were present among the fitted parameters (Table 11).

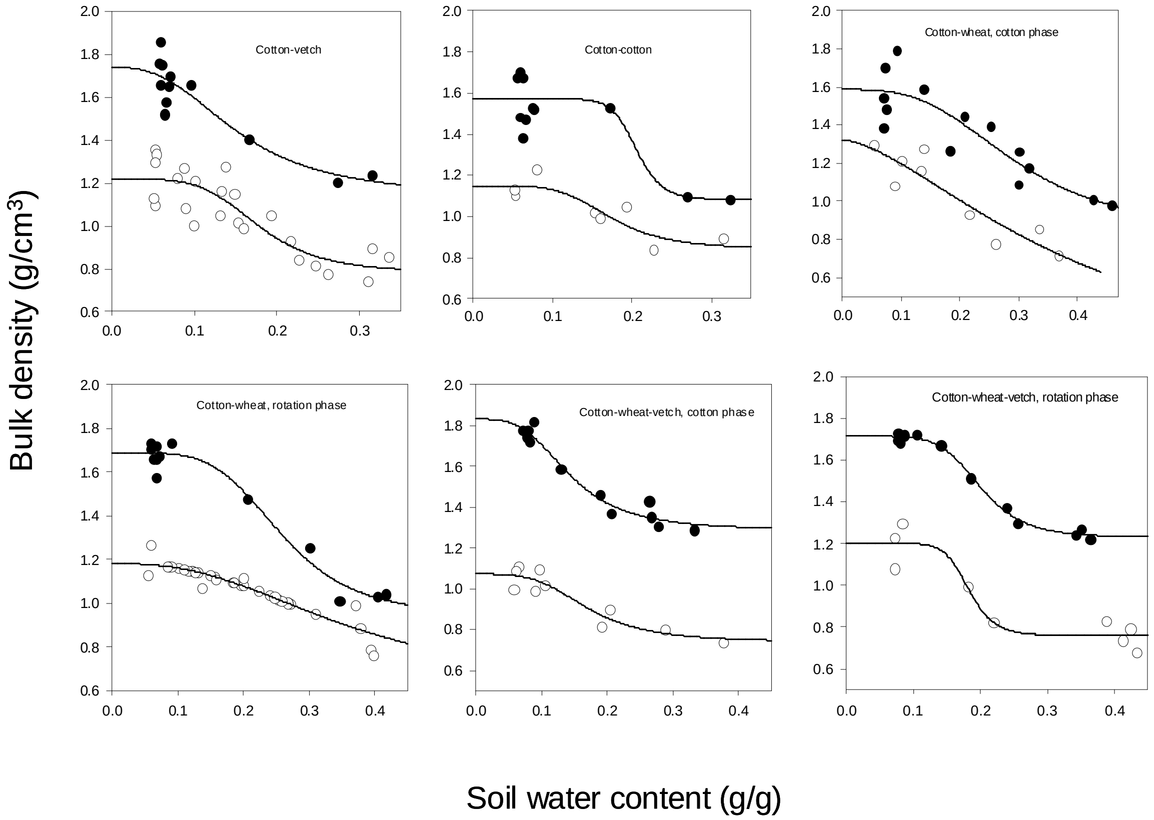

Fig. 23. Shrinkage curves in the 0-10 cm depth, Field D1, ACRI. ●, 2009 (clods); ○, 2008 (aggregates)

Table 11. Fitted parameters for shrinkage curves for clods from the surface 10 cm in Field D1, ACRI. A logistical 4 parameter model of the form: $y = y_0 + a/ (1+(x+x_0))^b$ was fitted to the data where y is bulk density and x is soil water content.

Rotation	**Rotation stubble management**	**a**	**b**	**x_0**	**y_o**	**R^2**
Cotton-vetch	*In situ mulch*	0.60	2.77	0.15	1.14	0.83^{**}
Continuous cotton		0.49	12.80	0.21	1.08	0.78**
Cotton-wheat (incorporated), cotton phase	Incorporated	0.75	4.61	0.26	0.94	0.97^{***}
Cotton-wheat (incorporated), rotation phase	Incorporated	0.76	3.18	0.30	0.83	0.78**
Cotton-wheat (*in situ* mulch)-vetch, cotton phase	*In situ mulch*	0.48	6.19	0.20	1.23	0.99^{***}
Cotton-wheat (*in situ* mulch)-vetch, rotation phase	*In situ mulch*	0.55	3.37	0.14	1.29	0.96^{***}

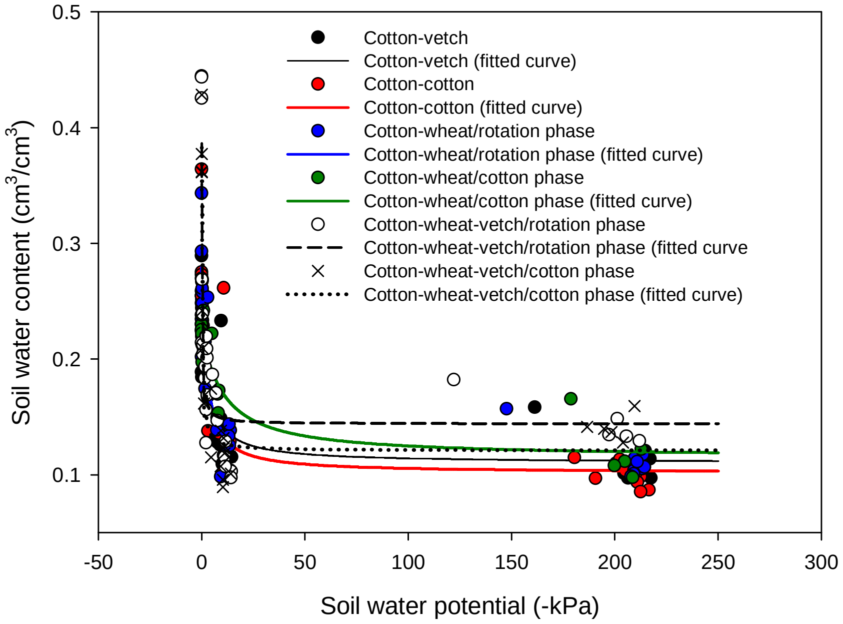

Fig. 24. Soil water retention characteristics for clods (2009) and aggregates (2008) from the 0-10 cm depth in the rotation experiment in Field D1, ACRI. Curves were derived by pooling results from both years.

Table 12. Fitted parameters for water retention characteristics of clods and aggregates from the surface 10 cm in Field D1, ACRI (Fig...). A modified 3-parameter exponential model of the form y = a*exp(b/(x+c)), where y is soil water content and x is soil water potential, and a, b and c are constants was used.

Rotation	**Rotation stubble management**	**a**	**b**	**c**	**R^2**
Cotton-vetch	*In situ mulch*	0.11	3.65	4.63	0.79^{***}
Continuous cotton		0.10	3.81	3.89	0.80^{***}
Cotton-wheat (incorporated), cotton phase	Incorporated	0.12	9.72	14.25	0.85^{***}
Cotton-wheat (incorporated), rotation phase	Incorporated	0.11	3.35	3.52	0.85^{**}
Cotton-wheat (*in situ* mulch)-vetch, cotton phase	*In situ mulch*	0.12	0.54	0.47	0.95^{***}
Cotton-wheat (*in situ* mulch)-vetch, rotation phase	*In situ mulch*	0.14	0.34	0.35	0.77^{***}

Soil water retention characteristics for both clods and aggregates sampled during 2008 and 2009 were pooled and a modified 3-parameter exponential model of the form y = a*exp(b/(x+c)), where y is soil water content and x is soil water potential, and a, b and c are constants (Table 12). The shapes of the curves and the parameters in Table.. suggest that some surface compaction was present in the rotation that included a wheat crop, although a clear pattern is not evident. This is confirmed by the pore size distribution calculated from the 2009 water retention characteristics (Fig. 26). Presumably this surface compaction is associated with trafficking on beds during wheat harvest (Fig. 25). Until 2009 wheel and axle widths of the wheat harvester used in this site were incompatible with the cotton system’s 1-m bed configuration.

Fig. 25. Compaction on beds due to trafficking by wheat harvester

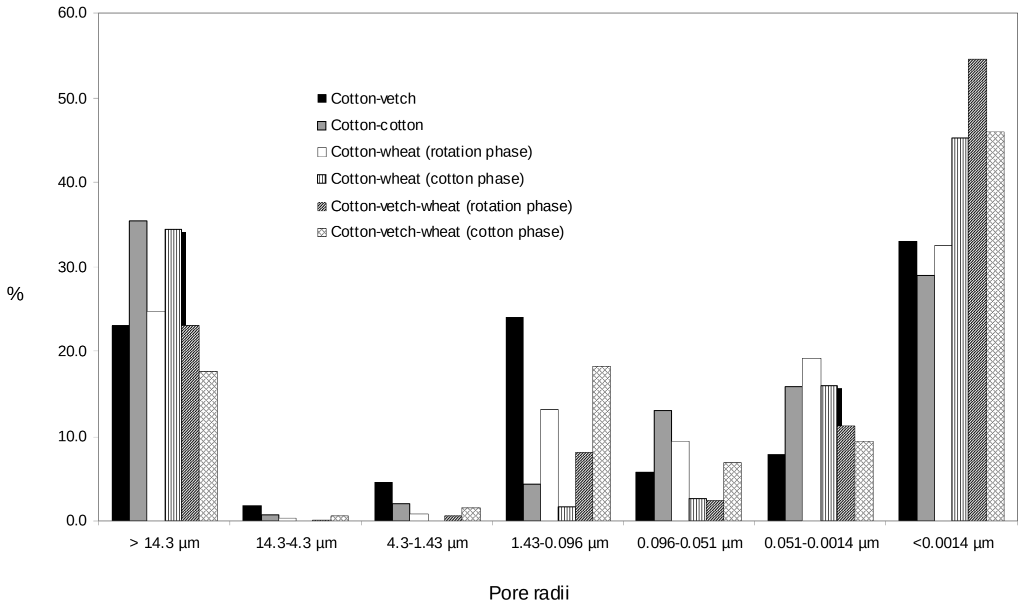

Fig. 26. Pore size distribution in the 0-10 cm depth of the rotation experiment in Field D1, ACRI, 2009

Except for nitrate-N, and SOC and exchangeable K concentrations, values of other soil chemical properties generally increased with depth but were affected by factors such as presence of a crop and length of fallow (Table 14). Key points in 2010 (which was preceded by a wet winter) were:

- Nitrate-N was influenced by fertiliser application (before cotton) and the presence of vetch (i.e. a legume) or wheat in the rotations. Hence, surface concentrations of nitrate-N were higher where N fertiliser was applied (cotton in cotton-wheat, cotton-cotton) and where legume had been sown. Between cotton-vetch and cotton-wheat-vetch, N values were lower in the latter, and may have been due to a ~4.5 month fallow in the latter, which may have facilitated N leaching and volatilisation. Lowest values occurred in the surface where a wheat crop was present. At depth, values were higher in rotations that include wheat and where sampling was preceded by a fallow. This highest nitrate-N values at depth and to a deeper depth were observed in the cotton plots in the cotton-wheat rotation, which had been preceded by a 11 month fallow. This treatment was also noted to have the highest drainage (see later discussion under "Hydrology").

- Evidence of leaching was present also with respect to electrical conductivity, Cl and ESP profiles, and similar trends to the nitrates were observed in the subsoil (Table 14).
- As notes in a previous chapter, surface SOC concentrations were highest where a wheat crop was present and followed by rotations that had been under vetch during the past few months. In other words, decreasing length of fallow was strongly related to increases in SOC concentrations in the surface. Differences among rotations in other depths were not significant.

6.3.2 Including corn in the rotation

Results in this section relate to the experiment at "New Haven", near Narromine (Experiment 5.1.1.5). Except for SOC concentration, soil properties (Table 13) in the 0-10 cm and 10-30 cm depths did not differ significantly (Student's t-test analyses). SOC concentration was, however, significantly higher with corn in the 0-10 cm ($t = 5.00$, $P < 0.001$) and 10-30 cm depth ($t = 2.69$, $P < 0.05$). When corrections are made for differences in sampling volume and soil water content at sampling, however, SOC content (in t/ha) in the surface 30 cm was lower with cotton-corn (Table 3).

Table 13. Soil properties in the 0-10 cm and 10-30 cm depths under cotton-wheat (*in situ* mulch) and cotton-corn (burnt) rotations, "New Haven", Narromine, 2009

		Depth	
Rotation	**Soil property**	**0-10 cm**	**10-30 cm**
Wheat/standing stubble	pH($CaCl_2$)	6.7	6.4
	$EC_{1:5}$ (dS/m)	0.27	0.20
	SOC (g/100g)	1.19	0.86
	Ca (cmol/kg)	16.6	16.7
	Mg (cmol/kg)	5.9	5.7
	K (cmol/kg)	2.0	1.4
	Na (cmol/kg)	1.5	1.9
	CEC (cmol/kg)	26.0	25.7
	ESP	5.6	7.3
Corn/burnt	pH($CaCl_2$)	6.8	6.8
	$EC_{1:5}$ (dS/m)	0.26	0.25
	SOC (g/100g)	1.24	1.12
	Ca (cmol/kg)	14.6	13.5
	Mg (cmol/kg)	5.4	5.0
	K (cmol/kg)	2.1	1.2
	Na (cmol/kg)	1.4	1.6
	CEC (cmol/kg)	23.5	21.3
	ESP	5.8	7.3

Table 14. Soil properties under cotton/vetch/wheat rotations, Field D1, ACRI, November 2010. Cotton stubble was incorporated but rotation stubble was managed as indicated in table. Sampled at time of sowing cotton. *, ** and *** indicate that means differed significantly at $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively.

Depth (cm)	Rotation	Rotation stubble management	pH ($CaCl_2$)	$EC_{1:5}$ (dS/m)	Cl (mg/kg)	SOC (g/100g)	Nitrate-N (mg/kg)	Exchangeable cations (cmol/kg)				ESP
								Ca	Mg	K	Na	
0-10	Cotton-vetch	*In situ mulch*	7.2	0.16	18	0.94	17.1	16.7	13.3	1.9	0.7	1.7
	Continuous cotton		7.2	0.12	18	0.82	14.7	16.8	12.9	2.1	0.6	1.6
	Cotton-wheat (incorporated), cotton phase	Incorporated	7.1	0.18	8	0.81	13.6	17.1	12.8	2.2	0.5	1.2
	Cotton-wheat (incorporated), rotation phase	Incorporated	7.0	0.13	36	1.21	0.3	17.1	12.8	2.1	0.5	1.4
	Cotton-wheat (*in situ* mulch)-vetch, cotton phase	*In situ mulch*	7.0	0.15	9	0.94	13.5	17.5	13.0	2.3	0.5	1.2
	Cotton-wheat (*in situ* mulch)-vetch, rotation phase	*In situ mulch*	7.0	0.16	38	1.21	7.1	18.5	12.8	2.2	0.6	1.4
10-30	Cotton-vetch	*In situ mulch*	7.4	0.18	68	0.41	5.6	20.0	15.7	0.8	1.9	4.5
	Continuous cotton		7.3	0.15	32	0.41	6.3	20.4	14.8	0.9	1.5	3.7
	Cotton-wheat (incorporated), cotton phase	Incorporated	7.1	0.09	12	0.43	7.7	20.7	14.8	1.0	1.2	2.9
	Cotton-wheat (incorporated), rotation phase	Incorporated	7.2	0.15	57	0.46	0.3	20.7	13.7	0.9	1.3	3.3
	Cotton-wheat (*in situ* mulch)-vetch, cotton phase	*In situ mulch*	7.3	0.11	12	0.44	4.4	21.1	14.7	1.0	1.3	3.2
	Cotton-wheat (*in situ* mulch)-vetch, rotation phase	*In situ mulch*	7.3	0.11	39	0.48	0.4	21.5	14.2	0.9	1.3	3.3
30-60	Cotton-vetch	*In situ mulch*	7.5	0.19	107	0.40	1.5	22.4	16.6	0.6	3.5	8.5
	Continuous cotton		7.5	0.22	83	0.38	3.4	22.8	16.7	0.6	3.3	7.8
	Cotton-wheat (incorporated), cotton phase	Incorporated	7.5	0.19	27	0.37	9.3	22.8	16.4	0.6	2.5	6.0
	Cotton-wheat (incorporated), rotation phase	Incorporated	7.4	0.18	88	0.43	0.2	22.8	15.7	0.6	2.4	6.0
	Cotton-wheat (*in situ* mulch)-vetch, cotton phase	*In situ mulch*	7.5	0.18	39	0.36	5.1	22.8	17.7	0.7	2.9	6.7
	Cotton-wheat (*in situ* mulch)-	*In situ mulch*	7.4	0.15	58	0.37	0.2	22.8	15.8	0.6	2.4	6.0

	vetch, rotation phase											
60-120	Cotton-vetch	*In situ mulch*	7.6	0.34	353	0.36	0.5	22.8	18.4	0.7	5.4	13.0
	Continuous cotton		7.6	0.34	327	0.31	1.2	23.1	18.5	0.8	5.0	11.9
	Cotton-wheat (incorporated), cotton phase	Incorporated	7.6	0.27	230	0.33	7.4	23.1	17.6	0.8	4.3	10.3
	Cotton-wheat (incorporated), rotation phase	Incorporated	7.6	0.23	168	0.34	0.4	23.2	17.2	0.6	3.9	9.9
	Cotton-wheat (*in situ* mulch)-vetch, cotton phase	*In situ mulch*	7.6	0.34	284	0.35	1.4	23.6	19.1	1.0	5.3	12.1
	Cotton-wheat (*in situ* mulch)-vetch, rotation phase	*In situ mulch*	7.5	0.24	170	0.34	0.2	23.9	18.1	0.7	4.0	9.6
	SEM											
	Rotations (R)		0.02^{**}	0.009^{*}	13.1*	0.015^{***}	1.22^{**}	0.38	0.50	0.04^{*}	0.20^{*}	0.43^{*}
	Depths (D)		0.02^{***}	0.011^{***}	12.9***	0.017^{***}	0.94^{***}	0.22^{***}	0.21^{***}	0.03^{***}	0.20^{***}	0.40^{***}
	R x D		0.04	0.027	31.6	0.043^{***}	2.31	0.54	0.51	0.08	0.48	0.99

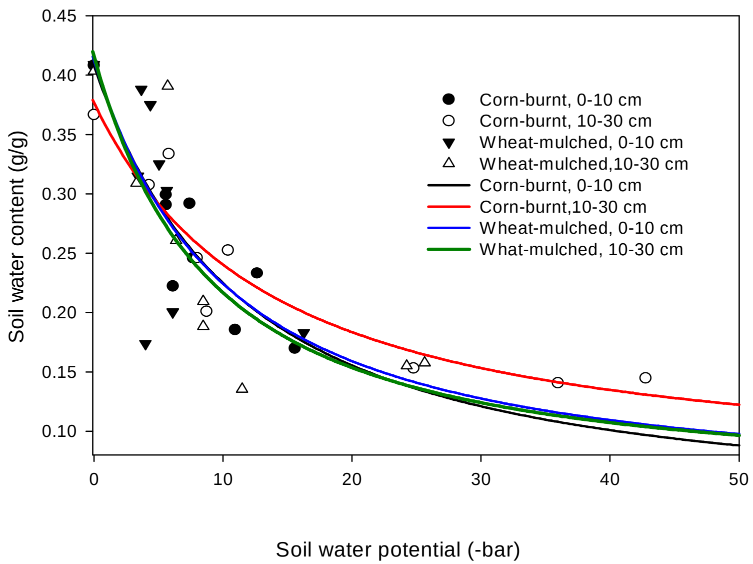

Fig 27.Soil water retention characteristics of aggregates in the 0-10 cm and 10-30 cm depths after corn (burnt) and wheat (mulched), September 2009

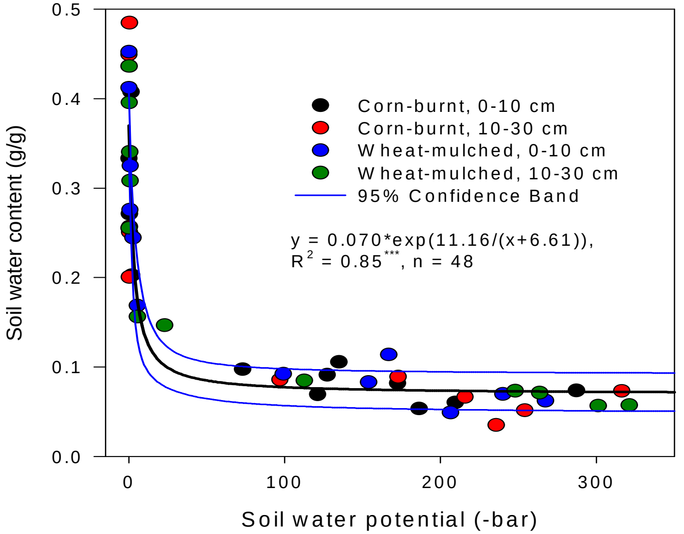

Fig. 28. Soil water retention characteristics of clods in the 0-10 cm and 10-30 cm depths after corn (burnt) and wheat (mulched), November 2010

Table 15. Fitted parameters for water retention characteristics of aggregates from the surface 30 cm at "New Haven", Narromine (Fig...). A modified 3-parameter exponential model of the form y = a*exp(b/(x+c)), where y is soil water content (g/g) and x is soil water potential (-bar), and a, b and c are constants was used.

Rotation	**a**	**b**	**c**	**R^2**
Corn (burnt), 0-10 cm	0.033	81.99	32.43	0.81^{**}
Wheat (mulched), 0-10 cm	0.046	58.81	25.96	0.45
Corn (burnt), 10-30 cm	0.062	54.15	30.06	0.89^{**}
Wheat (mulched), 10-30 cm	0.050	47.66	22.51	0.85^{*}

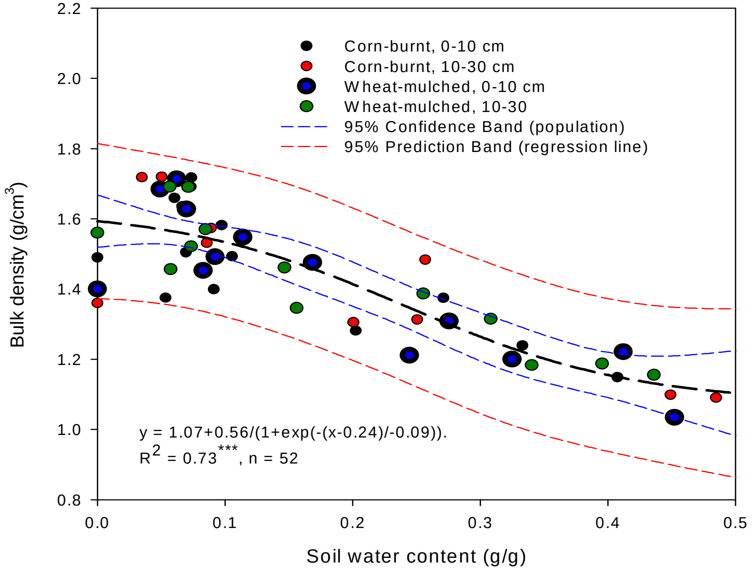

Fig. 29. Soil shrinkage in the 0-10 cm and 10-30 cm depths after corn (burnt) and wheat (mulched), November 2010

Table 16. Effect of applying soil amendments during 2005 on average soil properties from 2005 to 2007. Data shown are averages of 3 replicates in 18 plots and 3 years

Management practice	0-0.1 m	0.1-0.3 m	0.3-0.6 m	0.6-1.2 m	P <	SEM
Exchangeable Ca ($cmol_c$ kg^{-1})						
Ripping alone	25.5	22.4	17.7	11.8	0.05	0.87
Deep incorporation of P and Zn	25.7	21.8	17.9	12.8		
Deep incorporation of P, K and Zn	24.9	21.6	16.4	12.8		
Manure	24.1	22.5	18.1	12.7		
Gypsum	26.3	22.9	17.6	13.1		
Gypsum and deep incorporation of P, Zn and K	25.7	22.1	16.9	12.8		
Exchangeable Mg ($cmol_c$ kg^{-1})						
Ripping alone	7.5	10.2	13.4	13.3	n.s.	0.15
Deep incorporation of P and Zn	7.9	10.1	12.5	13.4		
Deep incorporation of P, K and Zn	7.7	9.4	12.8	13.9		
Manure	7.0	9.0	12.6	13.1		
Gypsum	7.2	9.3	12.1	13.0		
Gypsum and deep incorporation of P, Zn and K	7.6	9.4	12.7	13.2		
Exchangeable K^1 ($cmol_c$ kg^{-1})						
Ripping alone	0.8 (0.91)	0.3 (0.53)	0.2 (0.42)	0.1 (0.33)	(0.001)	(0.028)
Deep incorporation of P and Zn	1.0 (0.98)	0.4 (0.60)	0.2 (0.44)	0.2 (0.40)		
Deep incorporation of P, K and Zn	0.8 (0.89)	0.4 (0.60)	0.2 (0.41)	0.1 (0.36)		
Manure	1.2 (1.10)	0.3 (0.53)	0.2 (0.41)	0.1 (0.36)		
Gypsum	0.9 (0.93)	0.4 (0.61)	0.2 (0.43)	0.1 (0.34)		
Gypsum and deep incorporation of P, Zn and K	0.9 (0.94)	0.4 (0.60)	0.2 (0.41)	0.1 (0.32)		
ESP						
Ripping alone	2.0	7.2	13.8	22.3	0.01	0.53
Deep incorporation of P and Zn	2.0	7.2	14.4	22.4		
Deep incorporation of P, K and Zn	1.5	5.7	12.5	20.8		
Manure	1.2	5.1	11.5	20.0		
Gypsum	1.2	5.2	13.1	20.5		
Gypsum and deep incorporation of P, Zn and K	1.7	6.1	13.6	21.2		
$EC_{1:5}$ (dS m^{-1})						
Ripping alone	0.20	0.28	0.37	0.81	0.001	0.036
Deep incorporation of P and Zn	0.21	0.30	0.37	1.15		
Deep incorporation of P, K and Zn	0.21	0.26	0.34	1.07		

Manure	0.18	0.25	0.36	0.89		
Gypsum	0.33	0.40	0.38	0.89		
Gypsum and deep incorporation of P, Zn and K	0.37	0.36	0.41	1.04		
pH						
Ripping alone	7.6	7.6	7.6	6.7	n.s.	0.06
Deep incorporation of P and Zn	7.6	7.5	7.5	6.5		
Deep incorporation of P, K and Zn	7.6	7.5	7.6	6.6		
Manure	7.6	7.6	7.6	6.8		
Gypsum	7.5	7.5	7.6	6.9		
Gypsum and deep incorporation of P, Zn and K	7.5	7.5	7.6	6.7		
Dispersion index (g 100 g^{-1})						
Ripping alone	9.0	11.7	10.8	17.7	n.s.	1.20
Deep incorporation of P and Zn	10.0	11.2	10.4	17.2		
Deep incorporation of P, K and Zn	9.3	10.3	9.2	18.6		
Manure	9.1	11.6	10.0	15.2		
Gypsum	11.5	9.9	10.3	15.4		
Gypsum and deep incorporation of P, Zn and K	11.1	10.2	10.6	15.5		
Drainage^{2} (2005-06)						
Ripping alone	45 (7.42)	32 (6.47)	9 (4.38)	4 (3.71)	n.s.	(0.774)
Deep incorporation of P and Zn	43 (7.30)	31 (6.46)	4 (3.71)	-1 (2.93)		
Deep incorporation of P, K and Zn	59 (8.32)	35 (6.68)	8 (4.23)	3 (3.67)		
Manure	33 (6.56)	11 (4.62)	4 (3.75)	-1 (2.95)		
Gypsum	36 (6.78)	23 (5.70)	15 (4.96)	3 (3.65)		
Gypsum and deep incorporation of P, Zn and K	52 (7.89)	27 (6.10)	3 (3.64)	-5 (3.2)		
Drainage^{2} (2006-07)	36 (6.77)	18 (5.29)	6 (3.99)	0 (3.15)	n.s.	(0.774)
Ripping alone	33 (6.54))	17 (5.16))	10 (4.47)	3 (3.62)		
Deep incorporation of P and Zn	43 (7.29)	20 (5.48)	7 (4.16)	5 (3.91)		
Deep incorporation of P, K and Zn	35 (6.73)	15 (4.96)	9 (4.36)	-6 (2.11)		
Manure	40 (7.04)	20 (5.47)	10 (4.47)	4 (3.76)		
Gypsum	26 (5.98)	15 (5.03)	6 (4.05)	5 (3.88)		
Gypsum and deep incorporation of P, Zn and K						

[1] Values in parentheses were sqrt transformed

[2] Values in parentheses are sqrt transformed values of (drainage+10)

Soil water retention characteristics were measured on aggregates sampled during September 2009 and fitted to a modified 3-parameter exponential model of the form y = a*exp(b/(x+c)), where y is soil water content and x is soil water potential, and a, b and c are constants (Fig. 27, Table 15). The shapes of the curves suggest that among both depths and rotation crops, the 10-30 cm depth under the corn (burnt) plot had poorer structure. This may be related to the burning of corn residues[1]. Significant differences among the other treatments could not be ascertained, partly due to the large scatter in the data. Differences among all depths and treatments were also absent in clods sampled after the 2010 wheat crop. Consequently, results of soil shrinkage and water retention for all treatments and depths were pooled in 2010 when fitting curves (Figs. 28 and 29).

In summary, few differences existed between the plots sown with corn and wheat, namely higher SOC concentration and a transient difference in water retention characteristics in the corn plot, presumed to be associated with structural deterioration associated with burning stubble. When adjustment is made for sampling depth and volume, SOC under corn was found to be lower than that under wheat during both 2009 and 2010. The major cause of differences between the two treatments was therefore, burning of the corn residues. The general absence of differences between the two rotations may also have been due to the short time period of this study.

6.3.3 Applying organic and inorganic amendments

Application of manure to a rainfed Vertosol (Experiment 5.1.2.1) resulted in higher exchangeable K (50% higher relative to deep-ripping alone) in the in the 10-30 cm depth (Table 16). The same treatment also reduced ESP (relative to ripping alone) in the 10-30 cm, 30-60 cm m and 60-120 cm depths. ESP was also lower in the same depths with deep incorporation of P, K and Zn, albeit to a lesser extent than manure. Overall, the decreases in ESP were small. The ESP changes were also not of a sufficient magnitude to reduce dispersion or increase drainage in any depth. Drainage out of the 30-60 cm depth was low and out of the 60-120 cm depth negligible (Table 16), indicating that there was very little water movement at depths > 30 cm. Application of K in the form of manure or as mineral fertiliser appeared to be as effective as applying gypsum to reduce ESP. Relative to deep ripping alone or manure application, exchangeable K values were higher by a very small amount only in the 0.10-0.30 m depth, but not in other depths, where either mineral fertiliser or gypsum was combined with deep ripping. This is probably because the maximum operating depths of the tines were of the order of 50 cm. Godwin (2007)[2] notes that in clayey soils, the stable openings created by tines with operating depths of ~50 cm rarely exceed 30 cm. Consequently, the effects of the amendments incorporated with the tines were restricted to the 10-30 cm depth. These results are similar to those cited by Jayawardane and Chan (1994)[3] who noted that even when ameliorants and deep-ripping are combined amelioration of subsoil constraints such as sodicity is limited to shallow depths.

Gypsum application also resulted in increasing $EC_{1:5}$ in the 0-60 cm depth, presumably due to increases in the concentrations of calcium and sulphate ions in the soil. These increases in $EC_{1:5}$ did not, however, reduce dispersion or increase drainage in the subsoil as the ESI, electrochemical stability index ($EC_{1:5}$/ESP) values did not increase beyond the threshold value of 0.05, below which, significant structural instability occurs, which in turn leads to reductions in hydraulic conductivity and drainage rates. ESI was similar among all treatments and averaged 0.05 in the 0.1-0.3 m depth, 0.03 in the 0.3-0.6 m depth and 0.04 in the 0.6-1.2

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[1] Lal, R. (1987) Fire. In "*Tropical Ecology andPhysical Edaphology*", pp.452-502. Wiley, Chichester.

[2] Godwin, R.J. (2007). A review of the effect of implement geometry on soil failure and implement forces. *Soil & Till. Res.*, **97**, 331-340.

[3] Jayawardane, N.S. and Chan, K.Y. (1994). The management of soil physical-properties limiting crop production in Australian sodic soils – a review. *Aust. Soil Res.* **32**, 13-44

m depth, but was increased by gypsum in the 0-0.1 m depth such that it increased from 0.10 with ripping alone to 0.25 with gypsum (average of both gypsum treatments). The relationship between ESI and dispersion index for this site suggests, however, that decreases in the latter would be small when ESI exceeds 0.10 (Fig. 30). In comparison with manure application, exchangeable Ca concentration was higher in the surface 0.10 m where ripping was combined with gypsum (Table 16). Significant differences in exchangeable Ca did not occur among other treatments or in other depths. pH, exchangeable Mg, dispersion index and drainage were not significantly affected by treatments (Table 16).

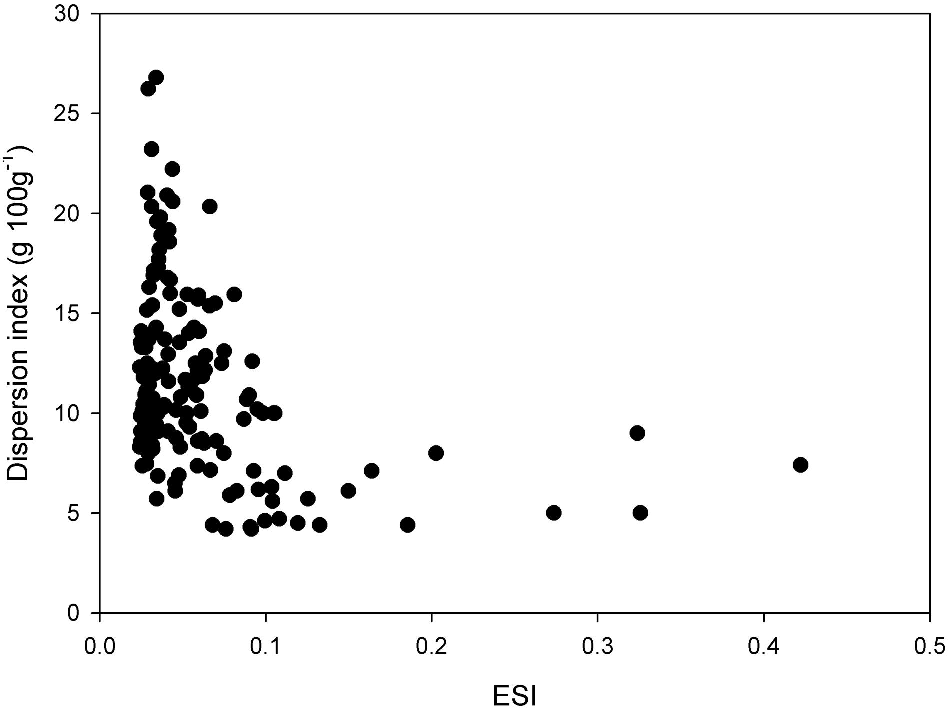

Fig. 30. Scatter plot of change in dispersion index with electrochemical stability index,ESI for all depths, Brigalow, Qld., 2005-2008

Overall the differences in soil properties among treatments were small in absolute terms. In comparison with ripping alone, the increase in exchangeable K with manure application was of the order of 0.16 t K/ha. The positive response to manure suggests that long-term cropping-related K depletion could be minimised by regular application of cattle manure; for example once every 5 years. It is notable that gypsum application, even at a rate of 9 t ha-1, did not significantly reduce dispersion and increase drainage. The recommended rates for gypsum, based on economic and bio-physical parameters, range from 2½ to 5 t/ha for grey Vertosols. At the same time, there are significant costs (2009 rates) associated with applying gypsum: the total cost of gypsum, spreading and ripping was of the order of $ 209.37/ha whereas ripping alone costs $A 41.40/ha. Given the absence of a response to gypsum application and the associated costs, the local farmer practice of not applying gypsum, which goes against advisory services’ recommendations, is a rational one in this soil type and environment. In other words, contrary to the widely-held opinion, frequent gypsum applications in the sub-tropical semi-arid dryland Vertosols of southern Darling Downs are not sustainable. The poor response to gypsum may be related to the typically erratic rainfall patterns of this region. Strong and positive effects of gypsum application have usually been reported where water availability, either through irrigation or frequent rainfall, and soil fertility were not limiting factors. In addition, the low stubble cover at the commencement of this experiment (20%) may also have facilitated evaporation and runoff, thereby decreasing water availability, which in turn may have reduced the impact of the applied gypsum.

6.4 Irrigation water quality

At ACRI irrigation water quality deteriorated between the 2008-09 and 2009-10 seasons such that there were marked increases in alkalinity and salinity that were characterised by increases in Na, pH and EC_w and decreases in Ca and Mg (Table 18). Consequently, SAR increased by 2-3 times, indicating that structural deterioration (instability)[1] may have been present. As the irrigation water was sourced from ground water, this suggests that aquifer quality had deteriorated as the duration of the drought lengthened and rate of groundwater extraction increased with limited replenishment. Irrigation water at ACRI was also a good source of nitrate-N and K, and suggests that fertiliser applied in other fields was being delivered via the reticulated water delivery system to fields C1 and D1. During 2010, after a wet winter and frequent runoff, water quality improved through increases in Ca and Mg, and decreases in SAR and pH. This may be due to replenishment of groundwater reserves through greater drainage and water storages at ACRI through greater inflow. Nitrate-N concentration in irrigation water decreased.

In comparison with ACRI, irrigation water (treated sewage effluent) at "Federation Farm" had very high SAR, EC_w, and soluble Cl concentration (Table 17). K concentration and pH_w were higher than at ACRI, but Ca and Mg were lower. In spite of the relatively high EC_w, the very high SAR suggests that soil structural stability may be poor in this site. Previous measurements of dispersion index in this site have shown that values were of the order of 12-20. In comparison, during the September 2001 (one year after irrigation with treated sewage effluent commenced) it was 8 in the 0-10 cm depth, 4 in the 10-30 cm depth, 3 in the 30-60 cm depth, and 6 in the 60-120 cm depth.

Table 17. Irrigation water quality July 2009-June 2010 at "Federation Farm", Narrabri. SAR, sodium adsorption ratio.

Field	**Date**	**Cl**	**K**	**Ca**	**Mg**	**Na**	**SAR**	**pH_w**	**EC_w**
				(mg/L)					**(dS/m)**
4A	20/10/2009	90	15	12	7	262	15.0	8.9	1.31
	11/12/2009	100	14	14	7	273	14.9	9.4	1.44
	25/01/2010	81	11	15	7	288	15.3	9.0	1.24
	25/02/2010	73	11	13	7	265	14.6	9.2	1.01
Seasonal sum (kg/ha)		344	52	54	28	1089			
2	4/12/2009	127	16	14	7	301	16.2	9.1	1.41
	25/01/2010	101	16	17	8	242	12.1	9.0	1.24
	25/02/2010	71	18	15	8	281	14.4	9.1	1.05
Seasonal sum (kg/ha)		299	49	46	24	824			
1	4/12/2009	85	18	16	8	270	13.7	9.2	1.30
	24/01/2010	76	22	23	13	298	12.4	9.2	1.28
	5/02/2010	80	19	18	10	263	12.2	9.3	1.41
	24/02/2010	79	5	17	9	292	14.4	9.3	0.93
Seasonal sum (kg/ha)		320	64	73	40	1123			

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[1] Maas, S., and Chapman, V. 2005. Water and soil quality, Australian Cotton Industry BMP. http://WWW.cottoncrc.org.au/files/ac52fc81-494a-420a-b398-994d00a50998/ISWQ_BMP.pdf

Table 18. Irrigation water quality July 2008-June 2009, July 2009-June 2010 and July 2010-June 2011 at ACRI (Fields C1 and D1), Narrabri. SAR, sodium adsorption ratio.

Season	Site	Date	Cl	K	Ca	Mg	Na	Nitrate-N[1]	SAR	pH$_w$	EC$_w$
						(mg/L)					(dS/m)
2008-09	Tillage/rotation experiment Field C1, ACRI,	22/12/2008	21	7	29	14	49	71	1.9	8.2	0.27
		12/01/2009	23	6	33	15	51	16	1.8	8.2	0.39
		22/01/2009	31	6	41	20	47	11	1.5	8.0	0.47
		4/02/2009	24	6	29	14	42	21	1.6	8.0	0.37
		6/03/2009	24	6	30	15	45	20	1.7	8.0	0.39
		19/03/2009	23	6	28	14	51	8	2.0	8.2	0.38
	Seasonal sum (kg/ha)		146	37	191	92	285	146			
	Cotton/vetch/wheat rotation experiment Field D1, ACRI, Narrabri	21/05/2008	23	6	25	15	51	12	2.0	7.8	0.38
		27/08/2008	25	5	31	17	47	5	1.7	7.6	0.43
		31/10/2008	25	4	24	16	54	23	2.1	7.9	0.40
		12/01/2009	21	6	32	15	39	8	1.4	8.0	0.39
		23/01/2009	30	6	37	18	61	4	2.0	8.0	0.44
		5/02/2009	26	6	31	16	75	8	2.7	8.0	0.39
		6/03/2009	24	6	30	16	65	6	2.4	8.0	0.38
	Seasonal sum (kg/ha)		174	37	210	112	391	65			
2009-10	Tillage/rotation experiment Field C1, ACRI, Narrabri	24/06/2009	20	3	24	11	103		4.4	9.0	0.45
		14/08/2009	22	3	21	11	117		5.1	8.8	0.40
		2/02/2010	20	4	23	11	143		6.2	8.7	0.37
		24/03/2010	24	5	27	13	121		4.8	8.3	0.41
	Seasonal sum (kg/ha)		86	16	94	45	484				
	Cotton/vetch/wheat rotation experiment Field D1, ACRI, Narrabri	23/06/2009	22	3	24	13	139		5.6	9.0	0.42
		13/08/2009	23	3	22	12	108		4.5	8.8	0.41
		17/11/2009	23	4	21	14	132		5.4	8.8	0.44
		23/11/2009	27	4	19	14	133		5.6	8.8	0.44
		21/12/2009	24	4	19	12	117		5.1	8.9	0.42
		3/02/2010	19	3	18	10	108		5.0	8.8	0.35
		4/03/2010	21	4	21	12	100		4.3	8.8	0.38
		30/3/2010	26	8	22	24	217		7.6	8.9	0.44
	Seasonal sum (kg/ha)		185	33	165	113	1054				
2010-11	Tillage/rotation experiment Field C1, ACRI, Narrabri	20/01/2011	23	5	32	17	69	0.50	2.5	8.4	0.36
		2/02/2011	35	6	34	23	69	0.02	2.2	8.5	0.51
		17/02/2011	25	4	32	15	63	0.03	2.3	8.4	0.36
		1/03/2011	25	7	52	27	85	<0.02	2.4	8.6	0.34
		16/3/2011	33	5	33	20	72	0.03	2.4	8.7	0.42
	Seasonal sum (kg/ha)		118	21	151	85	289	0.1			
	Cotton/vetch/wheat rotation experiment Field D1, ACRI, Narrabri	19/01/2011	21	4	28	15	57	0.30	2.2	8.4	0.33
		3/02/2011	34	5	36	18	67	0.07	2.2	8.4	0.48
		24/02/2011	28	4	28	15	79	0.04	3.0	8.6	0.38
		21/03/2011	29	5	36	18	64	0.03	2.2	8.5	0.43
	Seasonal sum (kg/ha)		112	18	128	66	266	0.4			

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[1] During 2010, it was discovered that the nitrate analyser in the CSIRO laboratory had been malfunctioning for some time. All nitrate-N results from 2009 were, therefore, rejected. Samples for the 2010-11 season were analysed at NSW DPI's laboratories at Wollongbar.

6.5 Soil hydrology

6.5.1 Sowing cotton into *in situ* mulch of wheat stubble

6.5.1.1 Soil water storage and infiltration

Among cropping systems, soil water storage was generally highest under the cotton-wheat rotation sown on permanent beds, although relative differences varied with seasonal rainfall during the cotton season (Figs. 31 and 32). During growing seasons when rainfall was the major source of early season water for the cotton crop (2004-05, 2008-09, see Fig. 31), soil water storage was greatest under the cotton-wheat rotation sown on permanent beds (Fig. 32). When a major proportion of early season water requirements were supplied by irrigation (2002-03, 2006-07), however, a similar, but smaller trend in soil water storage among cropping systems was present. This was such that, in comparison with continuous cotton, average soil water storage from October to December of 2004-05 and 2008-09 seasons was 52 mm higher under the cotton-wheat rotation, whereas for the same period during the 2002-03 and 2006-07 seasons it was only 26 mm higher. The higher early season soil water storage under the cotton-wheat rotation when rainfall was adequate reflects the greater rainfall infiltration and lower evaporation resulting from the *in situ* wheat stubble (see later discussion), and better soil water storage capacity due to its greater subsoil porosity[1]. As the season progressed, and water used by the cotton increased, with much of it coming from irrigation, the magnitude of the differences among treatments decreased or disappeared.

In comparison with either of the continuous cottons, seasonal infiltration was least during 2002-03, 2004-05 and 2008-09 where cotton-wheat was sown on permanent beds (Fig. 33), but did not differ significantly among cropping systems during 2006-07. This may be due to the higher in-crop rainfall during 2002-03, 2004-5 and 2008-09, and consequently, wetter conditions under the cotton-wheat system. Soil cracking, and therefore, infiltration would have been less in this treatment. The dominant pathway of water infiltration in drying Vertisols are soil cracks. Seasonal infiltration and soil water storage with “frequent” irrigation were greater than that with “infrequent” irrigation and reflects the water availability under the former. However, the proportions of water (as a percentage of rainfall and irrigation) which infiltrated differed. Averaged over 2006-07 and 2008-09, this was of the order of 64% with “frequent” irrigation and 79% with “infrequent” irrigation, and presumably reflects the drier and hence, deeper and more intensive soil cracking in the former treatment.

In summary, the rainfall harvesting and storage capability of a cotton-wheat rotation where cotton is sown into *in situ* wheat stubble is superior to continuous cotton sown either on permanent beds or after conventional tillage. In spite of the above-average rainfall during the past year, reduction in water availability due to a combination of drought and legislation has become a major constraint in irrigated farming systems in many Australian states during the past decade. Consequently, management systems which conserve all rainfall received *in situ*, thus reducing the requirements for irrigation water can contribute greatly to the sustainability of irrigated farming systems.

6.5.1.2 Deep drainage

Drainage, particularly in the deeper depths, was highest ($P < 0.01$) during the cotton seasons of 2004-05, 2006-07 and 2008-09 under the cotton-wheat rotation on permanent beds (Fig. 34). This reflects the distribution of drainage pores in these treatments[1]. During the 2002-03 cotton season, however, subsoil drainage did not differ significantly among treatments, although there was trend towards higher values under permanent beds. Drainage also varied significantly ($P < 0.001$) with depth, with that out of the 1.2 m and 0.3 m depths being lowest and highest, respectively. The low drainage out of the 1.2 m depth was

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[1] Hulugalle, N.R., Weaver, T.B., Scott, F. (2005). Continuous cotton and cotton-wheat rotation effects on soil properties and profitability in an irrigated Vertisol. *J. Sustainable Agric.* **27,** 5-24.

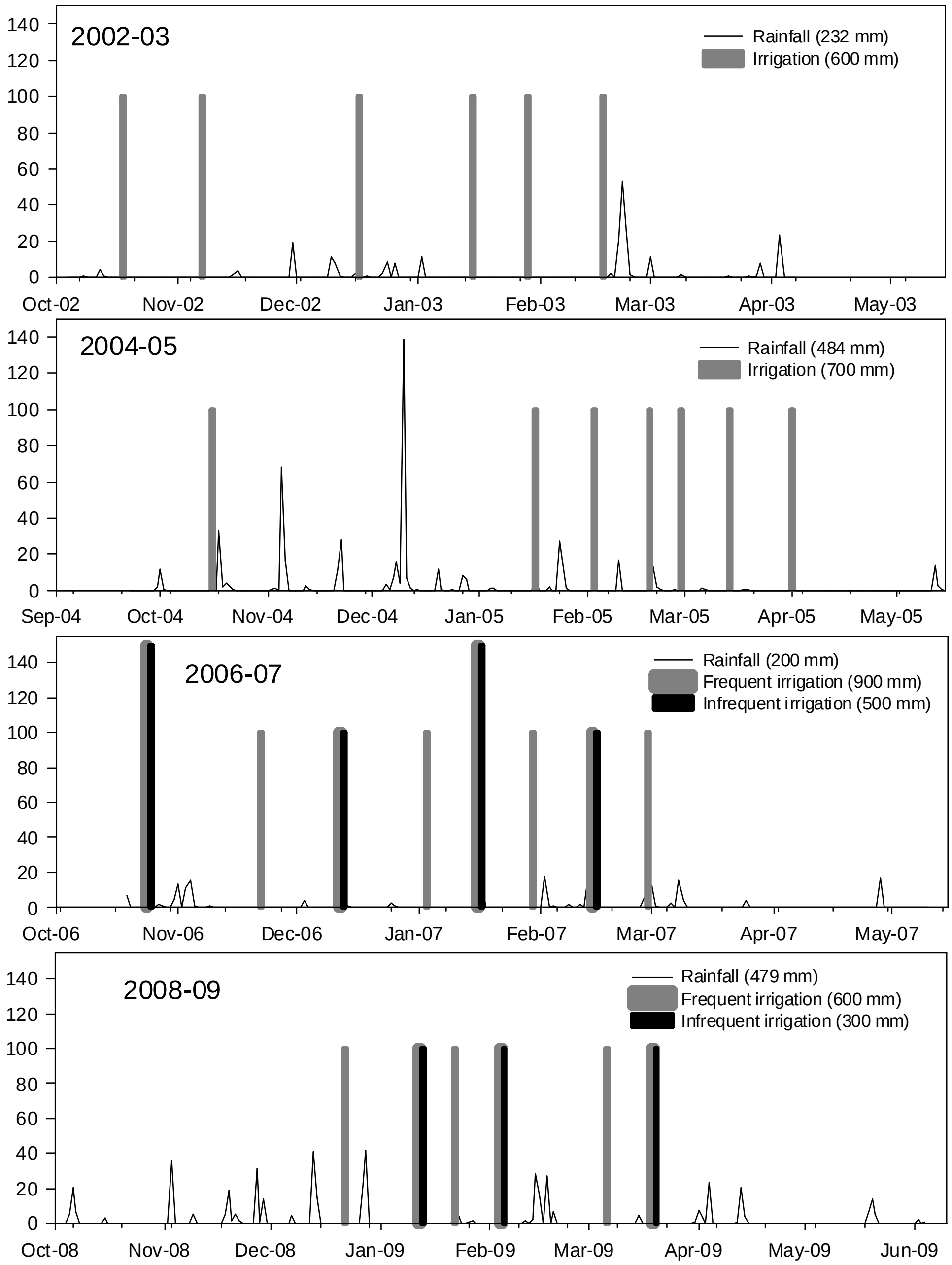


Fig. 31. Seasonal rainfall land irrigation during the cotton-growing seasons of 2002-03, 2004-05, 2006-07 and 2008-09.

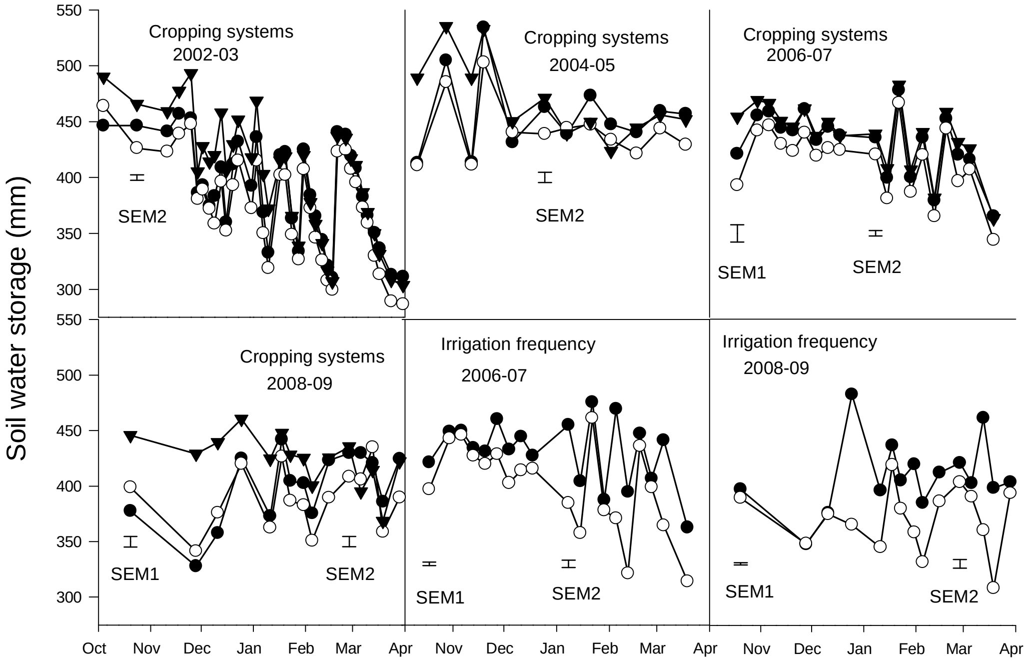


Fig. 32. Variation of soil water storage in the 0-1.2 m depth with cropping system (2002-03, 2004-05, 2006-07 and 2008-09 seasons) and irrigation frequency (2006-07 and 2008-09 seasons). Cropping Systems: ●, Conventional tillage/cotton-cotton; ○, Permanent beds/cotton-cotton; ▼, Permanent beds/cotton-wheat. Irrigation Frequency: ●, Frequent irrigation; ○, Infrequent irrigation. SEM1, standard error of the means for first data point, value measured with soil cores; SEM2, standard error of the means for all other data points, values measured with neutron moisture meter.

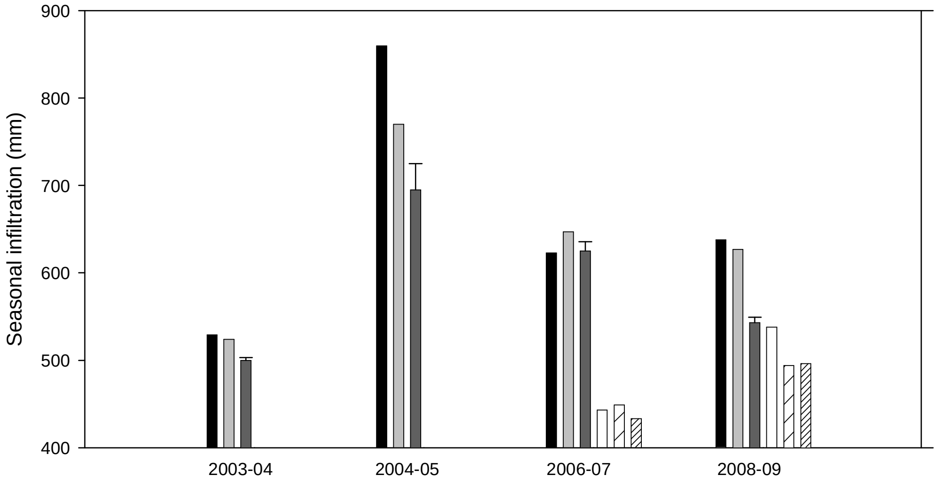


Fig. 33. Variation of seasonal water infiltration with cropping system (2002-03, 2004-05, 2006-07 and 2008-09 seasons) and irrigation frequency (2006-07 and 2008-09 seasons). Black, Conventional tillage/cotton-cotton/frequent irrigation; Light grey, Permanent beds/cotton-cotton/frequent irrigation; Dark grey, Permanent beds/cotton-wheat/frequent irrigation; White, Conventional tillage/cotton-cotton/infrequent irrigation; Coarse hatched, Permanent beds/cotton-cotton/infrequent irrigation; Fine hatched, Permanent beds/cotton-wheat/infrequent irrigation; Vertical bar is standard error of the means.

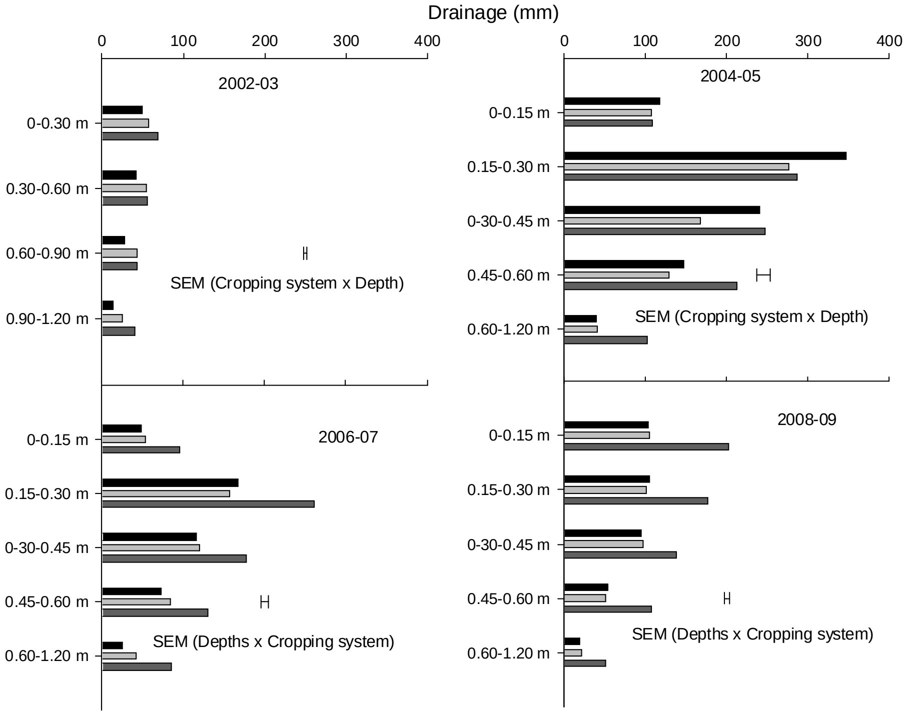


Fig. 34. Variation of drainage with cropping system and depth, 2002-03, 2004-05, 2006-07 and 2008-09 seasons. Black, Conventional tillage/cotton-cotton; Light grey, Permanent beds/cotton-cotton; Dark grey, Permanent beds/cotton-wheat; SEM, standard error of the means

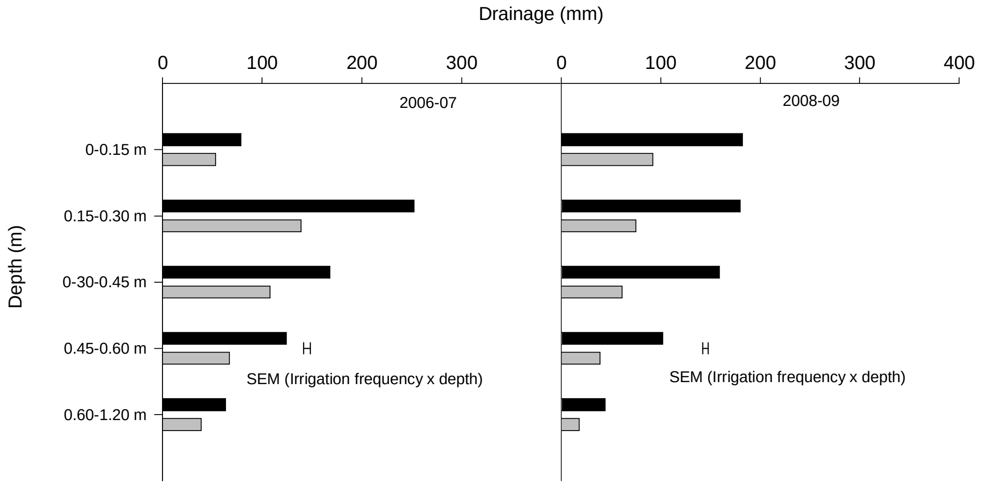


Fig. 35. Variation of drainage with irrigation frequency and depth, 2006-07 and 2008-09 seasons. Black, Frequent irrigation; Light grey, Infrequent irrigation; SEM, standard error of the means.

probably due to the low porosity and sodicity in the 1.2 m depth, whereas the tendency for the depths nearest the furrows (i.e. 0.3 m) to remain saturated for longer periods means that hydraulic conductivity also remains relatively high for extended periods in this depth. Drainage was also least during the 2002-03 season, presumably because water inputs were relatively low, but not low enough to cause deep cracking, such as with the infrequent irrigation during 2006-07. During the 2006-07 season water inputs were lower, but due to intensive soil cracking drainage was higher because of a high level of preferential flow (see below).

Drainage in all depths was greater ($P < 0.05$) with a higher irrigation frequency than with an "infrequent" one (Fig. 35) during the 2006-07 and 2008-09 cotton seasons. However, the pathways of drainage may have differed between the two treatments. The drier soil profile in the infrequently irrigated treatments would have resulted in more cracking, and consequently drainage via the soil cracks would have been the dominant pathway whereas with frequent irrigation and wetter soil, more water would have drained by matric flow.

The previous discussion on the possible pathways of drainage in this soil referred to conventional belief, which states that that drainage in Vertisols occurs by preferential flow through open soil cracks or mass flow through bulk (uncracked) soil. However, some authors have suggested, that a significant proportion of drainage may occur in wet soils through by-pass flow via slickensides.

6.5.2 Including vetch in cotton-based crop rotations

6.5.2.1 Soil water storage and infiltration

In comparison with rotations that included a wheat crop (cotton-wheat, cotton-wheat-vetch), soil water storage to a depth of 1.2 m during the early part of the cotton-growing season was generally characterised by lower values in systems that had cotton sown every year (cotton-cotton, cotton-vetch) (Fig. 36). The probable causes may include longer fallow periods, better subsoil structure and greater amounts of rotation crop stubble in the former two systems. Towards the latter part of the season, however, the cotton-wheat rotation tended to dry out the profile more, suggesting that uptake and evaporative losses were high. Soil water storage was lowest in the cotton-vetch rotation. This was probably due to the fact that the cotton-vetch sequence had virtually no fallow, whereas the three rotations included fallows that ranged from 3 to 10 months. Soil water storage in the cotton-wheat-vetch rotation was higher than that in the cotton-wheat sequence in years when rainfall was a major early season contributor to crop water requirements. The reverse occurred when irrigation contributed more to crop water needs. Retention of vetch and wheat mulch *in situ* in the cotton-wheat-vetch sequence may have facilitated rainfall harvesting. This observation is similar to soil

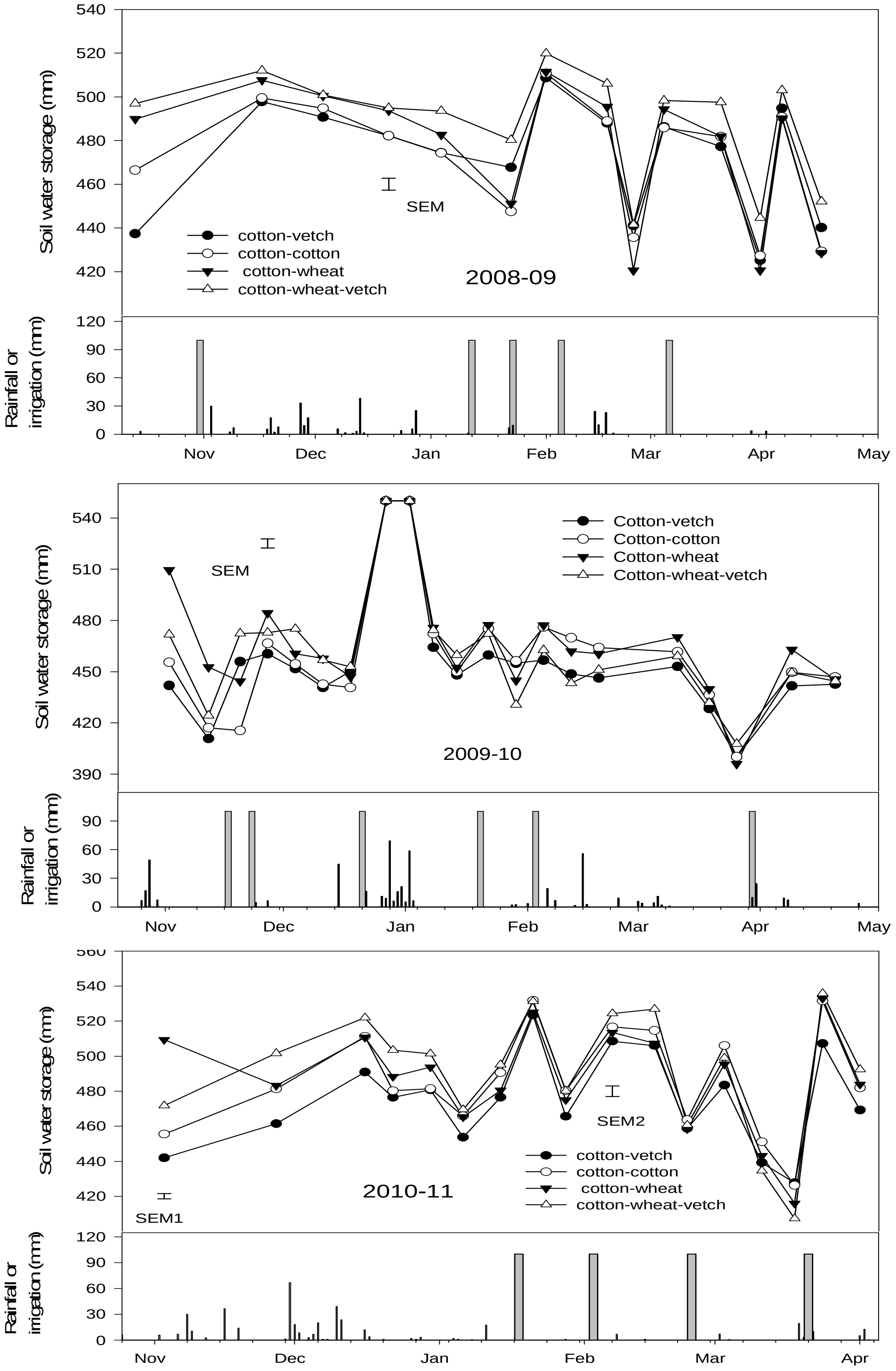
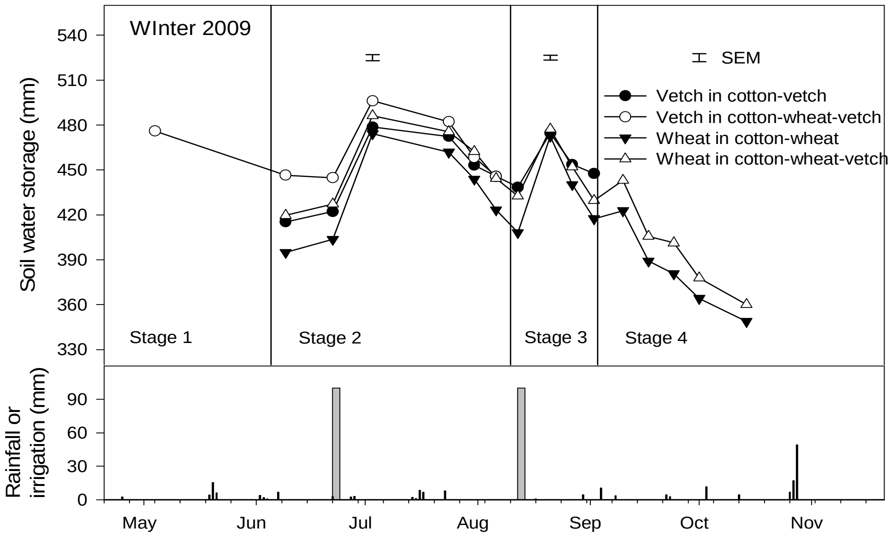


Fig. 36. Soil water storage, rainfall (black bars) and irrigation events (grey bars) in cotton-based crop rotations, cotton growing seasons 2008-09, 2009-10 and 2010-11, Field D1, ACRI, Narrabri



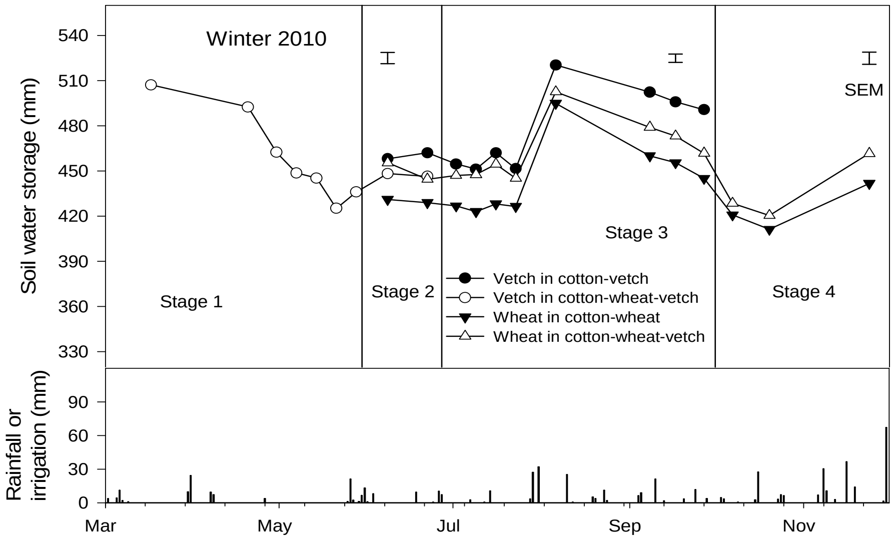


Fig. 37. Soil water storage, rainfall (black bars) and irrigation events (grey bars) in cotton-based crop rotations, winter 2009 and winter 2010, Field D1, ACRI, Narrabri

water storage patterns in the cotton-wheat rotation with *in situ* mulch reported in the previous section.

Seasonal water infiltration during the 2008-09 and 2009-10 cotton seasons did not differ significantly among rotations. Mean seasonal infiltration was 586 mm during 2008-09 and 396 mm during 2009-10. The lower value during the 2009-10 season may be related to the higher rainfall (464 mm in 2009-10 vs. 361 mm in 2008-09), and consequently wetter soil conditions that prevailed during 2009-10. This in turn would have minimised the occurrence of intense wetting/drying cycles (and soil cracking) during the cotton season. Soil cracks are the major pathways of infiltration in cracking clay soils (Vertosols). Thus, infiltration would have been reduced and runoff enhanced during 2009-10.

Results of soil water storage during the winter seasons were analysed by grouping according to the crops that were in the field at any one time; *viz*. stage 1 corresponds to the period when only vetch in the cotton-wheat-vetch sequence was present, stage 2 to the period when rotation crops from all four treatments were present, stage 3 to the period when wheat crops in the two rotations that included wheat and the vetch in the cotton-vetch sequence were present, and stage 4 the period when wheat crops in the two rotations that included wheat were present (Fig. 37).

During the rotation phase, soil water storage was higher with wheat in the cotton-wheat-vetch sequence than with wheat in the cotton-wheat sequence. As water stored in soil was higher shortly after sowing wheat in the former rotation, this suggests that there may have been some residual water remaining from the previous cotton season. Vetch in the cotton-wheat-vetch was always sown into moist soil as it followed a summer fallow (where stubble from the previous wheat crops had been retained as *in situ* mulch) whereas vetch in the cotton-vetch sequence was sown into dry soil as it followed a cotton crop, and thus required irrigation.

6.5.2.2 Deep drainage

Deep drainage in cropped plots was many times higher than that in fallow plots, during the cotton seasons of 2008-09, 2009-10 and 2010-11and is a reflection of the higher water inputs in the former (Fig. 38). Among rotations, cotton sown in either the cotton-wheat or cotton-wheat vetch rotations had higher drainage than either the continuous cotton or cotton-vetch rotation (Fig. 38). This is likely to be due to the higher proportions of drainage pores observed in soils where wheat had preceded cotton (see earlier discussions). Drainage out of the beds (0-10 cm depth) of the cotton-wheat rotation was also higher than that in the cotton-wheat-vetch sequence during 2008-09 and 2009-10 but not during 2010-11, and may have been related to early season soil water contents in this depth; *viz*. frequent rainfall on rotations with wetter soil conditions ensured greater drainage (Fig. 36).

During the winters of 2008 and 2009, drainage was higher in plots which had wheat or vetch sown than in fallow plots (Fig. 39). Irrigation and rainfall when combined with actively growing crops results in cycles of wetting and drying out of the soil profile, and thus, creation of soil cracks, root channels and slickensides, all of which function as preferential flow pathways for deep drainage. In addition, irrigation also results in transient saturated conditions and high hydraulic conductivity and thus, high drainage rates. The differences among the rotation crops reflect the varying growth periods, which in turn, lead to differences in water inputs (rainfall and irrigation) and soil drying. In this experiment, drainage was generally in the order of wheat in cotton-wheat and cotton-wheat-vetch > vetch in cotton-vetch and vetch in cotton-wheat-vetch. The last had the least amount of irrigation and subsisted mainly on stored soil water and in-crop rainfall.

Drainage during 2010 winter was lower than those during the 2008 and 2009 winters, presumably because no irrigation took place due to the frequent rainfall in 2010. Highest drainage during the 2010 winter occurred in the fallow phase (~ 11 months, Nov 2009 to November 2010) of the cotton-wheat rotation (Fig. 39). The primary difference between this year and previous years was the frequent rainfall (Fig. 37). This was such that no irrigation was required. Furthermore, rainfall received during 2010 winter was in addition to that received during the 2009-10 summer, ensuring a near saturated profile in the fallow of the cotton-wheat rotation and a relatively high hydraulic conductivity. This was not the case with the other treatments which either had a much shorter fallow (e.g. cotton-cotton, ~5 months fallow) or had crops growing in them after cotton, thus resulting in generally unsaturated soil conditions and lower hydraulic conductivities. High drainage under lengthy fallows when rainfall is frequent and high has been reported previously from this region (e.g. Liverpool Plains[1]).

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[1] Paydar Z., Huth, N., Ringrose-Voase, A., Young, R., Bernardi, T., Keating, B.,and Cresswell, H. (2005). Deep drainage and land use systems. Model verification and systems comparison. *Aust. J. Agric. Res*. **56**, 995–1007

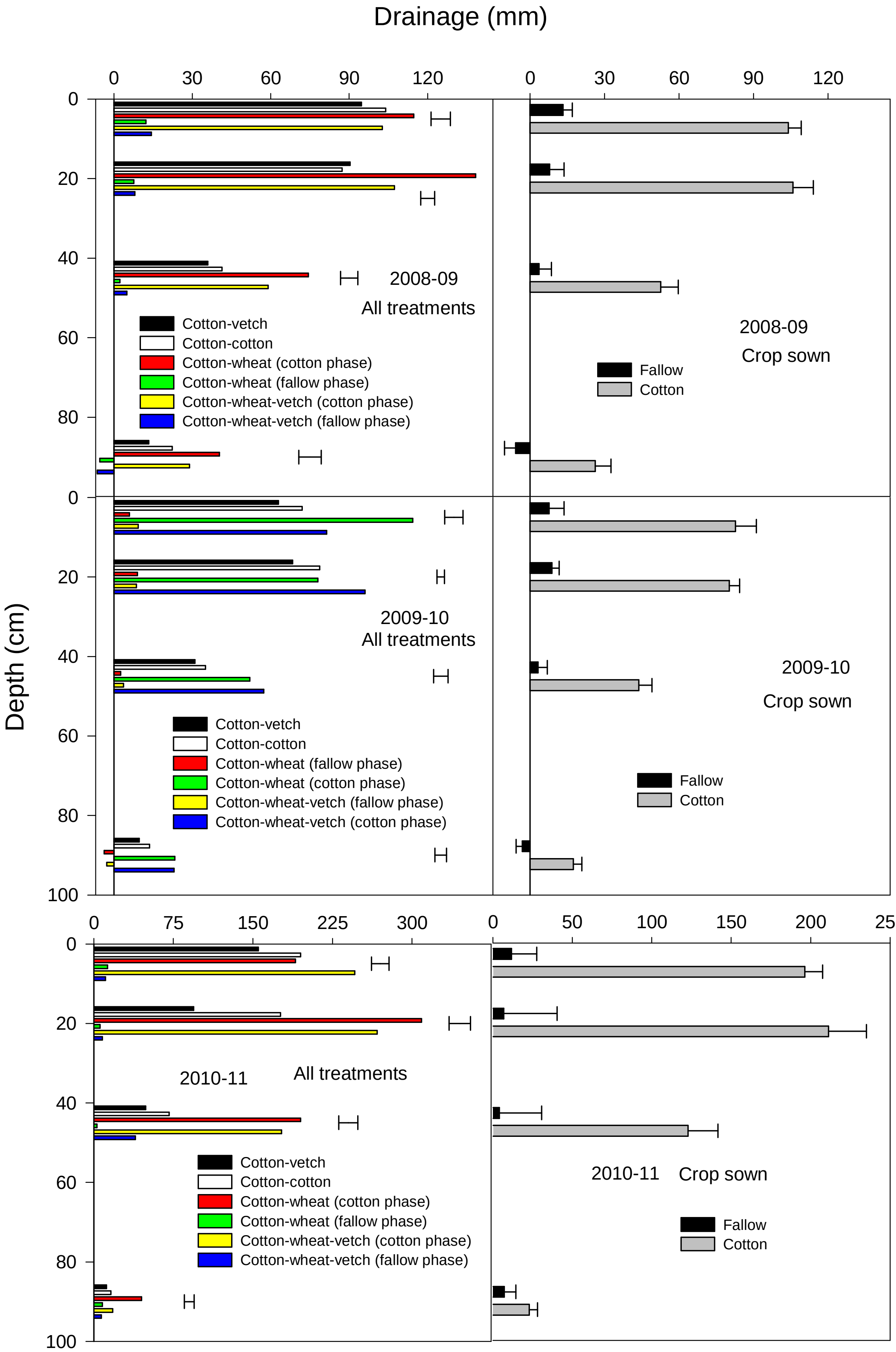

Fig. 38. Effect of crop rotation on deep drainage during the cotton seasons of 2008-09, 2009-10 and 2010-11, Field D1, ACRI. Horizontal bars are SEM's.

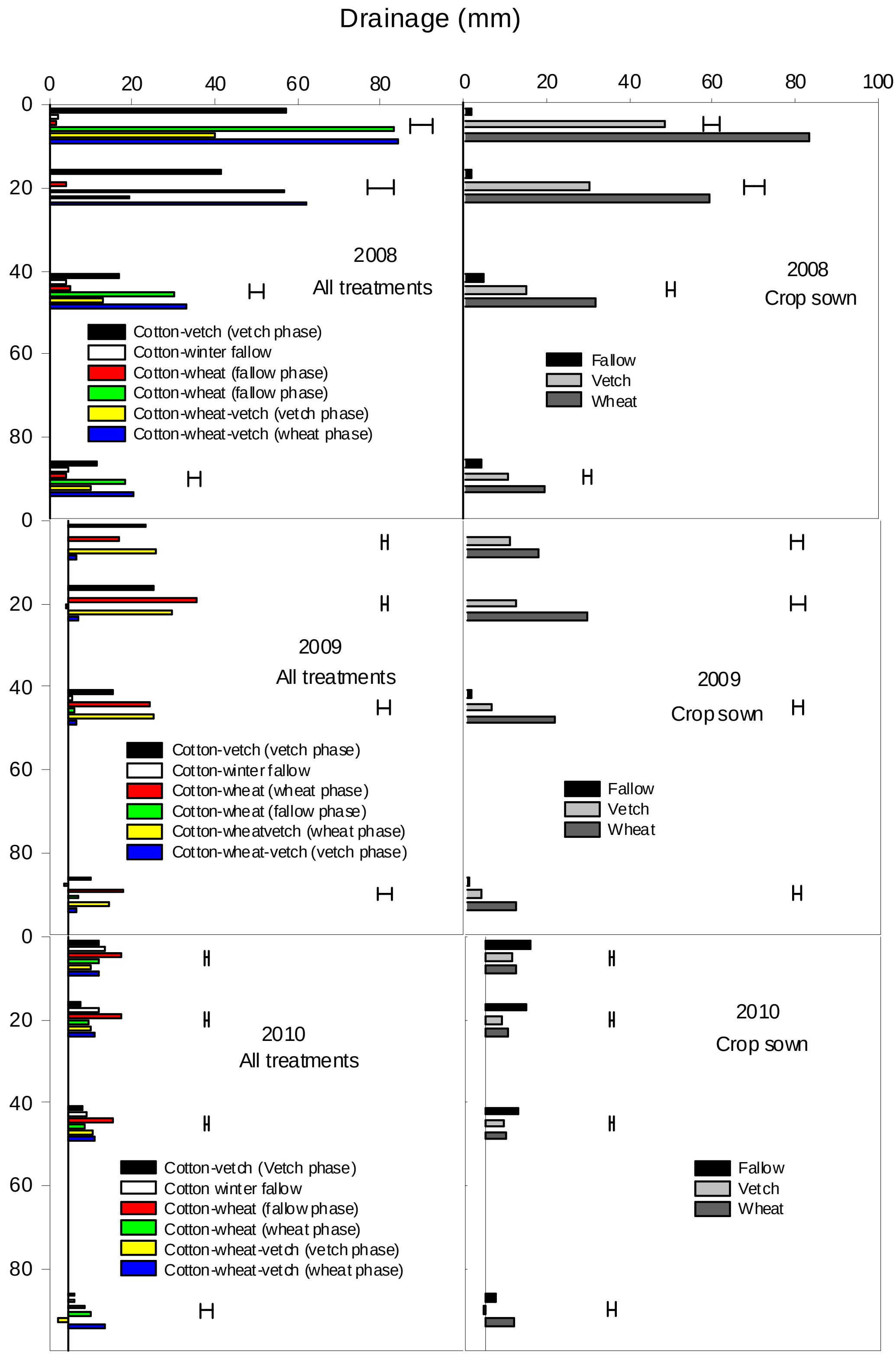

Fig. 39. Effect of crop rotation on deep drainage during the winters of 2008, 2009 and 2010, Field D1, ACRI, Narrabri. Horizontal bars are SEM's.

6.5.2.3 Evaporation

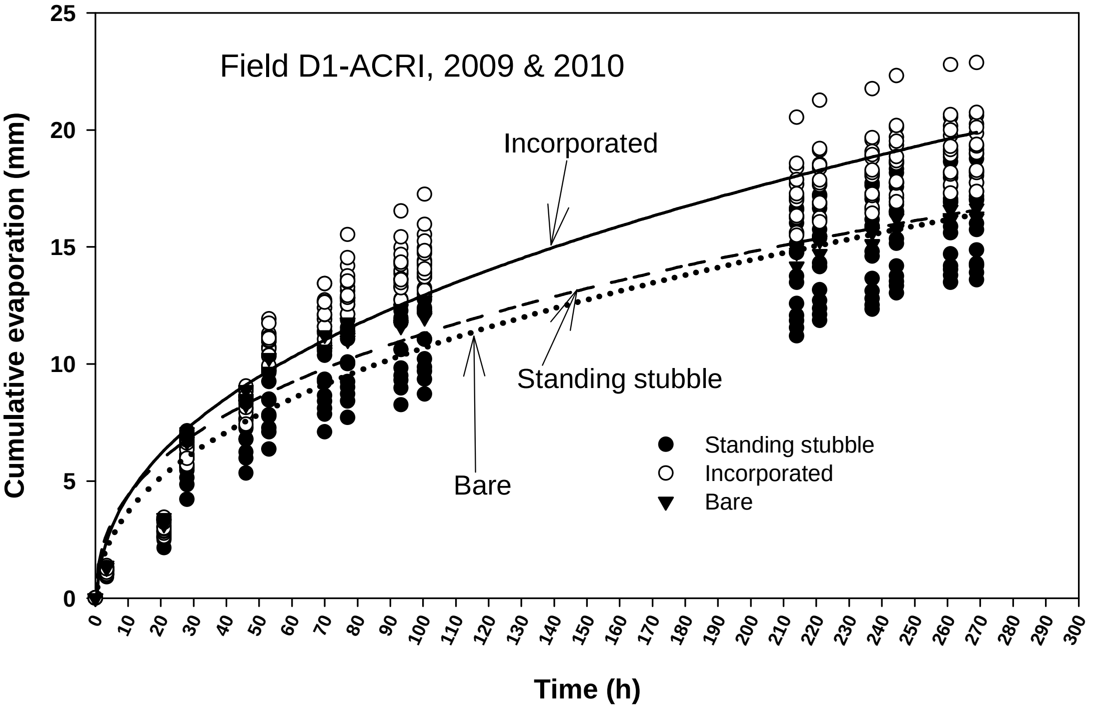

Fig. 40. Cumulative evaporation from soil with no stubble (crusted surface), wheat stubble incorporated or retained as in situ mulch, Field D1, ACRI, Narrabri.

Evaporation measured from bare/crusted soil and from soil where wheat stubble was either incorporated or retained as *in situ* mulch showed that incorporation of wheat stubble resulted in the highest water losses through evaporation (Fig. 40). However, there were no differences between the undisturbed, bare surface and where wheat stubble was retained *in situ* as mulch with no soil disturbance. This suggests that one of the consequences of the act of disturbing the soil is to facilitate evaporation. Furthermore, in a self-mulching soil, the practice of retaining the mulch may be of secondary importance in reducing evaporation.

Two empirical models were developed using linear multiple regression analysis: one, which used all drying sequences (laboratory and external) and a second, which used only exterior drying sequences. These were as follows:

(a) E_a=-2.46 +0.094θ-0.73S+4.82lnE_0, n = 1221, R^2 = 0.77***, MSE = 5.76 [all drying sequences];

(b) E_a=-10.17+0.35θ-1.36S +4.65lnE_0, n = 792, R^2 = 0.63***, MSE = 5.63 [exterior drying sequences only];

Where E_a is cumulative soil evaporation (mm), E_0 is cumulative evaporation from a free water surface (potential evaporation) (mm), θ is initial soil water content (mm), and S is a dummy variable indicating the presence (1) or absence (0) of surface mulch. The model was verified during February 2011 using samples taken from various fields at ACRI. A very close fit between estimated and observed evaporation occurred with the model based on exterior drying sequences, whereas the model based on all drying sequences overestimated evaporation (Fig. 41). The former model can be used to estimate evaporative water losses from cotton fields during the germination and emergence process. The model suggests that depending on evaporative demand over a 7-10 day period, the difference in available water in the surface 7 cm of stubble incorporated and *in situ* mulched plots can be of the order of 3-10 mm. Although this is small in absolute terms, the impact on hydraulic conductivity, and thus water movement through soil to the germinating seed can manyfold. This is because in clay soils, the relationship between water content and hydraulic conductivity is exponential (Fig. 42).

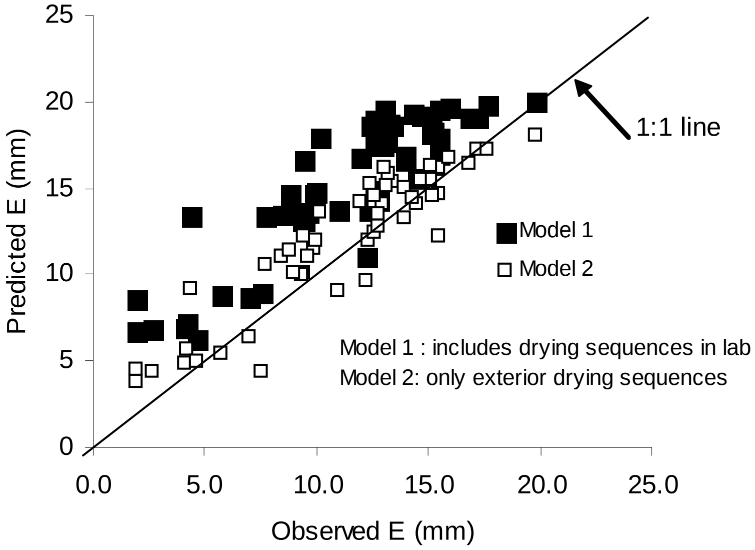

Fig. 41. Comparison of evaporation estimated using previously derived models with measured evaporation

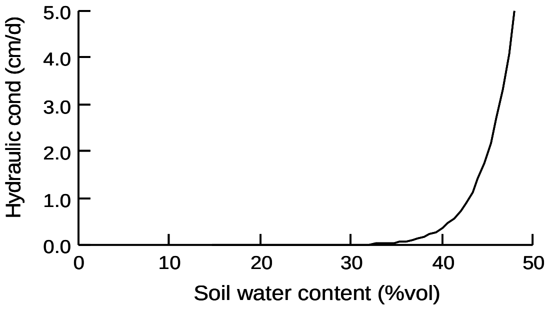

Fig. 42. Typical soil water content-hydraulic conductivity relationship for a clay soil

Provided rainfall and potential evaporation is available, the model derived from exterior drying sequences can be used to estimate_evaporation from mulched and stubble incorporated soils. An example that uses actual rainfall and potential evaporation (from weather records) for the first half of October 2008 is shown below (Fig. 43). It was assumed that as soil water storage at field capacity for the seedbed (0-7 cm depth) in grey clays ranges from 25-35 mm, the soil water storage in this site after the rainfall event shown was of the order of 30 mm. The results indicate that soil evaporation from the 8th to the 14th of October 2008 was 18 mm in the mulched soil and 28 mm in the stubble incorporated site.

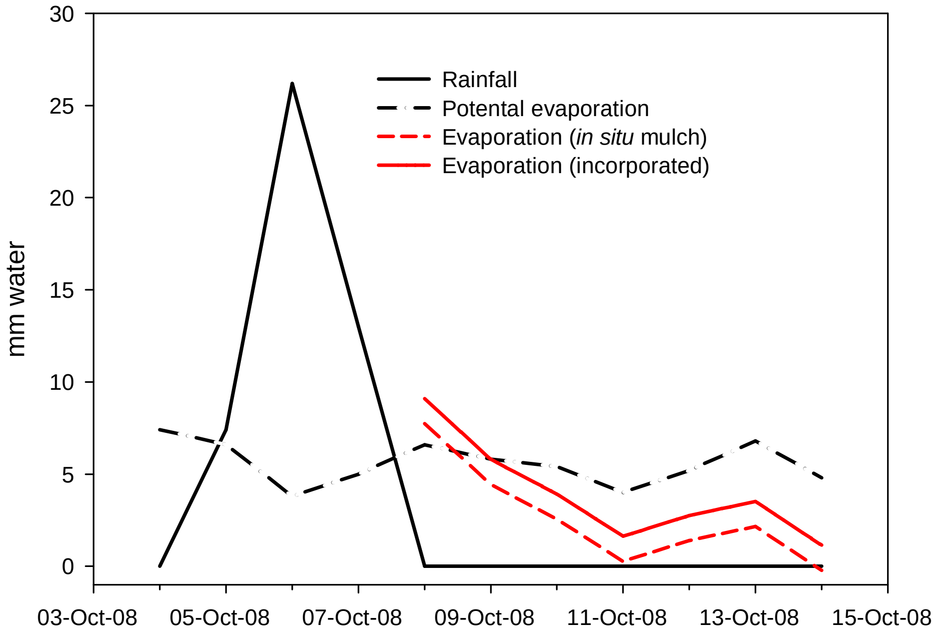

Fig...Simulated evaporation from mulched and stubble incorporated beds in a grey clay

6.5.3 Methods for measuring deep drainage in the field

6.5.3.1 Comparing deep drainage measured with a tension lysimeter and chloride mass balance method

Table 19. Comparison of drainage (means ± sd) measured with chloride mass balance method and tension lysimeter in the cotton-wheat rotation in Field C1, ACRI, Narrabri

Season	**Depth (cm)**	**Chloride mass balance (mm)**		**Lysimeter (mm)**	**Difference (mm)**	
		Steady state	**Transient state**		**Steady state**	**Transient state**
2006-07 cotton season	0-60	212 ± 40.3	256 ± 48.5	-		
	60-90	150 ± 35.9	181 ± 43.2	-		
	90-120	87 ± 17.6	104 ± 21.2	-		
	120-150	45 ± 8.5	54 ± 10.2	-		
	150-200	29 ± 4.0	35 ± 4.8	74	45	39
2008-09 cotton season	0-60	218 ± 20.3	277 ± 12.5	-		
	60-90	111 ± 1.8	175 ± 70.9	-		
	90-120	71 ± 23.2	150 ± 106.9	-		
	120-150	50 ± 6.4	74 ± 34.8	-		
	150-200	28 ± 1.2	40 ± 13.2	54	26	14
2010-11 cotton season	0-60	257 ± 31.0	259 ± 30.7		-	
	60-90	127 ± 42.6	126 ± 43.0		-	
	90-120	57 ± 28.5	55 ± 28.8		-	
	120-150	29 ± 13.0	28 ± 13.1		-	
	150-200	21 ± 13.0	21 ± 13.3	0.5	20.5	20.5

Except during the 2010-11 season, drainage out of the 200 cm depth estimated with the chloride mass balance method using either steady state or transient state assumptions was lower than that measured with the tension lysimeter (Table 19). However, values estimated using transient state assumptions were closer to the drainage measured with the lysimeter than those estimated using steady state assumption. Mean differences for the 2006-07, 2008-09 and 2011-11 seasons were of the order of 31 mm with steady state assumptions and 25 mm with transient state assumptions. These differences method may be due to a combination of factors that include:

- Drainage through preferential flow pathways is not taken into consideration by the chloride mass balance method.
- Spatial variability. Cores taken to estimate soil Cl were not taken from the exact same position as the lysimeter to avoid damage to the trays and to ensure that sampling did not result in preferential flow pathways adjacent to the trays.
- Exchange of chloride with the soil mass is not accounted for by the chloride mass balance method.
- A proportion of the chloride in pore water remains inaccessible to water draining through the soil profile[1]
- Artefacts may have been created by the lysimeter (e.g. soil disturbance associated with its construction, soil subsidence and ponding, retarding of water flow due to the access "chimney" etc.) (Fig. 44)

Fig. 44. Ponding of water near lysimeter

During the 2010-11 season drainage measured with the lysimeter was 41 times less than those measured with either chloride mass balance methods. This was probably caused by the absence of a significant potential gradient in the 25 cm thick layer immediately above the

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[1] Gee, G.W., *et al.* (2005). Chloride mass balance: cautions in predicting increased recharge rates. *Vadose Zone J.* **4**, 72-78.

lysimeter trays (A. Nadelko, pers. comm.). The frequent and heavy rains during the preceding winter and the first half of the 2010-11 growing season resulted in a uniformly wet profile to depths of approximately 2 m. The drainage front (i.e. the soil layer with a significant potential gradient) may, therefore, have existed deeper in the profile than in most years.

6.5.3.2 Estimating deep drainage using an EM38 in horizontal mode

The linear multiple regression model for estimating chloride concentration, $Cl^{-}_{predicted}$ from EM_H, soil water storage and ESP data was:

$\ln Cl^{-}_{predicted} = 4.05 - 0.15(\ln EM_H) - 0.74(\ln S) + 0.20ESP$, $n = 30$, $R^2 = 0.87^{***}$

Where $Cl^{-}_{predicted}$ is the estimated chloride concentration; S is soil water content (mm); EMH is the electromagnetic induction from the EM38 (mS/m) in horizontal mode and ESP is the exchangeable sodium percentage. Comparison of predicted with measured chloride concentrations in saturated extracts indicated that were two distinct relationships (Fig. 45).

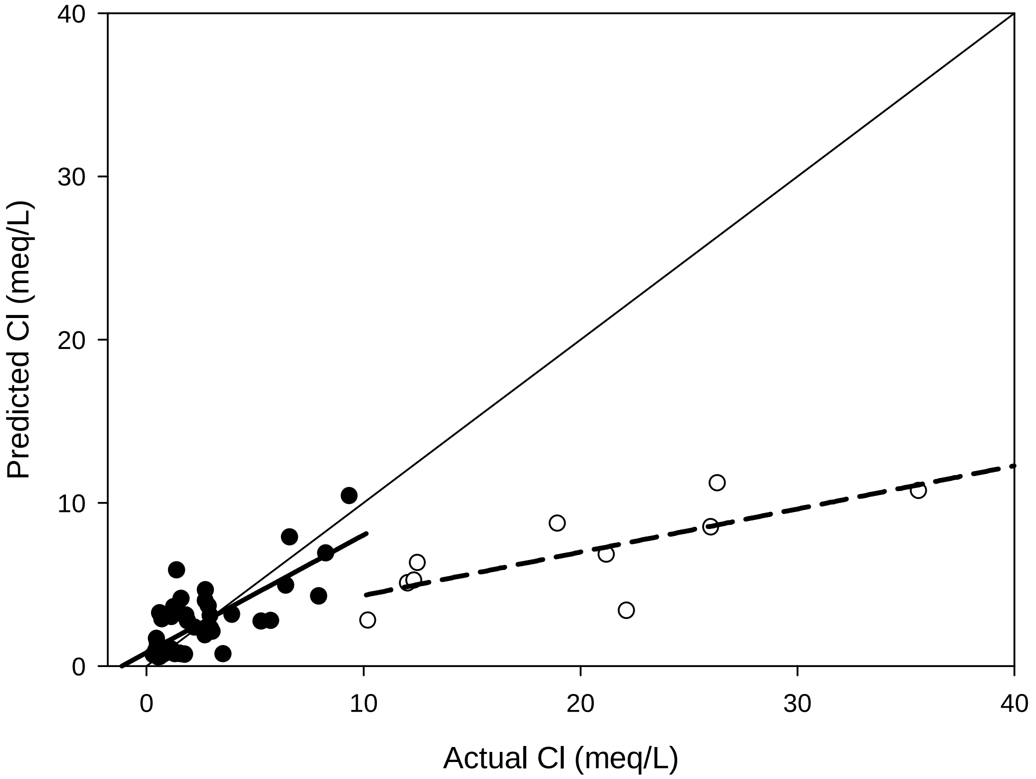

Fig. 45. Relationship between measured and predicted chloride concentrations in saturated extracts of soil sampled from "Beechworth, ACRI (Field C1) and "Glenarvon" during 2000 to 2002 and Field D1 at ACRI during 2010 and 2011.

Where Cl^- in saturated extract exceeded 10 meq/L (355 mg/L = 240 mg/kg)), predicted Cl^- diverged widely from actual Cl^-. Direct application of the model is therefore limited to soils where Cl^- concentrations were < 10 meq/L. The causes for this may include interference with neutron probe readings (i.e. absorption of fast neutrons) by chloride and incomplete extraction of cations due to salinity during soil chemical analyses. Thus in saline soils (chloride concentration > 10 meq/L), the predicted chloride concentration requires further adjustment with the following equation before using in a chloride mass balance model:

$Cl^{-}_{adjusted} = 5.04 + 2.13Cl^{-}_{predicted}$, $R^2 = 0.58^{*}$, SE est. = 5.73.

This also implies that neutron probes calibrated in non-saline or low saline soils cannot be used in saline soils without further calibrations *in situ*.

6.6 Crop growth and yield

6.6.1 Rotation crop root growth

6.6.1.1 Corn

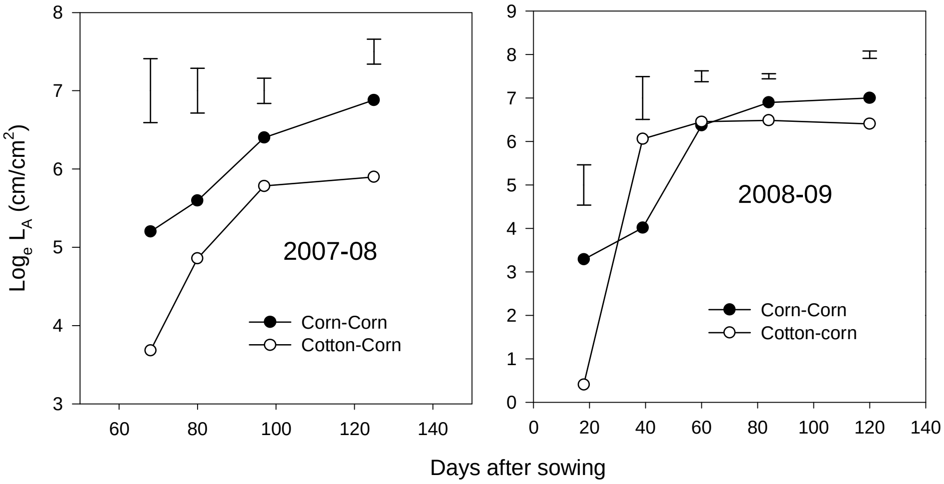

Fig. 46. Root length per unit area, L_A of corn in continuous corn and cotton-corn rotations, Field C1, ACRI, Narrabri

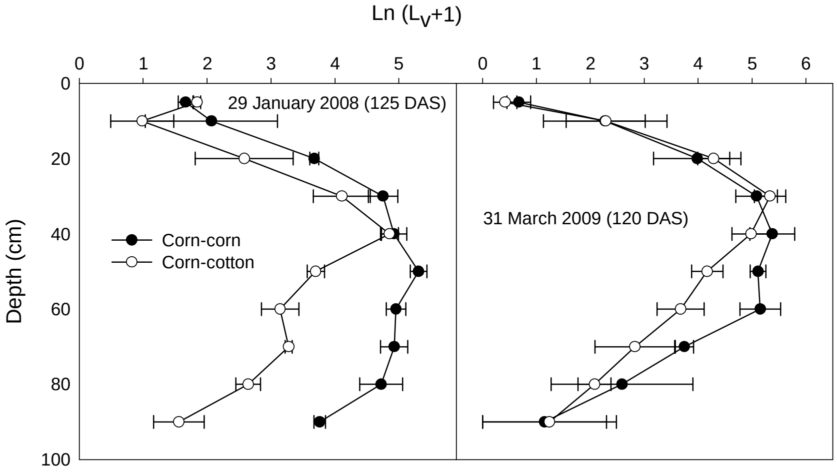

Fig. 47. Root length density, L_v (mm/cm^3) of corn at crop maturity 2007-08 and 2008-09 growing seasons, Field C1, ACRI, Narrabri. Horizontal bars are SEM's.

Corn root length, particularly towards the latter part of the growing season, were generally higher with corn monoculture than with cotton-corn rotation (Figs. 46 and 47). Values of L_A (cm/cm^2) at crop maturity under continuous corn ranged from 975 at 125 days after sowing (DAS) during the 2007-08 season to 1097 at 120 DAS during the 2008-09 season. L_A values for corn in the cotton-corn rotation at the same time were 365 and 606 during the 2007-08 and 2008-09 seasons, respectively. This may be related to the greater amount water stored in the soil after corn than with cotton[1]. The shorter growing season of the corn (5-6 months) results in a longer fallow period between corn crops whereas the longer growing season of the cotton (~6 months) results in a shorter fallow. Subject to rainfall, more water is therefore, likely to be stored under a corn monoculture than with a cotton-corn rotation.

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[1] Devereux, A.F., Fukai S., Hulugalle, N.R. (2008) The effects of maize rotation on soil quality and nutrient availability in cotton based cropping. In '*Global Issues – Paddock Action, Proceedings 14th Australian Agronomy Conference, 21-25 September 2008, Adelaide, SA (Unkovich M, Ed).' Australian Society of Agronomy, Adelaide, SA. [CD-ROM]*

6.6.1.2 Wheat and vetch

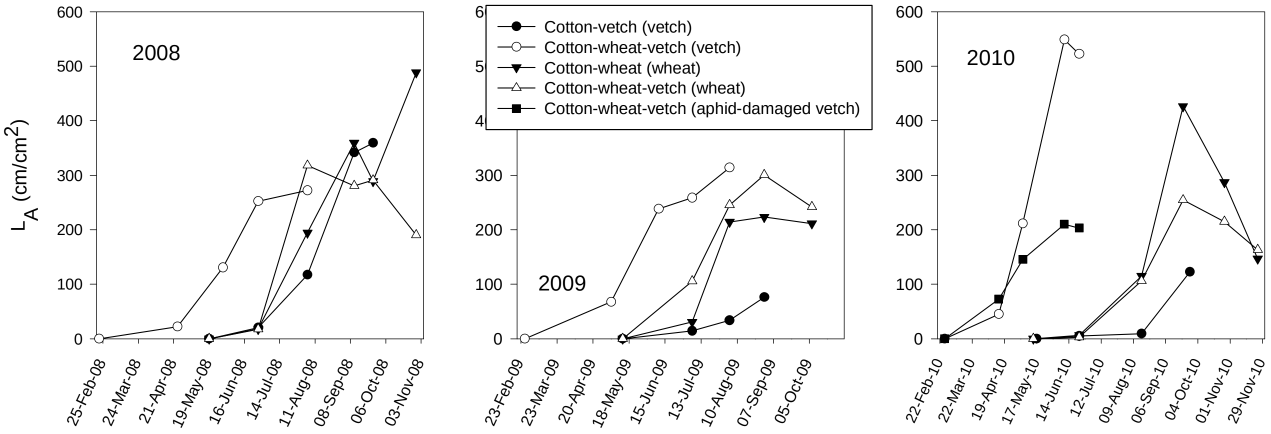

Fig. 48. Root length per unit area, L_A, of wheat and vetch under differing crop rotations, Field D1, ACRI, Narrabri

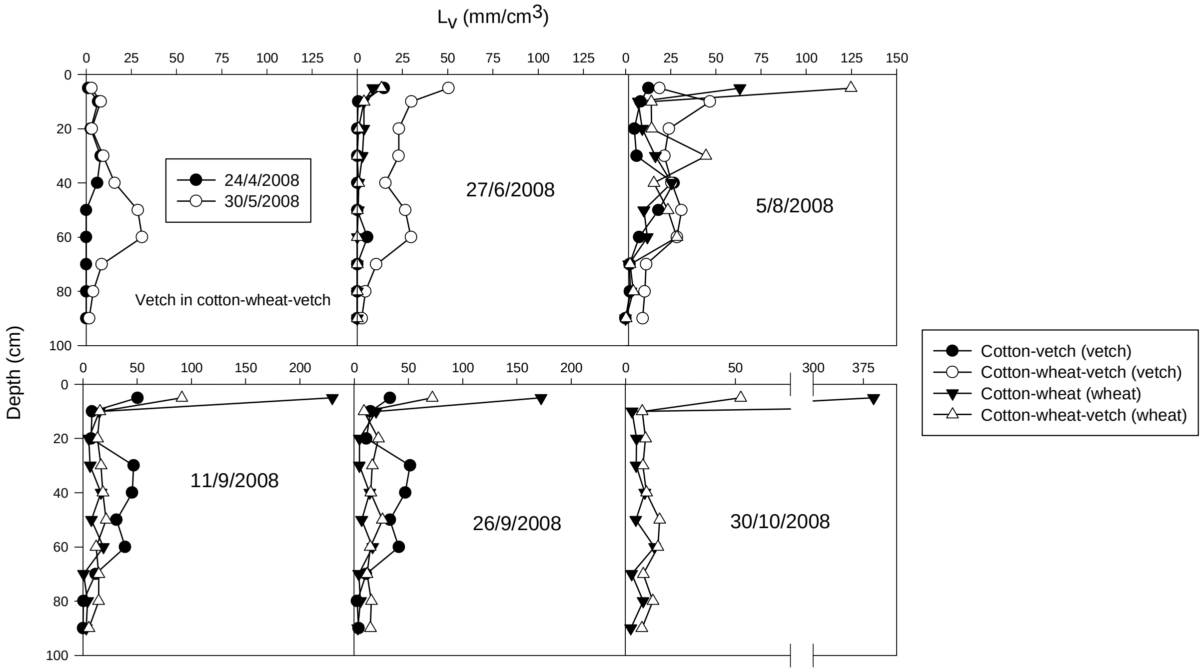

Fig. 49. Variation in root length density, L_V, of wheat and vetch under differing crop rotations during winter 2008, Field D1, ACRI, Narrabri

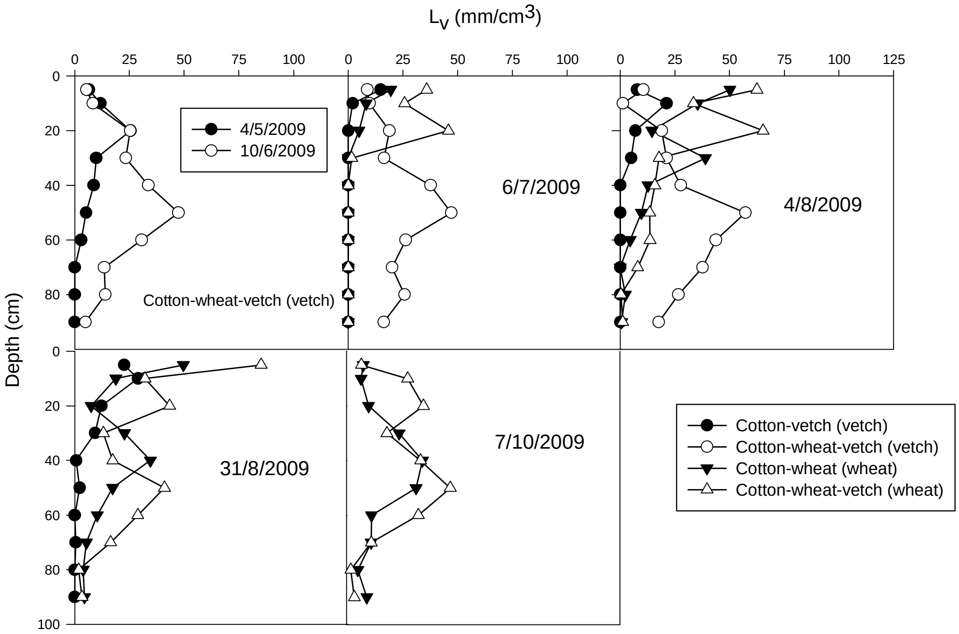

Fig. 50. Variation in root length density, L_V of wheat and vetch under differing crop rotations during winter 2009, Field D1, ACRI, Narrabri.

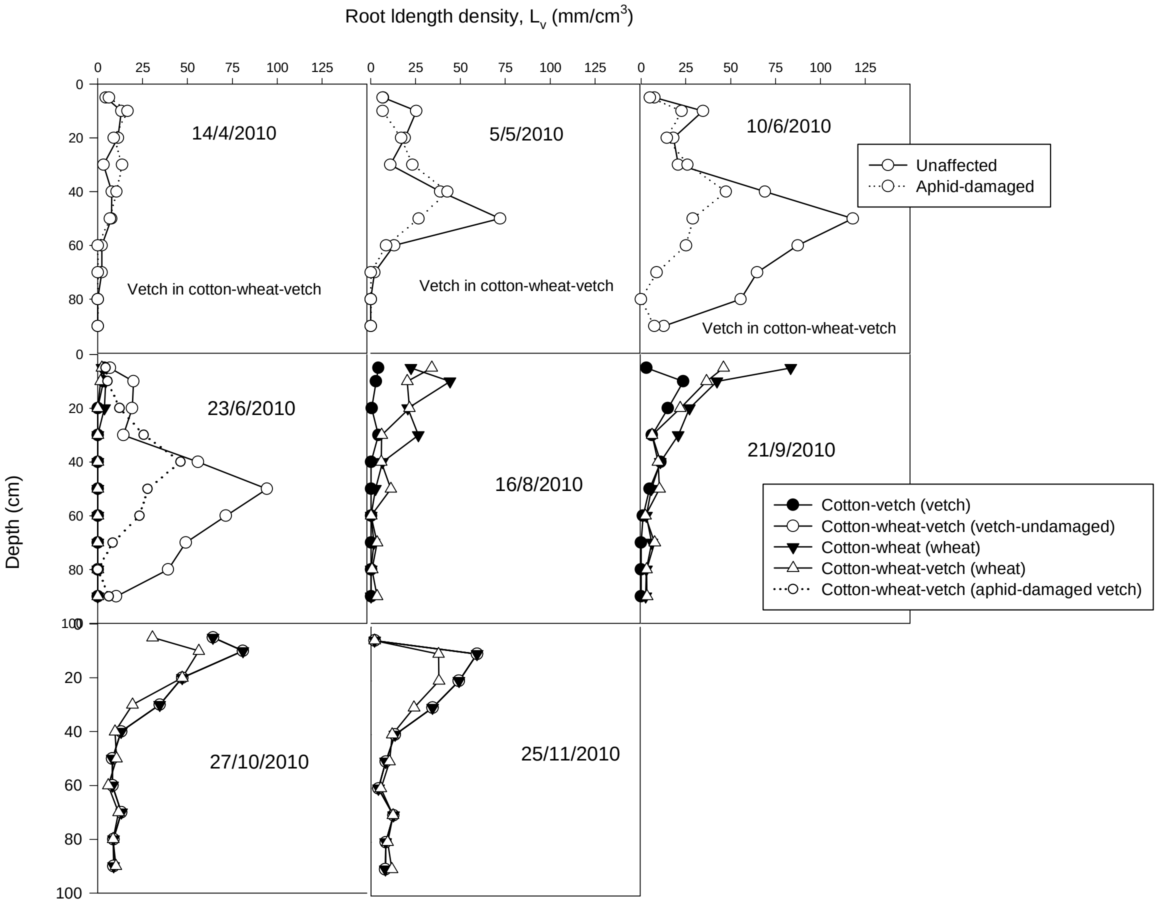

Fig. 51. Variation in root length density, L_V of wheat and vetch under differing crop rotations during winter 2010, Field D1, ACRI, Narrabri.

Table 20. Analyses of variance for root parameters, rotation experiment, Field D1, ACRI, Narrabri. L_v, root length density (mm/cm^3); L_A, root length per unit area (cm/cm^2). Back-transformed values are shown in Figs. 11, 48-51.

Root length:

	F-value[1]										
	Ln (L_V+10)										Ln L_A
Year and date	5 cm	10 cm	20 cm	30 cm	40 cm	50 cm	60 cm	70 cm	80 cm	90 cm	
2008:											
27/6/2008 (df = 3,30)	14.57***	12.47***	16.28***	16.93***	8.05***	21.45***	5.25**	5.52**	1.31	1.76	18.75***
5/8/2008 (df = 3.30)	67.01***	4.94**	2.71	3.72*	0.23	0.88	0.77	1.68	0.80	5.44**	4.21*
11/9/2008 (df = 2,22)	41.05***	0.39	0.66	4.66*	1.47	1.82	1.19	2.41	1.94	1.49	0.44
26/9/2008 (df = 2,22)	62.28***	0.94	4.04*	6.92**	1.88	3.40*	1.30	0.64	1.46	1.62	0.63
30/10/2008 (df =1,14)	79.93***	1.09	0.51	0.33	0.01	2.57	0.02	0.96	0.24	1.01	9.09**
2009:											
6/7/2009 (df = 3,30)	27.92***	4.35*	17.49***	10.58***	74.68***	48.64***	21.83***	15.14***	10.59***	7.21***	72.66***
4/8/2009 (df = 3.30)	78.14***	8.60***	9.46***	2.58	7.70***	17.30***	13.61***	20.77***	6.87**	6.68**	51.95***
31/8/2009 (df = 2,22)	29.49***	0.64	6.82**	0.88	22.12***	8.38**	8.62**	5.89**	1.17	1.91	27.91***
7/10/2009 (df =1,14)	1.52	6.59*	7.38*	0.24	0.00	0.61	3.12	0.00	0.67	1.82	0.60
2010:											
14/4/2010 (df = 1,7)	3.72	0.05	0.03	1.33	0.05	0.00	0.47	0.38	-	-	0.38
5/5/2010 (df = 1,7)	0.05	0.24	0.01	0.93	0.01	1.10	0.13	0.47	-	-	0.43
10/6/2010 (df = 1,7)	5.59*	0.30	0.05	0.13	0.22	3.96	1.83	3.17	9.92*	0.15	5.79*
23/6/2010 (df = 2,29)	21.56***	2.11	8.79***	23.80***	30.60***	39.26***	19.39***	12.78***	10.35***	3.58*	53.66***
16/8/2010 (df = 2,22)	22.91***	5.04*	7.04***	4.87*	2.28	5.85**	8.25**	1.32	1.00	1.00	28.12***
21/9/2010 (df = 2,22)	40.96***	0.61	0.60	2.58	0.03	0.66	0.67	5.94**	1.31	0.98	13.61***
27/10/2010 (df = 1,14)	1.53	0.47	0.00	0.79	0.18	0.21	0.20	0.06	0.00	0.02	0.58
25/11/2010 (df = 1,14)	0.01	0.64	0.19	0.45	0.02	0.10	0.18	0.00	0.02	0.13	0.03

Root carbon:

Parameter	F-value[1]		
	2008 (df = 3,30)	2009 (df = 3,30)	2010 (df = 2,29)
Ln (Carbon in crop roots at end of season)	10.07***	21.10***	3.52*
Ln (Carbon in roots that died)	4.18*	19.58***	19.93***
Ln (Total carbon potentially available for addition to soil)	12.71***	26.52***	3.87*

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[1] *, ** and *** indicate that means differed significantly at $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively.

While there were variations among treatments and years in the rotation experiment in Field D1, there were some discernible trends, *viz.*

- Early sown vetch (i.e. cotton-wheat-vetch) had more roots at depth, although overall L_A values were similar among both wheat treatments and the vetch in the cotton-wheat vetch rotation (Figs 48-51, Table 20).
- The later sown vetch (cotton-vetch rotation) had significantly lower root length than the other treatments in two years (2009, 2010) out of the three. This may partly reflect variations in rainfall distribution among years.
- Differences among treatments between years may also partly have been caused by differences in in-crop rainfall and soil water storage as the crops were sown at different times during the winter.
- Between wheat treatments, both of which were sown on the same date, cotton-wheat tended to have higher root length than cotton-wheat-vetch.
- Damage by aphids to the early sown vetch had a significant detrimental effect on vetch root growth and resulted in shallower and more sparse root system (Figs. 48 and 51).

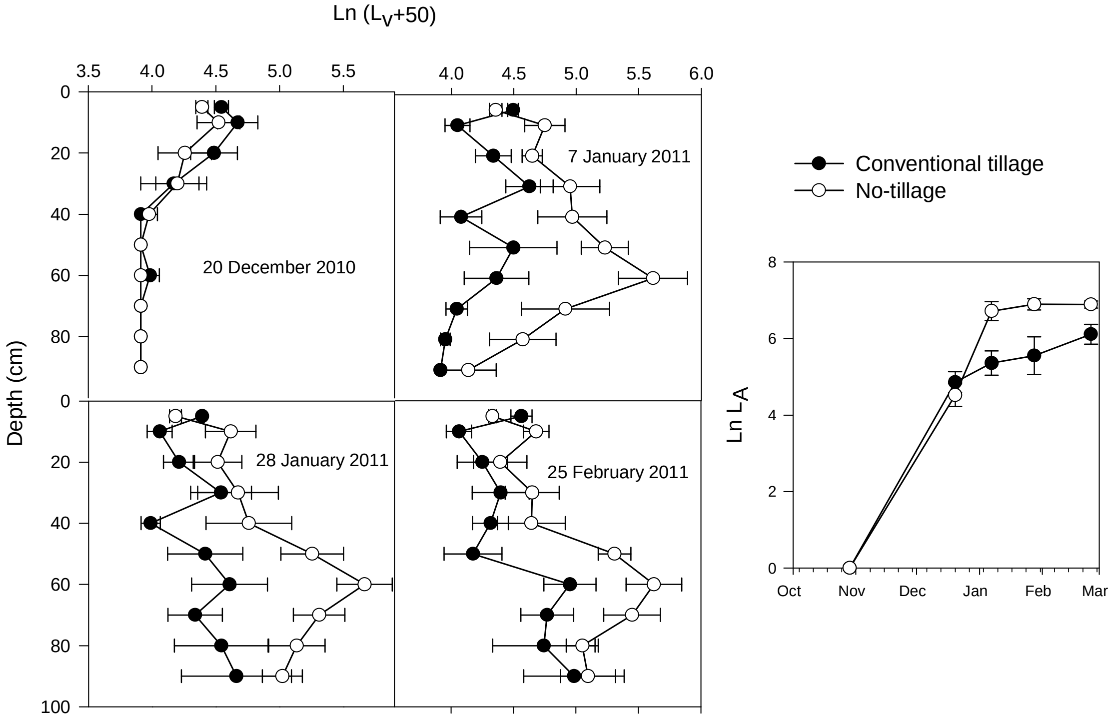

Fig. 52. Variation in root length density (L_v, mm/cm^3) and root length per unit area (cm/cm^2) with depth and time during summer 2010-11. Horizontal (L_v) and vertical (L_A) bars are standard errors of the means.

6.6.1.3 Grain sorghum

Densities of sorghum roots (Fig. 52) were vary much higher in the deeper subsoil than that of either wheat or vetch but were comparable to that of corn, although under the no-tilled sorghum values tended to be much higher. While these differences were undoubtedly caused by genetic factors, the differences between no-tilled and conventionally-tilled sorghum were probably due to the better drainage under the former. As noted in previous sections, heavy and frequent rainfall during December resulted in extended waterlogging in this site. Inhibition of sorghum growth by waterlogging was, however, less with no-tillage. The better drainage under minimum tilled systems has been previously documented in this field (Fig. 34). The high root densities and proliferation in the deep subsoil as the season progressed may be because in the absence of irrigation the wet subsoils may have stimulated root growth at depth in both treatments. It is unlikely that this “bulge” of roots in the deep subsoil would be present in a season where rainfall distribution was more typical of this region.

In both sorghum treatments the high root densities in the 90 cm depth also suggests that significant root growth may have been present at deeper depths. As the minirhizotron tubes did not extend beyond this depth, this could not be verified. The deep and extensive root system of sorghum does show, however, that roots of crops such as sorghum and corn, both C4 crops, can be important sources of carbon inputs into the soil.

6.6.2 Cotton and rotation crop yields

6.6.2.1 Sowing cotton into in situ mulch of wheat stubble

At ACRI, in the tillage/rotation experiment (experiment 5.1.1.1) pronounced differences ($P < 0.01$) between irrigation frequencies, all cropping systems and their interactions were present with respect cotton physiological growth indices such as squares/m^2, green bolls /m^2 and open boll/m^2 (Fig. 18). However, these differences did not translate in their entirety with respect to lint yields. Lint yield was less in both continuous cotton treatments than in plots where cotton was sown into a mulch of wheat stubble on permanent beds under both irrigation regimes during 2008-09 and under frequent irrigation in 2010-11 (Table 21). Between 2001 and 2011, averaged over both irrigation frequencies, cotton sown into wheat stubble yielded 18% more than continuous cotton. This compares favourably with cotton sown after wheat stubble incorporation in this site, which over a 6 year period from 1993 to 1999 resulted in lint yields higher than those in continuous cotton plots by 8%. During the 2009-10 season, when the cotton-wheat rotation was not sown, there were no significant differences in lint yield between continuous cotton sown after conventional tillage or on permanent beds. Significant

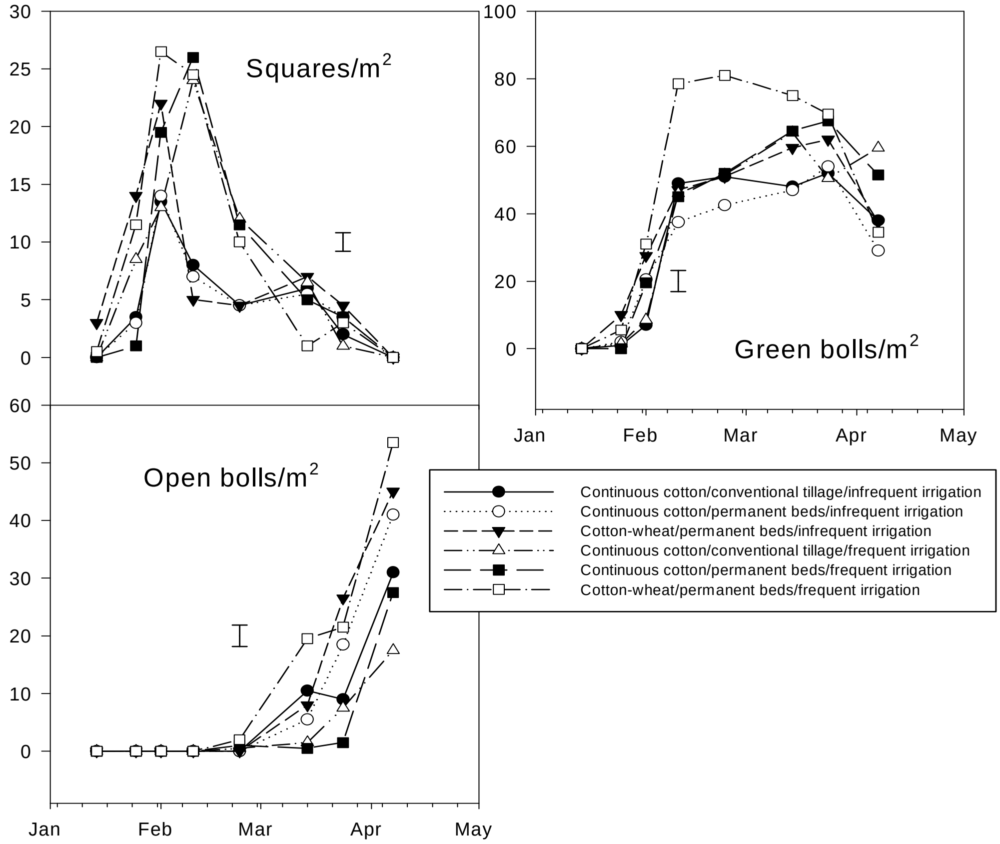

Fig. 53. Effect of irrigation frequency and cropping system on physiological growth indices (squares, green bolls and open bolls/m^2) of cotton. Vertical bars are standard errors of the means

differences between the two irrigation frequencies were absent (Table 10). This may be due to the wetter conditions (relative to the previous 3 years) prevailing during the cotton seasons of 2008-09, 2009-10 and 2010-11. Relative to 2008-09 and 2009-10, cotton lint yields were very low in 2010-11. The very low cotton yields during the 2010-11 season may be due to the extended waterlogging (~ 10-12 days) and cool, cloudy conditions that prevailed during December 2010. Supplementary N fertiliser application does not seem to have overcome these constraints.

Dryland wheat sown after frequently-irrigated cotton yielded 1.2 t/ha and that sown after infrequently-irrigated cotton 0.7 t/ha. This suggests that residual moisture in the subsoil from irrigation during the summer may have contributed to wheat growth and yield in the following winter.

Table 21. Yields of cotton (bales/ha) and wheat (t/ha) in tillage/rotation experiment, Field C1, ACRI. *, ** and *** indicate that treatments differ significantly at $P < 0.05$, $P < 0.01$ and $P < 0.001$, levels, respectively.1 bale = 227 kg.

Irrigation frequency	**Rotation**	**Tillage system**	**Cotton lint (bales/ha)**			**Wheat grain (t/ha)**		
			2008-09	**2009-10**	**2010-11**	**2008-09**	**2009-10**	**2010-11**
Frequent	Cotton-cotton	Conventional	10.0	8.7	5.4	-	-	-
	Cotton-cotton	Permanent beds	11.0	8.6	5.3	-	-	-
	Cotton-wheat	Permanent beds	12.3	-	7.6	1.2	-	1.6
Infrequent	Cotton-cotton	Conventional	8.5	7.2	4.9	-	-	-
	Cotton-cotton	Permanent beds	7.9	7.8	4.4	-	-	-
	Cotton-wheat	Permanent beds	9.7	-	4.8	0.7	-	1.6

SEM:

Parameter	**Cropping systems (CS)**			**Irrigation frequency (IF)**			**CS x IF**		
	2008-09	**2009-10**	**2010-11**	**2008-09**	**2009-10**	**2010-11**	**2008-09**	**2009-10**	**2010-11**
Cotton lint	0.38*	0.23	0.18*	0.55	0.53	0.30	0.54	0.32	0.25*
Wheat grain		-		0.04*		0.14	-	-	

Cotton lint yield was not significantly affected by wheat stubble management (Table 22), although wheat grain yields at “New Haven”, Narromine and soybean yields at “Federation Farm”, Narrabri were improved. This result is similar to other years where cultivation with an aer-way cultivator under dry conditions did not significantly decrease cotton lint yields at “Federation Farm”. Cultivation with an aer-way cultivator under dry conditions results in less soil disturbance than with conventional methods such as disc-ploughing (Fig. 10). Previous research in this site has also suggested that it may have minimal effects on soil quality, although the changes may be of a sufficient intensity to lower soybean yields. Due to heavy rains and extended waterlogging, the wheat crop sown during winter 2010 could not be harvested. Instead it was burnt and a soybean crop sown.

6.6.2.2 Sowing two cereal rotation crops (winter cereal fb. summer cereal) after cotton

The relevant experiments at Hillston and ACRI (experiment 5.1.3.1) had been in place for a short-time and hence, any differences between treatments should be interpreted with some caution. Nonetheless, the cotton in the cotton-wheat rotation was significantly higher than that in the cotton-wheat-wheat (sprayed out) (Table 22). Possible reasons for lower yields in the latter may be because the profile after the wheat may not have been replenished completely by irrigation. Hence, the cotton may have been more stressed than that in the cotton-wheat rotation. N immobilisation by the wheat stubble was ruled out as N concentrations in cotton seeds (an indicator of NUE) of both treatments were similar.

Relative to Cotton-wheat, lower cotton yield also occurred in the experiment in field D1 at ACRI in the Cotton-wheat-sorghum sequence. This may be due to either N immobilisation by the large amounts of sorghum stubble that remained in the field or other nutrient imbalance caused by export in the sorghum grain.

Table 22. Effect of wheat stubble management on cotton lint yield (bales/ha), and wheat, sorghum, chickpea and soybean grain yields (t/ha) at on-farm and on-station sites. Values in parentheses are $\log_e$ transformed values.

Site	Cropping system	2008-09		2009-10		2010-11	
		Rotation	Cotton	Rotation	Cotton	Rotation	Cotton
"Federation Farm", Narrabri[11]	Cotton-wheat (incorporated)	3.9^{a}, 1.0^{d}			12.1	2.7 $(0.978)^{c}$	-
	Cotton-wheat (*in situ* mulch)				11.8	3.1 $(1.123)^{c}$	-
	SEM				0.51	(0.0449)	-
	P <				ns	0.05	
"Merrowie", Hillston	Cotton-wheat			2.6^{a}	-	-	11.8
	Cotton-wheat-sorghum			2.3^{a}	-	Sprayed	9.9
	SEM			0.13			0.55
	P <			ns			0.05
"New Haven", Narromine	Corn (burnt) fb. Cotton-wheat	?			13.4	4.1^{a}	
	Cotton-wheat (*in situ* mulch)	?			13.0	3.7^{a}	
	t-value				0.45	2.34	
	P <				ns	0.05	
Field D1, ACRI, Narrabri	Cotton-wheat-sorghum (*in situ* mulch)		8.4	1.5^{a}, 4.9^{b}	8.9	4.7^{a}, 5.6^{b}	7.3
	Cotton-wheat (*in situ* mulch)		13.2	2.7	11.4	3.6^{a}	8.3
Field C1, ACRI Narrabri	Wheat stubble incorporated					5.2^{b}	-
	In situ wheat mulch					5.3^{b}	-

^{a}wheat; ^{b}sorghum; ^{c}soybean, ^{d}chickpea

6.6.2.3 Including vetch in the rotation

Table 23. Yields of wheat and cotton in rotation experiment, Field D1, ACRI.

Rotation	Rotation crop stubble management	Wheat grain yield (t/ha)			Cotton lint yield (bales/ha)		
		2008-09	2009-10	2010-11	2008-09	2009-10	2010-11
Cotton-vetch	Mulched	-	-	-	11.3	10.9	7.0
Cotton-cotton	-	-	-	-	10.8	10.5	6.5
Cotton-wheat	Incorporated	3.5	2.7	3.1	13.1	12.4	8.2
Cotton-wheat-vetch	Mulched	3.2	2.8	3.0	11.3	10.5	7.9
SEM		0.27	0.23	0.32	0.20	0.54	0.22
P <		ns	ns	ns	0.01	ns	0.01

Wheat yields were not significantly changed by sowing vetch (Table 23). Cotton yields were generally highest with the wheat-cotton rotation. In comparison with the cotton-cotton sequence, inclusion of vetch and concomitant reduction in mineral fertiliser inputs in the cotton-vetch rotation did not result in a decrease in cotton yields, thus suggesting that the N-fixed by the vetch sufficed to maintain cotton yields. Inclusion of vetch in a cotton-wheat rotation however, resulted in significantly reducing yields of cotton during the 2008-09 season. Relative to cotton-wheat, lint yield in the cotton-wheat-vetch sequence was numerically lower although statistically non-significant during the 2009-10 cotton season as well. This varies from that observed during the previous 5 years and may be due to two reasons. The vetch in the cotton-wheat vetch sequence was killed during between July and

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[1] Laser levelled in 2008 winter and sown to chickpea and wheat (treatments not imposed); values shown are an average of the two. Wheat sown in 2010 could not be harvested due to frequent, heavy rains and waterlogged conditions. The residue was burnt and soybean sown during summer 2010-11.

later August from 2008 to 2010, whereas during the early stages of this experiment it was killed between mid-August to mid-September. This was done with the objective of including a short fallow before sowing cotton, during which any rainfall received could be stored for use by the latter. In addition relative to 2003-2007, late winter and spring rainfall was higher between 2008 and 2010. Rainfall during this fallow averaged 52 mm from the 2003 to 2007, and 180 mm from 2008 to 2010. The wetter conditions may have resulted in faster decomposition and more N lost through a combination of leaching as nitrates and emissions as nitrous oxide. Thus, under conditions of adequate spring rainfall, early killing of vetch may have resulted in inadequate N for maximal yield by the cotton. The low cotton yields during the 2010-11 season may be due to the extended waterlogging (~ 10-12 days) and cool, cloudy conditions that prevailed during December 2010. Supplementary N fertiliser application does not seem to have overcome these constraints.

N contents in vetch DM averaged 114 kg N/ha in the cotton-vetch rotation and 155 kg N/ha in the cotton-wheat-vetch (Table 24). The vetch roots (through root death during the growing season and that contained in the roots at the time of killing) contributed an average of 45 kg N/ha[1] in the cotton-vetch and 136 kg N/ha[1] with the cotton-wheat-vetch rotation. Values were lowest during the 2010-11 season, presumably due to aphid damage (Fig. 1).

6.6.2.4 Applying organic and inorganic amendments

Due to poor rainfall during 2005 the wheat crop in the Brigalow site (Experiment 5.1.2.1) failed but cotton and sorghum yielded well due to adequate soil moisture (stored water from fallow + in-crop rainfall) in subsequent years. Crop yields were not affected by application of soil amendments. Mean yield of wheat grain (which was affected by drought) during 2005 was 1.8 t/ha, cotton lint during 2006-07 was 9.4 bales/ha and sorghum grain during 2007-08 was 9.4 t/ha. Lack of response to applied amendments may be related to the fact that they had only a small effect on ESP, and exchangeable K values in the surface, albeit low, were nonetheless higher than those suggested by Bell *et al.* (2008)[2] as causing yield reductions in sorghum and cotton. These authors reported that a 10% reduction in yield of sorghum and cotton was not achieved until exchangeable K concentrations had fallen to 0.19 cmol/kg and 0.3 cmol/kg, respectively. They further noted that the threshold value for cotton may well be higher as their cotton crops yielded poorly due to sowing late with a low yielding variety. Potassium stress during boll-filling is thought to be a possible cause of premature senescence, and hence, yield decreases in cotton. It is likely, therefore, that organic waste products will significantly improve crop yields in Vertisols only when soil fertility, particularly potassium availability, is very low.

6.6.3 Cropping systems and fibre quality

Cotton lint fibre quality in the tillage/rotation experiment in Field C1 was little affected by experimental treatments during the 2009-09 season; viz. elongation and micronaire in continuous cotton plots were reduced by infrequent irrigation (Table 25). Micronaire in the cotton-wheat rotation was not affected significantly by irrigation frequency, and presumably reflects the water availability in this treatment. Non-significant decreases in short fibre index and fibre strength also occurred.

Crop rotation and stubble management did not have any significant effect on fibre quality indices in the rotation experiment in Field D1, ACRI, although values differed between the 2008-09 and 2009-10 seasons (Table 26).

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[1] From a depth of 1 m

[2] Bell, M., Harch, G., Want, P., and Moody, P. (2008). Management responses to declining potassium fertility in Ferrosol soils. *Global Issues, Paddock Action, Proc. 14th Australian Agronomy Conference, Adelaide, South Australia, 21-25 September 2008* (Ed. M. Unkovich). Aust. Soc. AGron, Adelaide, SA. [CD-ROM].

Table 24. Nitrogen in vetch dry matter and roots, rotation experiment, Field D1, ACRI, Narrabri.

Rotation	**Rotation crop stubble management**	**N in above-ground dry matter (kg/ha)**			**N in roots at harvest (kg/ha)[1]**			**N released through root death (kg/ha)[1]**		
		2008	**2009**	**2010**	**2008**	**2009**	**2010**	**2008**	**2009**	**2010**
Cotton-vetch	Mulched	124	97	122	193 (2.960)	53 (1.167)	4 (1.280)	14 (0.309)	7 (-0.296)	0 (-3.426)
Cotton-wheat-vetch	Mulched	140	187	138	430 (3.762)	308 (3.428)	26 (3.261)	17 (0.552)	31 (1.142)	1 (-0.046)
SEM		7.5	8.8	10.1	(0.193)	(0.177)	(0.243)	(0.472)	(0.328)	(0.484)
P <		ns	0.05	ns	0.05	0.001	0.001	ns	0.01	0.001

[1] Values in parentheses are log$_e$ transformed values in units of kg/m^2

Table 25. Effect of cropping system on cotton fibre quality indices, Tillage/rotation experiment, Field C1, ACRI, Narrabri, 2008-09 cotton season. . *, ** and *** indicate that treatments differ significantly at P < 0.05, P < 0.01 and P < 0.001, levels, respectively.

Irrigation frequency	**Rotation**	**Tillage system**	**Elongation**	**Length (in”)**	**Micronaire (µg/in”)**	**Short-fibre index**	**Strength**	**Uniformity (%)**
Frequent	Cotton-cotton	Conventional	7.7	1.2	4.7	9.4	31.1	84
	Cotton-cotton	Permanent beds	7.7	1.2	4.2	10.1	33.6	83
	Cotton-wheat	Permanent beds	8.0	1.2	4.2	9.5	30.9	84
Infrequent	Cotton-cotton	Conventional	7.8	1.2	3.5	11.7	33.7	82
	Cotton-cotton	Permanent beds	7.9	1.1	3.2	12.2	33.8	82
	Cotton-wheat	Permanent beds	8.0	1.2	4.4	10.0	31.8	84

SEM:

Parameter	**Elongation**	**Length**	**Micronaire**	**Short-fibre index**	**Strength**	**Uniformity**
Irrigation frequency (IF)	1E-16***	0.01	0.07	0.51	0.72	0.4
Cropping system (CS)	0.06	0.01	0.17	0.62	0.56	0.7
IF x CS	0.08	0.02	0.24*	0.88	0.79	1.0

Table 26. Effect of crop rotation and stubble management on cotton fibre quality indices, in rotation experiment, Field D1, ACRI, 2008 to 2010. *, ** and *** indicate that treatments differ significantly at $P < 0.05$, $P < 0.01$ and $P < 0.001$, levels, respectively.

Season	**Rotation**	**Rotation crop stubble management**	**Elongation (%)**	**Length (in")**	**Micronaire (µg/in")**	**Short-fibre index (%)**	**Strength (g/tex)**	**Uniformity (%)**
2008-09	Cotton-vetch	Mulched	7.7	1.19	4.8	9.4	29.3	83.1
	Cotton-cotton	-	7.5	1.17	4.6	9.5	30.7	83.7
	Cotton-wheat	Incorporated	7.7	1.17	4.7	9.6	30.0	84.0
	Cotton-wheat-vetch	Mulched	7.7	1.18	4.6	9.4	30.0	83.1
2009-10	Cotton-vetch	Mulched	6.3	1.24	4.6	7.8	30.8	84.6
	Cotton-cotton	-	6.5	1.23	4.1	8.5	31.2	84.4
	Cotton-wheat	Incorporated	6.3	1.23	4.1	9.2	30.7	83.6
	Cotton-wheat-vetch	Mulched	6.5	1.22	4.5	9.2	29.2	84.1

SEM:

Parameter	**Elongation**	**Length**	**Micronaire**	**Short-fibre index**	**Strength**	**Uniformity**
Season (Y)	0.10*	0.004**	0.02**	0.13*	0.73	0.33
Cropping system (CS)	0.08	0.008	0.10	0.28	0.50	0.28
Y x CS	0.11	0.010	0.15	0.39	0.71	0.40

6.6.4 Cropping systems and profitability

6.6.4.1 Rotation experiment, Field D1, ACRI - Resilience of profitability to changes in input costs

In this section economic results from the long term (2003 – 2011) crop rotation experiment in Field D1, ACRI are presented and the consequences of increased fertiliser prices on profitability, measured as gross margins, are discussed. In order to compare different treatments in the current price context, where possible, 2011 prices have been used for inputs such as fuel, fertiliser, herbicides (including defoliants) and pesticides. In addition prices for cotton lint were set at $450/bale and a seed price of $300/t. Wheat prices for various grades were taken as ‘Feed’ and ‘ASW’ $195/t, ‘AH’ $202/t and ‘PH14’ $235/t.

The cropping systems were compared on a per field basis, e.g assuming a field was continuously farmed under a particular system, as might be the case if there was sufficient water to irrigate all the available land.

Basic Gross Margin Comparisons

At a cotton price of $450/bale, average annual gross margins per hectare were in the order of T2 (cotton-fallow-cotton-fallow) $2428/ha, T1 (cotton-vetch-cotton-vetch) $2282/ha, T3 (cotton-wheat-fallow-fallow) $1590/ha and T4 (cotton-wheat-fallow-vetch) $1557/ha. In terms of gross margin/ML of irrigation water applied, profitability was in the order of T3 $523/ML, T2 $489/ML, T4 $467/ML and T1 $379/ML (Fig. 54). On the basis of the results so far the inclusion of vetch between cotton crops has not been profitable. This is because the cotton yields in the rotations that include vetch have not exceeded yields in the non-vetch rotations.

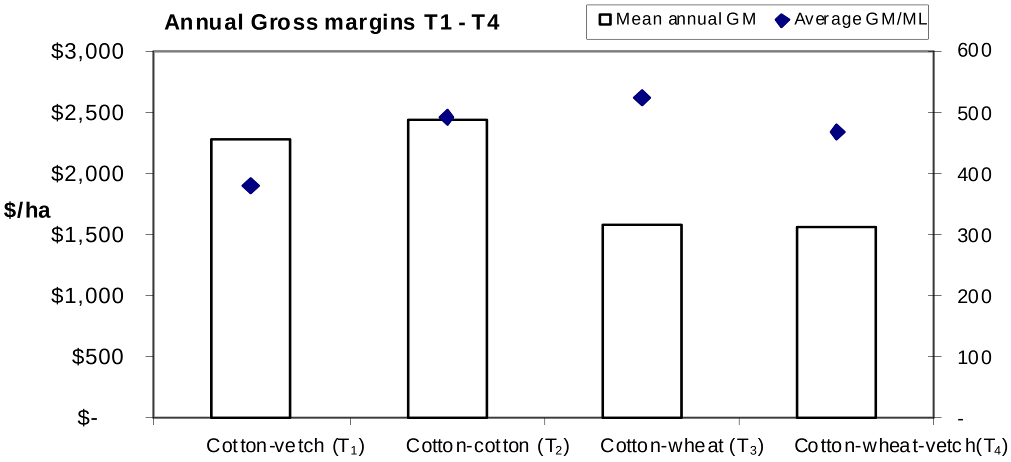

Fig. 54. Annual gross margin comparison

Whilst Figure 1 indicates a superior performance of cotton-vetch and cotton-cotton in terms of gross margin/hectare, due consideration must be given to the fact that both of the above grow cotton annually, compared with cotton-wheat and cotton-wheat-vetch, which grow cotton bi-annually. Consequently, cotton-vetch and cotton-cotton also used significantly more water/ha than cotton-wheat and cotton-wheat-vetch. Among all four rotations, cotton-wheat has so far returned the highest yield, lowest water use and highest gross margin/ML of irrigation water (Table 27).

Table 27. Cumulative results for the period 2003 to 2010/11 with cotton-wheat and cotton-wheat-vetch averaged. T_1, cotton-vetch; T_2, cotton-cotton; T_3, cotton-wheat;T_4, cotton-wheat-vetch

Parameter	**T1**	**T2**	**T3**	**T4**
Total Gross Margin ($)	18,257	19,423	12,723	12,452
Ave cotton yield (bales/ha)	8.7	8.7	10.3	10.2
Average GM/ha ($/ha)	2,282	2,428	1,590	1,557
Average GM/ML ($/ML)	379	489	523	467
Total water use/ha	48.2	39.7	24.4	25.9

The two bi-annual treatments (cotton-wheat and cotton-wheat-vetch) have lower cost on average due to having half the number of cotton crops. Between these two treatments, the costs were very similar, however cotton-wheat has given slightly higher returns and slightly lower water use. Of the two continuous cotton treatments, cotton-cotton had similar costs on average to cotton-vetch but gave higher returns, thus resulting in a higher gross margin/ha. Cotton-vetch used significantly more water which resulted in the overall lowest gross margin/ML. This is because most years between 2003 and 2010 had relatively dry winters and vetch was sown immediately after cotton, and thus required irrigation. As a consequence, cotton-vetch required more water than cotton-cotton, which was in fallow during the winter.

The dominance chart (Fig. 55) indicates that between cotton-vetch and cotton-cotton, and between cotton-wheat and cotton-wheat-vetch, the rotations without the vetch were more profitable in terms of gross margin/ha. The differences between the cotton-wheat and cotton-wheat-vetch were, however, relatively small.

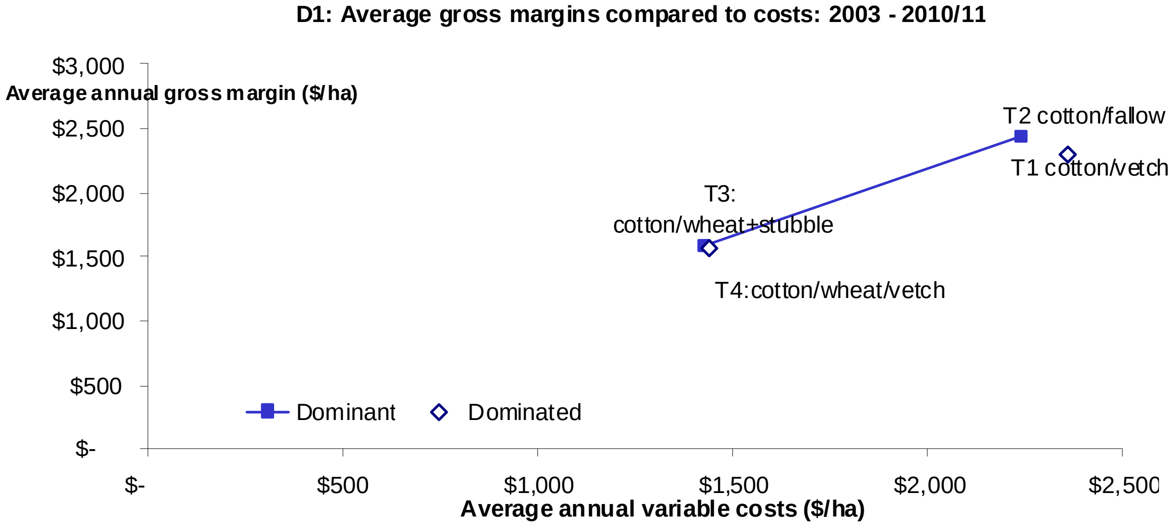

Fig. 55. Dominance chart for rotation experiment in Field D1, 2003 to 2010/11

<u>Impact of input and output price changes</u>

Whilst this analysis has been conducted using the long term average price of $450/bale, the price of cotton can be quite variable. Prices for the 2011 cotton season reached almost $1000/bale, these prices were not prolonged nor are they expected to be repeated in future seasons, however it is important to understand the effect that cotton price has on gross margin (Fig. 56). The rotations with a higher frequency of cotton crops (cotton-vetch and cotton-cotton) gave better returns with a higher cotton price, however with a lower cotton price the gap between the continuous cotton and bi-annual cotton rotations was lower. The bi-annual rotations were less sensitive to falling cotton prices due to lower overall costs and the lower proportion of cotton in the rotation. When fuel and fertiliser price changes are applied, the relative profitability of the rotations changed similarly.

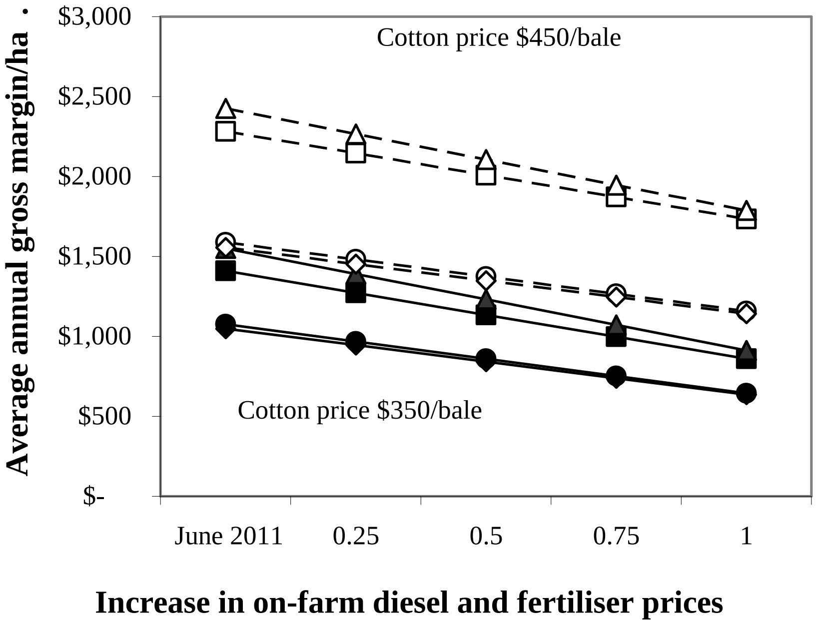

Fig. 56. Impact of cotton lint price and fuel/fertiliser increases on rotation returns, Field D1, ACRI. Squares, cotton-vetch; Triangles, cotton-cotton; Circles, cotton-wheat; Diamonds, cotton-wheat-vetch; Open symbols, $550/bale; closed symbols, $450/bale

6.6.4.1 Rotation experiment, Field C1, ACRI - Resilience of profitability to changes in input costs

In this section results (2000-2011) from the long term tillage/rotation/irrigation experiment in field C1 at ACRI are presented and the consequences of increases in fuel and fertiliser prices on profitability, measured as gross margins, are discussed. The experiment compared either conventional or minimum tillage (permanent beds) under continuous cotton (11 cotton crops since 2000) and minimum tillage (permanent beds) under a cotton-wheat rotation (6 cotton crops and 5 wheat crops since 2000) where cotton (grown bi-annually) was sown into standing wheat stubble. The treatments were split in 2005/06 into ‘infrequent (low)’ irrigation frequency and ‘frequent (normal)’ irrigation frequencies. These results cover 11 years of data for the ‘frequent (normal)’ irrigation, and only 5 ½ years under ‘infrequent (low)’ irrigation. These systems were compared on a per field basis assuming a field was continuously farmed under that particular system.

In order to compare different treatments in the current price context, where possible, 2011 prices have been used for inputs such as fuel, fertiliser, herbicides (including defoliants) and pesticides. In addition prices for cotton lint were set at $450/bale and a seed price of $300/t. Wheat prices for various grades were taken as ‘Feed’ and ‘ASW’ $195/t, ‘AH’ $202/t and ‘PH14’ $235/t.

<u>Basic Gross Margin Comparisons</u>

When comparing gross margins it should be noted that continuous cotton treatments have grown twice as many cotton crops and used significantly more water than the cotton-wheat treatments.

With respect to the 'normal' irrigated treatments and using a cotton price of $450/bale, minimum tilled cotton-winter fallow-cotton returned the highest average annual gross margin ($2,221/ha). This was 6% higher than the conventionally tilled cotton-winter fallow-cotton treatment ($2,104/ha) and 37% higher than the minimum-tilled cotton-wheat treatment ($1602/ha) (Fig. 57). With respect to gross margin/ML of irrigation water applied, minimum-tilled cotton wheat returned 8% higher returns ($432/ML) than conventionally tilled cotton-winter fallow-cotton ($398/ML). Minimum-tilled cotton-winter fallow-cotton was 6% higher ($423/ML) that the conventionally tilled treatment.

Cropping systems under 'low' irrigation frequency responded similarly to those under 'normal' irrigation frequencies (Fig. 57). Gross margin/ha were in the order of conventionally tilled cotton-winter fallow-cotton ($1305/ha) > minimum tilled cotton-winter fallow-cotton ($1203) >> minimum-tilled cotton-wheat treatment ($816). Gross margin/ML were in the order of the minimum-tilled cotton-wheat ($460)> conventionally tilled cotton-winter fallow-cotton ($427) > minimum tilled cotton-winter fallow-cotton treatment ($423).

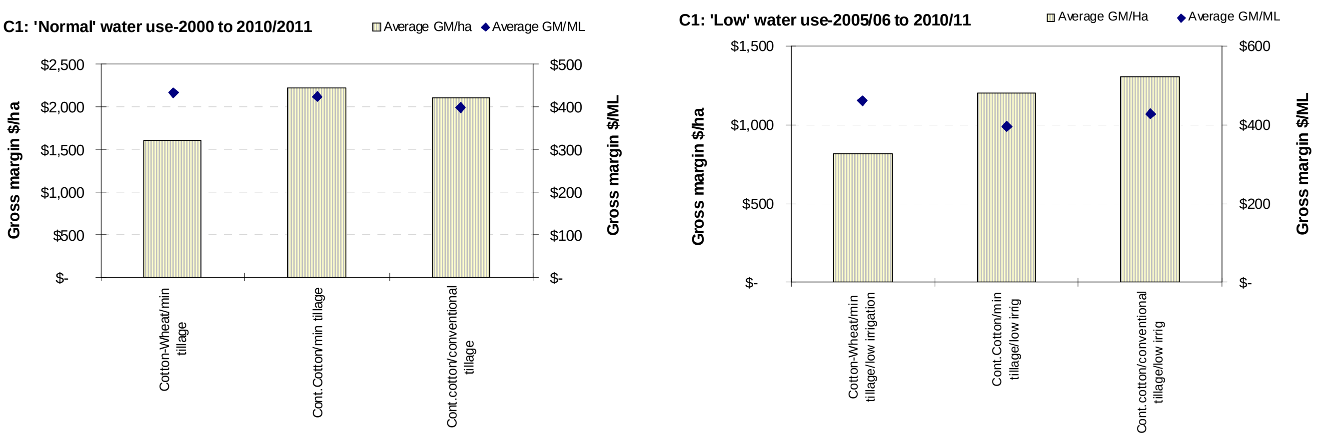

Fig. 57. Gross margins 2000-2010/11for the 'normal (frequent)' and 'low (infrequent)' irrigation regimes

Impact of input and output price changes

In addition to cotton lint price variability, growers also face issues of volatile fuel and fertiliser prices. The profitability of different rotations is affected by different cotton prices relative to wheat and rotations can also differ in terms of their resilience to changing input prices, especially as some crops require more machinery passes for cultivation, weed control and spraying. Generally, rotations with lower overall fuel costs will be less affected by rising fuel prices.

Price changes included using cotton lint prices of $450 and $550/bale, a cotton seed price of $300/tonne, and by increasing both on-farm diesel and nitrogen fertiliser prices by 25, 50, 75, and 100%. The base diesel price used was the July 2011 price of $1.50/litre at the bowser (which is equivalent to $0.98/litre on farm, ex GST and the off road rebate). The base price of the fertiliser urea was $700/tonne. All other input costs were not altered. Rising fuel prices may also affect other inputs such as insecticides, herbicides, growth regulators and other nutrients.

Contract costs are a large part of cotton operations, so it was assumed that there would be a 0.5% increase in contract charges for every 1% increase in the price of fuel. Even though in practice some contract rates are quoted 'plus fuel' (i.e the grower pays a base rate/ha and pays for fuel on top of that, for ease of calculation, contract rates used were calculated to include the cost of fuel. The relative rate increases were estimated by calculating the estimated contract rates for a sample tractor (using variable costs, including fuel and oil, and overhead costs per hectare plus a 20% profit margin). The average increase in estimated contract rates was in the order of 50% when fuel prices increased by 100%. Using this assumption, for example an aerial spraying charge of baseline $14/ha would increase to $21/ha if fuel prices rose by 100%.

The minimum-tilled cotton-wheat rotation was less affected than either the cotton monoculture systems (Fig. 58) by the increase in diesel and fertiliser costs and appears to be more resilient to such increases. This is due to a lower frequency of cotton crops in the cotton-wheat sequence compared with cotton monoculture and therefore lower use of inputs.

The relative profitability of the rotations also changes as the cotton price increased, due to the increase in the price of cotton relative to wheat.

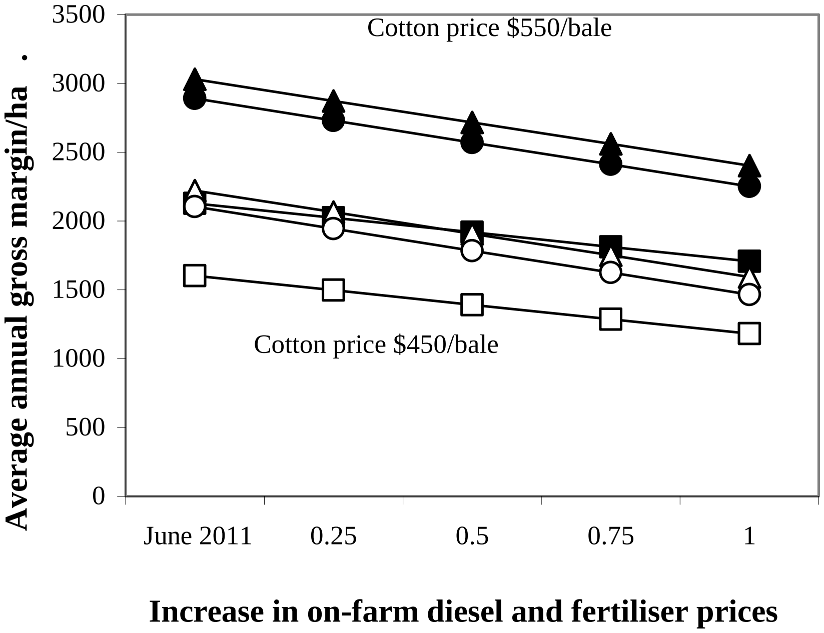

Fig. 58. Impact of cotton lint price and fuel/fertiliser increases on rotation returns, Field C1, ACRI. Squares, permanent beds/cotton-wheat; Triangles, permanent beds/cotton-cotton; Circles, conventional tillage/cotton-cotton; closed symbols, $550/bale; open symbols, $450/bale

To summarise, in field D1, inclusion of vetch was less profitable than a fallow or wheat rotation. In terms of gross margin/ha the difference was minor; however in terms of gross margin/ML the treatments without vetch were significantly more profitable. In field C1, the minimum-tilled cotton-wheat treatment consistently achieved the highest cotton yields and the highest gross margin return/ML. In years of plentiful water (or when crop area is the limiting factor), however, the reducing water use on a continuous cotton crop was a false economy.

6.6.5 Determinants of cotton lint yield, water use efficiency and nitrogen use efficiency

6.6.5.1 Cotton lint yield

Table 28. Results of multiple linear regression analyses of management and climatic variables on cotton lint yields in individual sites. Max till, number of tillage operations > 10 cm deep; Min till, number of tillage operations < 10 cm deep; N, N fertiliser applied (kg N/ha); Water, total water inputs, irrigation and rainfall (mm); T_{max}, annual average daily maximum temperature (^{o}C); T_{min}, annual average daily minimum temperature (^{o}C); VIF, variance inflation factor.

Site	Variable	Coefficient	VIF	P <	R^2	n
Field C1, ACRI, Narrabri, NSW	N	0.032	1.1	0.001	0.48***	55
	Water	0.003	1.1	0.001		
	T_{max}	-0.76	1.1	0.05		
Field D1, ACRI, Narrabri, NSW	Water	0.013	1.0	0.001	0.61***	42
	Min till x N	0.008	1.0	0.05		
“Glenarvon”, Wee Waa, NSW	Max till	0.24	1.0	0.01	0.51**	16
“Beechworth”, Merah North, NSW	Max till	-1.41	1.7	0.01	0.78***	65
	N	0.019	2.3	0.001		
	Water	0.002	2.5	0.01		
	T_{min}	-2.77	1.6	0.001		
	T_{max}	1.64	1.4	0.01		
“Auscott-Warren”, Warren, NSW	T_{max}	0.70	1.1	0.001	0.84***	33
	Max till	0.76	1.7	0.001		
	Water	0.003	1.4	0.001		
	T_{min}	-1.33	1.4	0.001		
Pooled results for cotton-wheat rotations on permanent beds[1]	Water	0.004	2.1	0.001	0.73***	78
	N	0.027	2.1	0.001		
	T_{min}	-1.49	1.0	0.01		

Within site multiple linear regression of management and climatic variables with cotton lint yields for Field C1 and D1 at ACRI, “Glenarvon”, “Beechworth” and “Auscot-Warren” produced similar results (Table 28). Except for “Glenarvon”, N and total water inputs had a positive relationship to cotton lint yield. Lint yield was related negatively to annual average minimum temperature at “Auscott-Warren” and “Beechworth”, Positively to average annual maximum temperature in the same sites, and negatively to annual average maximum temperature in Field C1. The relationships to temperature at Warren and Merah North may be associated with the cooer conditions in the former and sodic conditions, poorer drainage and thus, cooler soil conditions in the latter. In Field C1 at ACRI, which was only mildly sodic at depth, increasing annual temperatures had a negative effect on lint yield.

Some differences occurred with respect to the number of tillage operations greater than 10 cm deep where positive relationships were present at “Glenarvon” and “Auscott-Warren”, negative relationship at “Beechworth” and no significant effect at ACRI. As with SOC, the positive effect of the tillage in the two former sites may be related to the aeration effect previously noted whereas the negative effect at “Beechworth” may be a consequence of the sodic soil in this site. Yield was not significantly affected by the number of tillage operations at ACRI, although a positive relationship occurred in Field D1 with respect the interaction between the number of shallow tillage operations and N inputs.

Pooling of results for cotton-wheat rotations on permanent beds from Fields C1 and D1, ACRI, Narrabri; “Glenarvon”, Wee Waa; “Auscott-Warren”, Warren, NSW; and “Merrowie”,

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[1] Fields C1 and D1, ACRI, Narrabri; “Glenarvon”, Wee Waa; “Auscott-Warren”, Warren, NSW; “Merrowie”, Hillston, NSW. Tmax was significant at P =0.08

Hillston, NSW indicated that increasing N inputs, water (irrigation and rainfall), and falls in average daily minimum temperature increased cotton lint yields (Table 17).

In summary, cotton lint yields, in general, were positively related to water and N inputs, soil aeration in some sites and average annual daily maximum temperature in cooler or poorly-drained sites but were lowered by higher average annual daily minimum temperature. In a sodic soil, a high frequency of the tillage practices intended to aerate the soil may have caused yield decreases, presumably due to exposure of more sodic soils.

6.6.5.2 Water use efficiency

For the purpose of this study, we have defined cotton water use efficiency (WUE) as cotton lint yield per mm of water (rainfall + irrigation) inputs (bales/ha/mm).

Table 29. Results of multiple linear regression analyses of management and climatic variables on cotton water use efficiency in individual sites. Max till, number of tillage operations > 10 cm deep; Min till, number of tillage operations < 10 cm deep; N, N fertiliser applied (kg N/ha); Water, total water inputs, irrigation and rainfall (mm); T_{max}, annual average daily maximum temperature (^oC); T_{min}, annual average daily minimum temperature (^oC); Stubble, dummy variable for rotation stubble management: 0, no rotation stubble, 1, surface mulch, 2, incorporation; SOC, soil organic carbon in 0-60 cm depth (t/ha), VIF, variance inflation factor.

Site	**Variable**	**Coefficient**	**VIF**	**P <**	**R^2**	**n**
Field C1, ACRI, Narrabri, NSW	N	0.004	1.3	0.01	0.48***	55
	SOC	-0.040	1.5	0.001		
	Max till x N	-6.26E-04	1.4	0.05		
Field D1, ACRI, Narrabri, NSW	T_{min}	0.72	1.4	0.001	0.75***	28
	T_{max}	-0.62	1.4	0.001		
	Stubble	0.25	1.1	0.01		
	SOC	-0.032	1.4	0.05		
“Glenarvon”, Wee Waa, NSW	Max till	0.36	1.3	0.001	0.88***	16
	T_{min}	-1.11	1.3	0.001		
“Beechworth”, Merah North, NSW	Max till	-0.56	2.1	0.001	0.66***	41
	Min till	-0.26	1.5	0.001		
	N	0.003	1.1	0.01		
	Water	-8.99E-04	1.2	0.001		
	T_{min}	-1.03	2.4	0.001		
“Auscott-Warren”, Warren, NSW	T_{max}	0.069	2.2	0.05	0.91***	33
	Max till	0.14	1.7	0.001		
	Water	-5.36E-04	2.3	0.001		
	SOC	0.007	3.3	0.05		
	T_{min}	-0.25	1.4	0.01		
Pooled results for cotton-wheat rotations on permanent beds	Min till	0.42	2.8	0.05	0.67***	66
	N	0.011	1.5	0.01		
	Max till x N	-0.004	2.0	0.01		
	SOC	0.051	1.2	0.001		
	Max till x min till	0.26	3.5	0.001		

As with SOC and yield, there was considerable variation among individual sites with respect to the determinants of water use efficiency (Table 29). Overall, however, SOC and frequent deep tillage were positively related to WUE at Warren and Wee Waa whereas total water inputs had a negative relationship. In most sites average minimum temperature was negatively related to WUE but was not evident in the pooled results across all sites. In contrast to the on-farm sites, SOC was negatively related to WUE and total water had no significant effect at ACRI. This may be due to higher water application rates in on farm sites. N was either positively related to WUE or had a negative interaction with frequent deep tillage. In summary, variable such as depth and frequency of tillage, N and SOC played significant roles in determining WUE of cotton.

6.6.5.3 Nitrogen use efficiency

For the purpose of this study, we have defined cotton nitrogen use efficiency (NUE) as cotton lint yield per kg N of mineral fertiliser (bales/ha/kg).

Table 30. Results of multiple linear regression analyses of management and climatic variables on cotton nitrogen use efficiency in individual sites. Max till, number of tillage operations > 10 cm deep; Min till, number of tillage operations < 10 cm deep; N, N fertiliser applied (kg N/ha); Water, total water inputs, irrigation and rainfall (mm); T_{max}, annual average daily maximum temperature (^oC); T_{min}, annual average daily minimum temperature (^oC); SOC, soil organic carbon in 0-60 cm depth (t/ha), Legume, dummy variable for presence (1) or absence (0) of a leguminous rotation crop in the rotation; VIF, variance inflation factor.

Site	Variable	Coefficient	VIF	P <	R^2	n
Field C1, ACRI, Narrabri, NSW	Max till x N	-0.004	1.3	0.05	0.48^{***}	51
	Water	0.006	1.2	0.001		
	T_{min}	-1.91	1.2	0.05		
	SOC	-0.19	1.5	0.001		
Field D1, ACRI, Narrabri, NSW	Legumes	10.13	1.0	0.001	0.45^{***}	40
	Water	0.033	1.0	0.001		
"Glenarvon", Wee Waa, NSW	Max till	0.29	1.2	0.05	0.97^{***}	16
	Min till	0.30	1.3	0.01		
	N	-0.066	1.1	0.001		
"Beechworth", Merah North, NSW	Max till	-3.93	1.8	0.001	0.52^{***}	41
	Min till	-1.85	1.5	0.001		
	N	-0.015	1.1	0.01		
	T_{min}	-9.94	2.3	0.001		
"Auscott-Warren", Warren, NSW	T_{max}	0.97	2.2	0.01	0.96^{***}	33
	Max till	1.83	2.8	0.091		
	Water	0.007	2.7	0.001		
	N	-0.092	4.0	0.001		
Pooled results for cotton-wheat rotations on permanent beds	T_{min}	-5.43	1.4	0.001	0.59^{***}	75
	T_{max}	1.93	1.3	0.01		
	Water	0.010	1.0	0.001		

As with SOC, yield and WUE there was considerable variation among individual sites with respect to the determinants of NUE (Table 30). SOC was positively related to NUE only in Field C1 at ACRI. Within individual sites, frequent deep (> 10 cm) tillage and total water inputs were positively related to NUE whereas mineral N inputs and in two sites, average minimum temperature were negatively related. The inclusion of legumes in a crop rotation had a large positive effect on NUE in Field D1 at ACRI but did not do so at "Glenarvon". This is probably because N applications rates were reduced in Field D1 to account for N fixation by the legumes but was not done so at "Glenarvon". When the results were pooled across all sites, however, only water and the two temperature variables were significantly related to NUE. In summary, variable such as frequency of deep tillage, N, water and average maximum and minimum temperatures played significant roles in determining NUE of cotton.

6.6.6 <u>**Effect of crop rotation on black root rot incidence**</u>

Black root rot incidence in cotton seedling was measured during December of 2008-09 and 2009-10 seasons in the rotation experiment infield D1, ACRI (Experiment 5.1.1.2). Measurements could not be made during the 2010-11 season due to heavy rainfall and waterlogging of the site.

Black root rot incidence had a significant effect on cotton seedling growth (Fig. 59). Crop rotation significantly affected black root rot incidence only during 2008, but not during 2009 when overall incidence increased by 2 or 3 times (Table 31). During 2008, least incidence occurred in cotton sown in the cotton-wheat-vetch rotation.

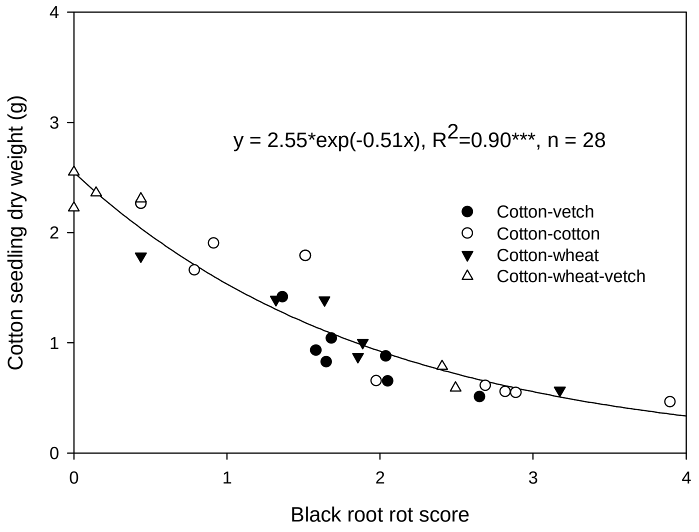

Fig. 59. Variation of cotton seedling growth (plant dry weight) with black root rot infestation rate. Pooled results from 2008-09 and 2009-10 season.

Table 31. Effect of rotation on black root rot infestations (represented as black root rot score) in young cotton. Values within parentheses are ln(black root rot score+1) transformed values.

Rotation	**2008**	**2009**	**Mean**
Cotton-vetch	1.7 (0.989)	2.1 (1.139)	1.9 (1.064)
Cotton-cotton	0.8 (0.614)	2.7 (1.320)	1.6 (0.967)
Cotton-wheat	1.2 (0.786)	2.7 (1.302)	1.8 (1.044)
Cotton-wheat-vetch	0.1 (0.112)	2.5 (1.240)	1.0 (0.676)
Mean	0.9 (0.625)	2.5 (1.250)	
	P <	sem	
Rotation	ns	(0.098)	
Year	0.001	(0.063)	
Rotation x year	0.05	(0.125)	

6.7 Performance of the "Mulch manager"

6.7.1 Greenhouse gas emissions, and herbicide and labour costs

In-field fuel use and greenhouse gas emissions, and emissions associated with fuel production and transport were in the order of Stage 2 > Stage 1 > Stage 3 (Table 32). This was because, relative to Stage 1, 10% more fuel was used by Stage 2 and 3% less by Stage 3. Emissions associated with herbicide production and transport were, however, in the order of Stage 1 > Stage 2 = Stage 3. In comparison with the Stage 1, herbicide production and transport resulted in Stages 2 and 3 emitting 21% less CO_2-e. This was because Stages 2 and 3 used less herbicides. Overall, emissions associated with in-field activities, and herbicide and fuel production and transport were least with Stage 3: 11% less than Stage 1 and 7% less than Stage 2.

A significant proportion of emissions (32-37%) in all three stages were accounted for by the mowing. It is likely that major improvements in terms of fuel and emission reduction may be achieved by seeking alternatives to the slasher. Flail mowers, undercutters, cutter bars and band mowers are other possible alternatives. An alternative to mowing may be to graze the vetch with livestock, although this may result in N fixed by the vetch moving off-field when the stock are relocated. The subsequent crop may, therefore, not benefit from the N fixation by the vetch.

Costs of herbicides (using September 2010 prices of $A 10.75/Litre of Spray.Seed® and $A 4/Litre of Glyphosate 450®) were of the order of $A 75.50/ha for Stage 1, and $A 44.25/ha for Stages 2 and 3. In all three stages, a complete kill of vetch and weeds was obtained. In Stage 3 ("Final design"), Spray.Seed® was applied at an overall average rate of 3 L/ha to a 0.2 m wide band at 1-m intervals, (i.e. 20% of the land area). Glyphosate 450® was similarly applied to 80% of the area.

Labour requirements were in the order of Stage 1 > Stage 2 > Stage 3 (Table 32). Stage 3 required 36% less labour than Stage 1, and 26% less labour than Stage 2. This is a significant cost saving. For example, assuming that the hourly cost to an employer for a farm worker is $A 31.55/hour (salary of $A 45,000/annum and on-costs (sum of payroll tax, workers compensation, leave loading, extended leave and superannuation) of 35%), then estimated labour costs/ha would be of the order of $A 347 for Stage 1, $A 300 for Stage 2 and $A 221 for Stage 3. Other benefits would include reduced herbicide exposure and fatigue to workers due to reduced working hours and Spray.Seed® application rates.

6.7.2 Soil compaction

Depth and pattern of compaction in furrows, as indicated by changes in penetrometer resistance differed among the three stages (Fig. 60). Maximum statistically significant depth of compaction was shallow in Stage 1 and was of the order 0.120 m with an average (geometrical mean) increase of 101% in the 0-0.120 m depth, whereas maximum depths of compaction in Stages 2 and 3 were 0.315 and 0.390 m, respectively, and average increases to maximum depths of compaction were 20% and 39%, respectively. In other words, Stage 1 (total weight of 6.9 t, axel load of 1.0 t) had a shallow but intense pattern of compaction, whereas Stages 2 and 3 had less intense but deep compaction patterns. In comparison with Stage 2, more intense and deeper compaction occurred with Stage 3. Although there was a weight differential between Stage 3 (total weight of 4.5 t, axel load of 0.7 t) and Stage 2 (total weight of 4.4 t, axel load of 0.6 t), the small difference of 0.1 t alone does not adequately explain the near doubling of compaction between the two stages. We surmise that relative to Stage 2 (Figs. 4(a)), the inclusion of an additional tank and altered weight distribution in Stage 3 (Fig. 5) may have resulted in a significant increase in vibrations, and when combined with the relatively moist, clayey soil, a deeper and more intense compaction (and possibly, smearing) may have occurred in the latter[31]. The varying patterns of compaction between Stage 1, and Stages 2 and 3 may be due to a combination of factors such as greater weight of the tractor/boom sprayer/herbicide tank combination (6.9 t), more vehicle passes and wider tyres in the JD6130 used in Stage 1 (Table 32) relative to the JD5303 used in Stages 2 and 3[31]. Widths of the front and back tyres of the JD6130 were 410 mm and 320 mm, respectively, and of the JD5303 were 370 mm and 240 mm, respectively. Air pressure in the tyres is unlikely to have been a contributory factor as those in the JD6130 were higher (207 and 117 kPa in the front and back tyres, respectively) than those in the JD5303 (124 and 103 kPa in the front and back tyres, respectively). Shallow compaction patterns are characteristic of wider tyres and low air pressures.

In summary, an integrated mechanical and chemical management system, the "Mulch manager" that was able to kill aggressive and bulky prostrate cover crops such as vetch with fewer machine passes, also reduced use of more toxic herbicides such as Spray.Seed®, decreased labour, lowered risk to operators and had a lower carbon footprint. In comparison to spraying with an 8-row boom sprayer, depth of compaction was more when this 4-row implement was used, although the former resulted in more intense and shallower compaction.

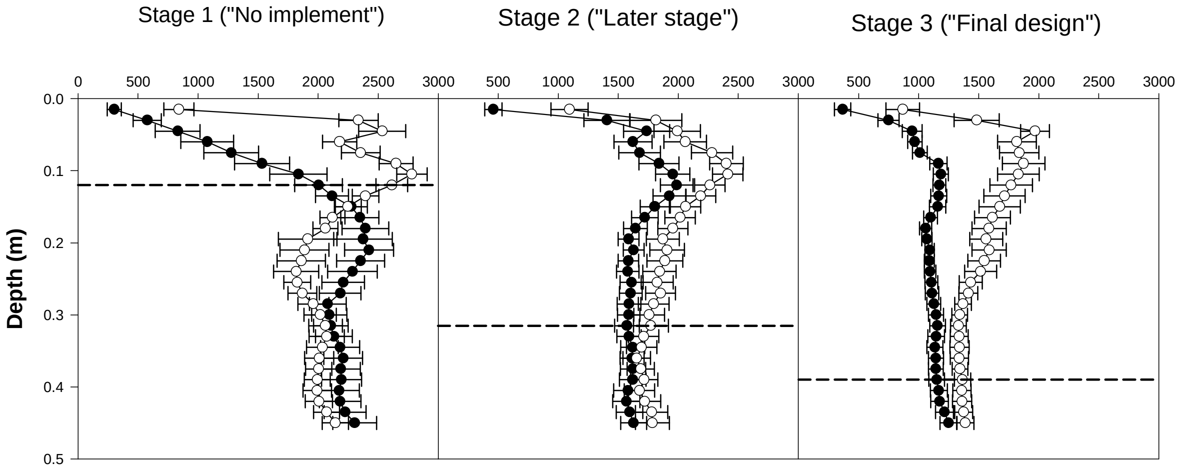

Fig. 60. Penetrometer resistance (standardised to a gravimetric soil water content of 0.275 g/g) to a depth of 0.45 m with the three developmental stages (Table 1) of vetch management, 5 October 2010. ● - Before trafficking; ○ - After trafficking. Stage 1 – Mowing followed by applying Spray.Seed® with 2 passes of an 8-row boom sprayer ("No implement"); Stage 2 - Mowing followed by applying Spray.Seed ® in a single pass with an intermediate stage of the implement and Glyphosate 450® with a single pass of an 8-row boom sprayer ("Later stage"); Stage 3 - Mowing followed by applying Spray.Seed® and Glyphosate 450® with the final version of the implement in a single pass ("Final design"). Horizontal bars are standard errors of the means. Dotted line is the maximum depth that significant changes were detected

Table 32. Estimated emissions and labour requirements (including setting-up time). JD, John Deere; weight of the JD8100 was 8.8 t, JD6200 3.8 t, 8-row boom sprayer with 550 L of herbicide 1.0 t and 4-row coulter / band sprayers in Stages 2 and 3, 0.6 t and 0.7 t, respectively. Emissions estimated for herbicide and fuel production includes those associated with transport

Options	**Operation**	**Tractor**	**Implement**	**Diesel used**	**In-field emissions**	**Herbicide production emissions**	**Fuel production emissions**	**Total**	**Labour**
				(L/ha)	**CO_2-e (kg/ha)**				**(man h/ha)**
Stage 1 (No implement)	Mowing	JD8100	4-row Slasher	10.7	31.0		4.5	35.5	3.5
	Applying Spray. Seed® (3 L/ha) x 2	JD6200	8-row boom sprayer	4.4	12.8	20.0	1.9	34.7	5.0
	Applying Glyphosate 450® (3 L/ha)	JD6200	8-row boom sprayer	2.2	6.4	28.8	0.9	36.1	2.5
Total				17.3	50.1	48.8	7.4	106.3	11.0
Stage 2 (Later stage)	Mowing	JD8100	4-row Slasher	10.7	31.0		4.5	35.5	3.5
	Applying Spray. Seed® (3 L/ha)	JD 6200	4-row coulter / band sprayer	6.2	17.8	10.0	2.6	30.4	3.5
	Glyphosate 450® (3 L/ha)	JD6200	8-row boom sprayer	2.2	6.4	28.8	0.9	36.1	2.5
Total				19.1	55.1	38.8	8.1	102.0	9.5
Stage 3 (Final design)	Mowing	JD8100	4-row Slasher	10.7	31.0		4.5	35.5	3.5
	Applying Spray.Seed® (3 L/ha) + Glyphosate 450® (3 L/ha)	JD 6200	4-row coulter / band sprayer	6.2	17.8	38.8	2.6	59.2	3.5
Total				16.9	48.8	38.8	7.2	94.7	7.0

7 Conclusions

Soil organic carbon:

- In general, SOC stocks in the 0-60 cm depth ranged between 50 and 70 t/ha. Legumes, even if they contribute large amounts of carbon to the soil are unable to retain it due to their low C/N ratios facilitating rapid microbial decomposition. Carbon inputs of C4 crops such as sorghum and corn were much larger than those of C3 crops such as wheat. A major proportion of that contributed by the C4 crops came from their root systems.
- SOC storage was positively related to dry matter inputs, average maximum temperature, soil aeration and water availability but was negatively associated with N fertiliser inputs. The last three variables are those that can be manipulated by cotton growers. Stubble burning resulted in lower SOC storage.
- Average maximum temperature and soil organic carbon in the 0-60 cm depth had curvilinear relationship. The temperature optima were higher in the Namoi valley (27-28 ^{o}C) than in the Macquarie (25.5 ^{o}C), presumably due to differences in the soils' ecosystems. Although not addressed in this report, it is known that that N and water have similar relationships to SOC.
- SOC sequestration rates were generally negative or neutral, except where a stressed soil (disease, sodicity, salinity) was in the process of recovering. Estimates of carbon inputs, based on above-ground and root dry matter, indicated that large losses of carbon were occurring in all soils. This was probably due to a combination of accelerated erosion, runoff and microbial decomposition.
- SOC storage increased when moving northwards from Hillston to Emerald.

Greenhouse gas emissions

- Farming practises that could reduce emissions include reducing frequency and depth of tillage, excluding or minimising use of groundwater, sowing winter crops in rotation with cotton, reducing/optimising mineral N fertiliser rates, substituting a legume an thus, fixed N for mineral N fertiliser.
- Given the constraints of the static chamber method noted earlier, the production systems studied in the project do not appear to result in sustained emissions of high concentrations of nitrous oxide. Episodic events with large fluxes were observed, and these can be correlated with incidence of gross system disturbances, such as irrigation and cultivation type operations (see above point). Carbon dioxide emissions are in line with what could be expected from an agricultural production system. Treatment effects are suggested by the data, but inherent variability masks much of the impact. In the absence of the availability of a continuous, automated system future sampling should be more intensively directed at a smaller number of targeted events.

Soil and water quality

- In a year when rainfall was frequent, surface concentrations of nitrate-N were higher where N fertiliser had been recently applied and where a legume had been sown whereas subsoil concentration were higher after the fallow in cotton-wheat or cotton-wheat-vetch. Length of fallow was also negatively correlated to SOC concentration in the soil surface.
- In comparison with ripping alone, the increase in exchangeable K with manure application was of the order of 0.16 t K/ha. Long-term cropping-related K depletion can, therefore, be minimised by regular application of cattle manure; for example once every 5 years. Gypsum application did not significantly reduce dispersion and increase drainage. Given

the absence of a response to gypsum application and the associated costs, not applying gypsum is a rational one in this soil type and environment. The poor response to gypsum may be related to the typically erratic rainfall patterns of this region

- Irrigation water quality at ACRI deteriorated (increase in SAR, pH and salinity) between 2008 and 2009 due to an increased dependency on bore water but had improved (falls in SAR, pH, salinity) by 2010 because of the frequent rainfall during the 2010 winter and spring, which is likely to have replenished the aquifer and on-farm storage. Quality of the treated sewage effluent was generally poor and characterised by high alkalinity, salinity and SAR.

Soil hydrology

- Soil water storage, particularly during the early part of growing season when rainfall provided the major proportion of crop water requirements, and drainage were high when a cotton-wheat rotation with *in situ* retention of wheat stubble was sown on permanent beds. Soil water storage and drainage were also higher when irrigation frequency was high. Infiltration was less in management systems which resulted in wetter soil; viz. frequent irrigation or a cotton-wheat rotation on permanent beds with *in-situ* stubble retention. Thus, water losses through drainage may be reduced and soil water storage increased (i.e. water conservation improved) by sowing a cotton-wheat rotation with *in situ* stubble retention under less frequent irrigation. Management systems which conserve all rainfall received *in situ*, thereby reducing the requirements for irrigation water can contribute greatly to the sustainability of irrigated farming systems.
- In comparison with rotations that included a wheat crop, soil water storage during the early part of the cotton-growing season was generally lower in systems that had cotton sown every year. Soil water storage in the cotton-wheat-vetch rotation was higher than that in the cotton-wheat sequence in years when rainfall was a major early season contributor to crop water requirements. Retention of vetch and wheat mulch *in situ* in the cotton-wheat-vetch sequence may have facilitated rainfall harvesting. Deep drainage in cropped plots was many times higher than that in fallow plots, and reflects the higher water inputs in the former. Among rotations, drainage was higher in the cotton-wheat or cotton-wheat vetch rotations than either the continuous cotton or cotton-vetch rotation.
- Drainage during most winters was in the order of wheat in cotton-wheat and cotton-wheat-vetch > vetch in cotton-vetch and vetch in cotton-wheat-vetch. The last had the least amount of irrigation and subsisted mainly on stored soil water and in-crop rainfall. In winters when rainfall was frequent and no irrigation was required, drainage was highest in fallowed treatments, with fallow length being positively correlated to drainage.
- A simple model was derived that used rainfall and potential evaporation data to estimate soil evaporation from beds where stubble was either incorporated or retained as *in situ* mulch.
- In “normal” years drainage measured with the lysimeter was greater than that estimated with chloride mass balance model whereas in wet years the reverse occurred. A model that used measurements made with an EM38 in horizontal mode, soil water storage and sodicity (ESP) was able to accurately estimate chloride in soils where concentration in the saturation extract was 335 mg/L (= 240 mg/kg) or less. These values could then be used to estimate drainage using chloride mass balance models. In more saline soils, large differences occurred between actual and estimated chloride.

Root growth of rotation crops

- Corn root densities are generally higher with corn monoculture than with cotton-corn rotation.

- Early sown vetch (i.e. cotton-wheat-vetch) has more roots at depth, although overall L_A values are similar among both wheat treatments and the vetch in the cotton-wheat vetch rotation. The later sown vetch (cotton-vetch rotation) has significantly lower root length than the other treatments in most years. Between wheat treatments, cotton-wheat generally has higher root densities than cotton-wheat-vetch. Aphid damage to above-ground parts of vetch inhibits vetch root growth and results in shallower and more sparse root system
- Densities of sorghum roots were higher in the deeper subsoil than that of either wheat or vetch but were comparable to that of corn, although under no-tillage sorghum values tend to be higher. The deep and extensive root system of sorghum does show, however, that roots of crops such as sorghum and corn, both C4 crops, can be important sources of carbon inputs into the soil.

Cotton yields and profitability

- Cotton yields were generally higher where wheat was included in the rotation. Sowing sorghum may result in yield losses due to nutrient imbalances.
- Amendments such as gypsum or manure did not improve crop yields under dryland conditions.
- Inclusion of vetch was less profitable than a fallow or wheat rotation. With respect to gross margin/ha the difference was minor, but in terms of gross margin/ML the treatments without vetch were significantly more profitable. Generally, including vetch in the rotation did not result in sufficient improvements in cotton yield to compensate for the increase in production costs.
- In recent years, water has been the major limiting resource for cotton production, and consequently, cotton growers are looking for a farming system that gives them the greatest return by ML. Reduced water cotton rotation may, therefore, be an option. The minimum-tilled cotton-wheat rotation consistently achieved the highest cotton yields and the highest gross margin/ML. In years of plentiful water (or when crop area is the limiting factor), however, reducing water application rates on a continuous cotton crop is a false economy.

Lint yield, WUE and NUE determinants

- Cotton lint yields, in general, were positively related to water and N inputs, soil aeration in some sites and average annual daily maximum temperature in cooler or poorly-drained sites but were lowered by higher average annual daily minimum temperature. In a sodic soil, a high frequency of the tillage practices intended to aerate the soil may have caused yield decreases, presumably due to exposure of more sodic soils.
- Depth and frequency of tillage, average annual maximum and minimum temperature, N and SOC played significant roles in determining WUE of cotton. The relative importance of individual factors varied among sites.
- Frequency of deep tillage, N fertiliser rates, water, presence of legumes and average maximum and minimum temperatures played significant roles in determining NUE of cotton. N fertiliser rate had a negative effect whereas legumes had a positive effect on NUE. The relative importance of individual factors varied among sites.

Performance of the "Mulch manager"

- The "Mulch manager" an integrated mechanical and chemical management system, that was able to kill aggressive and bulky prostrate cover crops such as vetch with fewer machine passes, also reduced use of more toxic herbicides such as Spray.Seed®, decreased labour, lowered risk to operators and had a lower carbon footprint. In comparison to spraying with an 8-row boom sprayer, depth of compaction was more when this 4-row implement was used, although the former resulted in more intense and shallower compaction.

8 Suggested areas of future research

- The processes related to long-term carbon sequestration in irrigated Vertosols and their interactions with rotation crop type, and soil physical and chemical properties such as clay mineralogy and aggregation.
- Pathways of carbon loss (erosion, dissolved organic carbon in runoff and drainage) and entry into irrigated and dryland cotton fields. Although considerable information is available on some pathways of carbon inputs such as crop residues and organic waste products (manure, composted gin trash etc.), the contribution through irrigation water (i.e. dissolved organic carbon) and sediments is unknown for Australian soils.
- Expanded field research program to investigate the use of solid waste materials (e.g. cotton gin trash, manure, biosolids) as soil amendments in dryland and irrigated cotton farming systems, particularly in sodic and nutrient-depleted Vertosols. Issues which should be addressed include the direct effects on soil quality, environmental costs such as N and P enrichment of water supplies, potential for carbon sequestration and greenhouse gas emissions, detailed economic analyses and their potential for use as biochar.
- In the absence of the availability of a continuous, automated system measurement of greenhouse gas emissions from soil should be more intensively directed at a smaller number of targeted events.
- Identify origin of recalcitrant and stable soil carbon in cotton fields under differing management systems.
- Carbon distribution in the soil profile under differing irrigation systems.

9 Suggested/planned extension activities

- Decline in the numbers of cotton industry extension staff results in a “bleeding” of expertise with respect to soils capability (N.B. A significant number of extension staff equate soil management with fertiliser management, with little emphasis given to other aspects such as soil structure. This is of some concern in view of the larger, heavier round-bale pickers that are becoming popular). Regular workshops are suggested as a pathway to extend the research outcomes from this and other projects related to soil management and farming systems and to maintain the skills base of the cotton extension staff.
- Presentations to industry groups at workshops.
- Field tours and farm walks
- Being part of the extension network’s soil health and nutrition team and providing technical support to the Cotton extension staff when called upon to do so.
- Articles in rural industry magazines such as the “Australian Cottongrower” and “Spotlight” or newspapers such as “Agriculture Today” or the “Land”.
- Media releases of NSW Department of Primary Industries.
- Articles in local and regional newspapers.
- Via interviews with print and electronic media. The Cotton RDC in co-operation with the Cotton CRC could provide significant assistance in this area by identifying and contacting the relevant publications.

10 New methods and techniques

- Water retention curves using modified filter-paper method. The accuracy of the method is uncertain at the soil water potentials > -20 kPa.
- During the previous phase of this project a management system was developed whereby vetch regrowth and suffocation of emerging cotton seedlings was avoided through a combination of mechanical methods (slashing, cutting vetch lateral stems with coulter discs) and herbicides (paraquat-based herbicides such as “Spray.Seed”) as either herbicides or mechanical methods alone resulted in poor control. The different steps were combined into a single operation which also reduced the amount of “Spray.Seed” applied (see pp. 17-20 and 90-93 of this report).
- Simple models were developed to estimate soil evaporation using meteorological data and soil Cl concentration using EM38 readings, soil water content and sodicity. The Cl values can be used in mass balance models to estimate deep drainage.
- A whole-farm model to analyse the profitability of cotton farming systems.

11 Problems encountered

- Poor winter growth of wheat continued at Windmill farm” in Moree. The experiment was discontinued as the rotation phase was an essential component of the treatments.
- The nitrate-N analyser managed by CSIRO was found to have malfunctioned. Results for 2009 were rejected. Samples for 2010 were analysed at NSW DPI’s laboratories in Wollongbar.
- Heavy rains and flooding during November/December 2010 resulted in some soil sampling being aborted.
- Obtaining accurate and complete records of site management practices was difficult. Many staff who controlled these records for the on-farm experiments have either retired or moved onto other positions and locations.

12 Outcomes

The project had several outcomes which could be of significance to the Australian Cotton Industry. These are briefly summarised as follows:

- Identifying soil and crop management practices, and climatic variables that had direct impacts on soil carbon stocks, yield, water and nitrogen use efficiency in irrigated cotton soils. Modification of these management practices could improve soil carbon stocks, water and nitrogen use efficiency.
- Among rotation crops, identifying those that used the C4 photosynthetic pathway such as sorghum and corn as potentially being of more benefit with respect to sequestration of carbon in soil.
- Quantifying rainfall harvested, and associated drainage and evaporation, and thus, water saved by retaining rotation crop stubble as *in situ* mulch.
- Identifying practices that could reduce carbon footprint of cotton farming systems with life cycle analysis.
- A machinery attachment for managing prostrate cover crops bed-furrow systems.
- Simplified field methods to estimate soil evaporation and deep drainage.
- A whole-farm model of profitability for cotton farming systems that can be used as an analytical research tool. We suggest that this model could be used as a foundation for a whole farm carbon accounting framework.

13 Training

The following student projects have either been completed or are on-going in the experimental sites described in this project:

Table 25. Postgraduate and honours research conducted within Project CRC 1.04.16

Student	Degree	University	Years	Project title
T. B. Weaver	PhD (P/T)	Griffitth University, Nathan, Qld.	2000-to date	Deep drainage and leaching in irrigated Vertosols
K. Broughton	BSc (Agric.)	University of Sydney	2008-09	Root growth and soil microbial biomass in Bt transgenic cotton
D. McLane	B. Nat. Res. (Hons.)	University of New England, Armidale	2008-09	Nutrient release to vetch phases in cotton rotation systems – the role of P
A. Devereaux	MPhil	University of Queensland, St. Lucia, Qld.	2006-to date	Quantifying effects of maize rotation on soil quality and nutrient availability on cotton growth and yield

The project hosted two work experience students. They were:

- Gabby Saliba, Mudgee High School, 29 June-1 July 2010
- Gavin Whitburn, University of Queensland (Gatton), 4-6 August 2008

The project hosted Mr. Mansoor Ahmad from Faisalabad University in Pakistan (2009). Mr. Ahmad studied methodologies related to root measurements and soil water monitoring.

14 Communication of results

Results from this project have been disseminated in national and international technical journals and conferences, cotton industry publications such as the "Australian Cottongrower", ACGRA Cotton Conference Proceedings and field trial books, field days and industry workshops.

Specific details of published articles and oral presentations (1 July 2008 to 30 June 2011, including those “in press”) are given below. The hyperlinks for those items which have been published on-line are also provided.

14.1 Technical journals

1. Hulugalle, N.R., Weaver, T.B., Finlay, L.A., Luelf, N.W., and Tan, D.K.Y. (2009). Potential contribution by cotton roots to soil carbon stocks in irrigated Vertosols. Aust. J. Soil Res., **47**, 243-252. http://www.publish.csiro.au/?paper=SR08180
2. Hulugalle, N.R., McCorkell, B.E., Weaver, T.B., and Finlay, L.A. (2010). Managing sodicity and exchangeable K in a dryland Vertisol in Australia with deep tillage, cattle manure and gypsum. Arid Land Res. Mgmnt., **24**, 181-195. http://www.informaworld.com/smpp/section?content=a922818553&fulltext=713240928
3. Hulugalle, N.R., Weaver, T.B., and Finlay, L.A. (2010). Carbon inputs by irrigated corn roots to a Vertisol. Plant Root, **4**, 18-21. http://www.plantroot.org/PDFarchive/2010/4_18.pdf
4. Hulugalle, N.R., Weaver, T.B., and Finlay, L.A. (2010). Soil water storage and drainage under cotton-based cropping systems in a furrow-irrigated Vertisol. Agric. Water Mgmnt., **97**, 1703-1710. http://www.sciencedirect.com/science/article/pii/S0378377410001988
5. Powell, J. and Scott, F. (2011). *A Representative Irrigated Farming System in the Lower Namoi Valley of NSW: An Economic Analysis*, 63 pp. Economic Research Report No. 46, Industry & Investment NSW, Orange. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/377346/ERR-46.pdf

6. Hulugalle, N.R., Finlay, L.A., and Weaver, T.B. (2011). An integrated mechanical and chemical method for managing prostrate cover crops on permanent beds. Renew. Agr. Food. Syst., In Press. Published on-line, June 2011. DOI: 10.1017/S1742170511000226. http://journals.cambridge.org/action/displayFulltext?type=6&fid=8306560&jid=RAF&volumeId=-1&issueId=-1&aid=8306559&bodyId=&membershipNumber=&societyETOCSession=&fulltextType=RA&fileId=S1742170511000226.
7. Weaver, T.B., Hulugalle, N.R., and Ghadiri, H. (2011). Estimating soil chloride concentration and deep drainage with an EM38. Submitted for publication.

14.2 Conference & workshop papers

1. Farrell, T., Hulugalle, N., and Gett, V. (2008). Healthier cotton soils through high input cereal rotations. Proc. 13th Australian Cotton Conference, 12-14 August 2008, Broadbeach, Qld., Australia. (Australian Cotton Grower's Research Association, Narrabri, NSW, Australia). [USB flash drive].
2. Holden, J., Devereux, A., Hulugalle, N., Fukai, S., Terry, J., and Tan, D.K.Y. (2008). Irrigated maize in cotton systems. Proc. 13th Australian Cotton Conference, 12-14 August 2008, Broadbeach, Qld., Australia. (Australian Cotton Grower's Research Association, Narrabri, NSW, Australia). [USB flash drive].
3. Terry, J.H., Tan, D.K.Y., Hulugalle, N.R., Field, D.J. Weaver, T.B., and Knox, O.G. (2008). Cotton yield and soil carbon under continuous cotton, cotton-corn, cotton-vetch-corn and cotton-wheat rotations. In “Global Issues – Paddock Action”, Proc. 14th Australian Agronomy Conference, 21-25 September 2008, Adelaide, SA (Ed. Unkovich, M.). Australian Society of Agronomy, Adelaide, SA. http://www.regional.org.au/au/asa/2008/poster/agronomy_landscape/5595_terryjh.htm
4. Hulugalle, N.R., Weaver, T.B., Finlay, L.A., Luelf, N.W., and Tan, D.K.Y. (2009). Potential contribution by cotton roots to soil carbon stocks in furrow-irrigated Vertisols of NW New South Wales, Australia. In “Root Research and Applications”, Proc. 7th Symposium of International Society of Root Research, 2-4 September 2009, Vienna, Austria. Institute for Hydraulics and Rural Water Management, University of Natural Resources and Applied Life Sciences, Vienna, Austria. http://rootrap.boku.ac.at/fileadmin/files/RRcd/session04/oral/001.pdf
5. Weaver, T.B., Hulugalle, N.R., and Ghadiri, H. (2010). Estimating deep drainage with an EM38 in horizontal mode. In “Recent Advances in Soil Science and Management”, ASSSI Fourth Forum, 19 March 2010, Armidale, NSW. ASSSI, Armidale, NSW, Australia.
6. Hulugalle, N.R., Weaver, T.B., Finlay, L.A., Broughton, K., and Tan, D.K.Y. (2010). Potential contribution by corn and Bollgard II cotton roots to soil carbon stocks in a furrow-irrigated Vertisol. In “Soil Solutions for Changing World”, Proc. 19th World Congress of Soil Science, 1-6 August 2010, Brisbane, Qld., Australia, pp. 182-185, (Eds. Gilkes, R., and Prakongkep, N.). ISSS, Brisbane, Australia [DVD-ROM].
7. Hulugalle, N.R., Weaver, T.B., and Finlay, L.A. (2010). Drainage under permanent beds in a furrow-irrigated Vertisol. In “Soil Solutions for Changing World”, Proc. 19th World Congress of Soil Science, 1-6 August 2010, Brisbane, Qld., Australia, pp. 21-24, (Eds. Gilkes, R., and Prakongkep, N.). ISSS, Brisbane, Australia [DVD-ROM].
8. Hulugalle, N.R., Weaver, T.B., and Finlay, L.A. (2011). Soil carbon management and water conservation with irrigated permanent beds. Proc. Rural Climate Change Solutions Symposium, 3-4 May 2011, Armidale, NSW, Australia, p. 57, (Ed. A. Cowie). National Centre for Rural Greenhouse Gas Research, Armidale, Australia.

9. Hulugalle, N. (2009). Greenhouse gas related research in long-term experiments of cotton farming systems. Cotton Matters Forum, 12-13 August 2009, Narrabri, NSW. (Cotton Australia, Sydney, NSW). http://www.cottonaustralia.com.au/news/view.aspx?id=188
10. Powell, J., and Scotto, F. (2011). A whole farm comparison of irrigated cotton rotations in the Lower Namoi Valley, NSW. Proceedings of 55th Conference of Australian Agricultural and Resource Economics Society, 8-11 February 2011, Melbourne, Vic. AARES, Melbourne. http://ageconsearch.umn.edu/handle/100698
11. Hulugalle, N.R., Finlay, L.A., and Weaver, T.B. (2011). A new approach to manage prostrate cover crops on permanent beds. Paper accepted for presentation at 5th World Congress of Conservation Agriculture, 26-29 September 2011, Brisbane, Qld.
12. Hulugalle, N.R., Tann, C., and Weaver, T.B. (2011). Minimum tillage systems can reduce heliothis pupae emergence in irrigated cotton farming systems. Paper accepted for presentation at 5th World Congress of Conservation Agriculture, 26-29 September 2011, Brisbane, Qld.
13. Hulugalle, N.R. (2011). Overcoming problems associated with retaining crop stubble on permanent beds in furrow-irrigated cotton farming systems. Paper accepted for presentation at 5th World Congress of Conservation Agriculture, 26-29 September 2011, Brisbane, Qld.

14.3 Cotton industry magazines and extension publications[1]

1. Hulugalle, N., Weaver, T., and Finlay, L. (2010). Irrigated corn roots can contribute to soil carbon stocks in grey clays. Aust. Cottongrower, 31(2), 44-45.
2. Hulugalle, N. (2010). Reducing greenhouse gas emissions from cotton farming practices. Aust. Cottongrower, 31(3), 49-50.
3. King, D., Hulugalle, N., and Leven, T. (2011). Field selection and preparation. In "Australian Cotton Production Manual 2011", pp. 34-36. Cotton Catchment Communities CRC, Narrabri, NSW, Australia.
4. Contributed to revision of Cotton rotation poster (March 2009) http://www.cottoncrc.org.au/files/32966203-3fb1-4b87-a43a 9c4700a1cecc/Rotation_chart_Back_pages_.pdf
5. Several articles were published in "Spotlight". They were as follows:
    - "New rotation: New system", Autumn 2008, p. 5.
    - "Rotation offers natural solution", Autumn 2009, p. 31.
    - "Cotton's Big Day Out", p. 4, and "Fallow management and no-till cotton in action", p. 8, Winter 2009.

14.4 Presentations

Presentations by N. Hulugalle

1. Presenter/resource person for "Cotton's Big Day Out" (Moree, February 2009), Auscott Ltd. Agronomy team workshop (Narrabri, November 2009), and Lower Namoi Valley Cotton field day (March 2009)
2. Interviewed by journalist for a video made for presentation at the ACGRA Cotton conference in August (July 2008)
3. Oral presentation entitled "Greenhouse gas related research in long-term experiments of cotton farming systems" at Cotton Australia's Cotton Industry Forum, 1Narrabri, 12-13 August 2009.
4. Field presentation to ACRI farm staff on research activities of soils group, November 2009.

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[1] Includes publications by staff from other organisations and units within NSW DPI where data collected by this project or its preceding projects were used.

5. Interviewed by Patrick Francis, "Australian Farm Journal", 2 June 2010
6. Oral presentation entitled “Potential contribution by cotton roots to soil carbon stocks in furrow-irrigated Vertisols of NW New South Wales, Australia” at the 7th Symposium of International Society of Root Research, 2-4 September 2009, Vienna, Austria.
7. Oral (“Drainage under permanent beds in a furrow-irrigated Vertisol”) and poster presentation (“Potential contribution by corn and Bollgard II cotton roots to soil carbon stocks in a furrow-irrigated Vertisol”) at the 19th World Congress of Soil Science, 1-6 August 2010, Brisbane, Qld.
8. Oral presentation entitled “Soil carbon management and water conservation with irrigated permanent beds” at the Rural Climate Change Solutions Symposium, 3-4 May 2011, Armidale, NSW.

Presentations by T. B. Weaver

1. Oral presentation entitled: “Estimating deep drainage with an EM38 in horizontal mode” at Australian Soil Science Society Inc., Fourth Regional Forum, 19 March 2010, Armidale, NSW. ASSSI, Armidale, NSW, Australia.
2. Oral presentation on soil science to Narrabri West Primary School students on 30 June 2009

Presentations by L. Finlay

1. Oral presentation on working as a technical support staff at ACRI to Regional High School students during visits on 16 April 2009 and 19 March 2010.
2. Oral presentation on soil science to Narrabri West Primary School students on 30 June 2009

Presentations by J. Powell

1 Oral presentation by J. Powell entitled “A whole farm comparison of irrigated cotton rotations in the Lower Namoi Valley, NSW” at the 55th Conference of the Australian Agricultural and Resource Economics Society, 8-11 February 2011, Melbourne, Vic.

Presentations by other co-operators

1. Oral presentation by D. Tan entitled “Cotton yield and soil carbon under continuous cotton, cotton-corn, cotton-vetch-corn and cotton-wheat rotations” at the 14th Australian Agronomy Conference, 21-25 September 2008, Adelaide, SA.
2. Oral presentations by T. Farrell (“Healthier cotton soils through high input cereal rotations”) at the 13th Australian Cotton Conference, 12-14 August 2008, Broadbeach, Qld.

14.5 Theses

1. Broughton, K. (2009). Root growth, turnover and soil microbial biomass in Bt and Non-Bt cotton, 52 pp. University of Sydney, Sydney.
2. McLane, D. (2009). Nutrient release to vetch in cotton systems, 46 pp. UNE, Armidale.

14.6 Popular media

1. Media releases by NSW DPI and articles for "Agriculture Today". These were as follows:
    - Cotton Institute research team patents money saver (In “Agriculture Today, March 2010, p. 4) http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0016/321109/agriculture-today-march-2010.pdf

- Death, decay…corn roots boost carbon (In “Agriculture Today, April 2010, p. 7) http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/332851/Agriculture-today-may-2010.pdf
- Potential for corn to boost soil carbon levels. http://www.dpi.nsw.gov.au/aboutus/news/recent-news/agriculture-news-releases/corn-to-boost-soil-carbon

2. Video presentation at the ACGRA Cotton conference in August 2008 by journalist sponsored by CRDC.
3. Two articles: “Vetch proves top winter rotation legume” and “Rotation crops: how they rank” in the Cotton Outlook insert in “The Land” (June 2009)

15 Acknowledgements

The technical assistance of Mr. L. Finlay is gratefully appreciated. Our thanks to the many cottongrowers who supported this project by providing land to conduct the trials, management expertise and continuing support and interest. Mr. B. McCorkell is thanked for biometrical support. We gratefully appreciate the support of Messrs A. Meppem (Manager, ACRI, until December 2010), D. Halliday (Manager ACRI, since March 2011) and D. Magann (Farm Supervisor, ACRI) with respect to on-station experiments, and laboratory and office facilities.

16 Statement on Intellectual Property

This research is based on research publications which are in the public domain. All publications which have come about from this research are also in the public domain. A provisional patent was obtained for the “mulch manager” but was not followed up with a full patent.

17 Budget

Item	2008-09	2009-10	2010-11
	($)		
A. STAFFING			
Total Salaries	64,792	67,383	70,079
On costs	15,679	16,306	16,958
TOTAL	**80,471**	**83,689**	**87,037**
B. TRAVEL			
Sustenance	4625	4226	5038
TOTAL	**4625**	**4226**	**5038**
C. OPERATING			
Soil & gas analyses	5085	8382	9849
Laboratory/office maintenance	0	1645	1095
Field sampling (inc. Vehicle costs)	9120	7079	7433
Maintenance/purchase of field equipment	2500	2263	1276
Research levy	7143	7500	7811
Economic analyses	3000	3000	3000
Computer & software leasing, licences, freight	3756	4500	4500
Extension/publication costs	1000	1000	1000
Farm operations	37,300	37,652	39,058
ACGRA Cotton Conference registration	400	0	400
TOTAL	**69,304**	**73,021**	**75,422**
D. CAPITAL	0	0	0
GRAND TOTAL	**154,400**	**160,936**	**167,497**

TOTAL FUNDS (2008-2011): $482,833