Cotton Catchment Communities CRC

FINAL REPORT

Maintaining profitability and soil quality in cotton farming systems II

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NSW DEPARTMENT OF
PRIMARY INDUSTRIES

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1. Executive Summary

The effects of rotation crops and stubble management on soil quality, carbon sequestration, deep drainage, nutrient leaching, yield and profitability of succeeding cotton in irrigated and dryland Vertosols was studied from 2005 to 2008 in seven irrigated experiments (near Ashley via Moree, Narrabri and ACRI in NSW and Goondiwindi in Queensland), and one dryland experiment in Queensland (Brigalow in the Darling Downs). Key management issues considered were tillage systems, rotation crops and stubble management, sowing cotton into standing wheat and vetch stubble, in particular.

Within the overall aim of the project there were three key objectives pertaining to cropping systems in Vertosol-based cotton farming systems:

- Determine the effects of sowing cotton into standing wheat and vetch stubble on soil and water quality and conservation. Find solutions to management problems associated with *in situ* mulch in furrow-irrigated Vertosols.
- Compare cotton-wheat and cotton-vetch rotations in terms of soil quality, water conservation and long-term cotton production.
- Determine efficacy of organic and inorganic amendments in stubble-mulched irrigated and dryland Vertosols.

Measurements taken in all experiments were: soil physical and chemical properties (e.g. soil organic matter, plastic limit, soil structure, exchangeable Ca, Mg, K and Na, ESP, pH, electrical conductivity). Profile water content to 1.2 m, crop growth, , nitrate-N, cotton lint yield and fibre quality were also measured. Economic returns in irrigated sites at ACRI and Ashley were evaluated by comparing seasonal and cumulative gross margins. Spatial and temporal deep drainage (with the chloride mass balance model) and nutrient leaching were measured at ACRI, and drainage at Narrabri and Ashley. Investigations were also conducted at ACRI into soil and cotton crop management practices and machinery which could overcome problems associated with sowing cotton into standing rotation crop stubble.

Sowing cotton into standing wheat stubble facilitated drainage and leaching of salts, and water conservation through rainfall harvesting. Leaching of nutrients such as nitrates was also higher. Due to drought during 2006 and 2007, winter rotation crop growth was poor, and consequently carbon sequestration did not differ significantly from control treatments. Under restricted water availability and on a whole-farm basis minimum-tilled cotton-wheat was more profitable than continuous cotton, whereas with unlimited water or on an individual field basis the reverse was true. In comparison with infrequent irrigation (10-14 day interval), frequent irrigation (7-10 day interval) doubled cotton lint yield and profitability (measured as gross margins), and improved fibre quality. Growers would, therefore, be better off reducing the area of cotton sown and giving it sufficient water rather than reducing irrigation frequency over a larger area. Within soil layers in the cotton root zone, drainage with frequent irrigation was greater than that with infrequent irrigation. Drainage out of the crop root zone was, however, similar under both irrigation frequencies and may be related to differing drainage pathways.

Vetch in a cotton-wheat-vetch sequence responded positively in terms of growth and N fixation to phosphate fertiliser whereas in a cotton-vetch sequence it did not. N fixation by vetch in the former rotation was also higher due to a longer growth period (sown in Late-February vs. later May) and wetter soil profile at sowing (sown into fallow vs. sowing immediately after cotton). Wheat grain yield and quality was improved by including vetch in the rotation (i.e. cotton-wheat-vetch) relative to cotton-wheat rotations. Cotton yield was highest when a wheat crop was included in the rotation. However, in comparison with cotton-wheat where stubble was incorporated, the cotton-wheat (standing stubble)-vetch sequence required less N fertiliser (due to N fixation by the vetch) and irrigation water (due to better

subsoil water storage and presumably, reduction of evaporation by the *in situ* mulch). Under restricted water availability and on a whole-farm basis, profitability was in the order of cotton-wheat-vetch > cotton-wheat > cotton-winter fallow-cotton > cotton-vetch-cotton. Adding vetch to a cotton-wheat rotation is more profitable but adding vetch to a continuous cotton rotation is less profitable. The "Mulch Manager", a machinery attachment which is able to kill vetch while minimising herbicide application rates and trafficking was developed.

The amount of C added to soil C stocks by the roots of Bollgard II-Roundup Ready Flex varieties was less than that added by non-Bollgard II varieties. Above-ground stress such as insect pressure also reduced cotton root growth and C addition to soil, whereas minimum tillage and wheat rotation crops increased them. In comparison with above-ground dry matter, however, contribution by cotton root material to soil C stocks is small.

Sowing corn in rotation with cotton increased concentrations of the light carbon fraction but not total soil carbon. A close relationship was present between the light carbon fraction and microbial activity. Microbial activity and hence, nutrient cycling may be improved by including corn as rotation crop. Including vetch in a cotton-corn rotation increased SOC and exchangeable K, and decreased exchangeable Na concentrations.

Furrow soil in continuous cotton systems sown with minimum tillage had lower pH and higher SOC than that under conventional tillage. In comparison with non-wheel-tracked furrows, $EC_{1:5}$ and geometric mean diameter of aggregates were higher in wheel-tracked furrows, and plastic limit lower. Differences were small between conventionally-tilled and minimum-tilled furrows, and between wheel-tracked and non-wheel-tracked furrows. Large inter- and small intra-seasonal changes also occurred with respect to soil physical and chemical properties in furrows. Interactions between surface soil factors in furrows may not, therefore, play a major role in influencing water application efficiency and infiltration within a season. Inter-seasonal differences could, however, affect hydrological processes.

In a K-deficient dryland Vertosol with high subsoil salinity and sodicity, only application of cattle manure (16 t FW/ha) resulted in a sustained improvement in soil quality, whereas gypsum and inorganic fertilisers had no effect.

Between 2005 and 2008, training was provided for two postgraduate students, and one honours student. During the same period, 6 journal articles, 5 conference papers and 12 cotton industry and extension publications were published by project research and technical staff. A total of 21 public presentations were given by project and associated staff.

Key outcomes included:

- identifying cotton-wheat-vetch with *in-situ* stubble mulching as one which can reduce cotton's N fertiliser and irrigation water requirements while maintaining yields;
- identifying the practice of irrigating with treated sewage effluent as potentially risky to soil health;
- determining that increasing complexity of cropping systems (i.e. sowing rotation crops) under conditions of restricted water availability can improve whole farm profitability;
- identifying carbon sequestering management practices such as minimum tillage, vetch rotation crops and manure application
- identifying corn as a rotation crop which could facilitate nutrient cycling;
- Identifying manure as a soil amendment which could alleviate K deficiency.

2. Introduction

In agricultural systems, soil quality is thought of in terms of productive land that can maintain or increases farm profitability, as well as conserving soil resources so that future farming generations can make a living. Management practices which can modify soil quality include tillage systems and crop rotations.

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.

With continuous cotton, soil structural degradation, particularly that due to shearing and compaction during land preparation and harvesting under wet conditions, fertility decline and increasing disease intensity can occur. Although soil structural degradation can be ameliorated by growing a rotation crop to maximize the frequency and intensity of wetting/drying cycles in the soil profile, until 1993 little attention had been directed towards the effects of the rotation crop and its management on subsequent stability of soil aggregates and pores, soil fertility (except for N balance) and biology, and economic profitability of such cropping systems. At the same time many cotton growers had shown an interest in utilising rotation crops and their management as an aid in maintaining sustainability of cotton-based farming systems. As a consequence, a research program on cotton rotations was initiated during the early 1990's with the main objective of identifying sustainable cotton-rotation crop sequences; *viz*. crop sequences which maintained and improved soil quality, minimised disease incidence, facilitated soil organic carbon sequestration, and maximised economic returns and cotton water use efficiency in the major commercial cotton growing regions of Australia. Several long-term experiments were conducted between 1993 and 2005 to evaluate the effects of the rotation crops, their residual effects and retention of their stubble (i.e. standing stubble) on soil quality, field management, deep drainage and profitability.

These experiments showed that yield reduction with continuous cotton was related to a combination of structural degradation, sodicity, reduced nutrient uptake and increased disease incidence, all of which strongly interacted with soil conditions at the start of the trial, and cotton management practices. Other issues such as higher profitability and ease of management of cereal rotation crops when compared with leguminous rotation crops, the poor performance of leguminous rotation crops under saline-sodic soil conditions, the potential for allelopathy following legumes, potentially better nutrient recycling with deeper rooted cereal rotation crops, nitrogen benefits of legumes and differential soil quality, mainly soil physical changes, due to legumes and cereals were also identified. The beneficial effects of rotation crops could be seen within 2 rotation cycles under irrigated conditions but it was only at the commencement of the 3rd rotation cycle that the benefits of the rotation crops under dryland conditions became evident.

Other issues, which came to light post-2000, were the occurrence of deep drainage and nutrient leaching and the significant economic costs of such nutrient losses. Likewise, although initially it was hoped that sowing rotation crops would increase soil organic carbon, and hence carbon sequestration, in soil, the results have been mostly negative. (This issue is addressed further in this report). Associated projects conducted on the same sites identified issues such as the higher probability of seedling diseases such as black-root rot of cotton occurring with continuous cotton. These latter projects also identified the possibility of using hairy vetch in rotation with cotton to control black root rot.

Post-2000 research from central Queensland and northern NSW have also indicated many advantages in cotton-rotation crop systems where the rotation crop stubble is not incorporated but is retained as standing stubble. Clear benefits were shown to occur with respect to reducing runoff, erosion and sediment-bound movement of pesticides into the river system. The standing stubble may also function as protective barriers for young cotton against insect pests such as Heliothis moths. Retention of stubble from cereal and leguminous crops such as vetch also minimise water losses through evaporation and runoff, and hence, optimise water conservation.

While sowing cotton into standing crop stubble has many environmental benefits, management-related disadvantages can occur. These include blocking up of gas-knives during anhydrous ammonia fertiliser application, poor weed control and waterlogging. Modifications to existing machinery can overcome blocking up of gas-knives whereas judicious site preparation and sowing Roundup-Ready® cotton varieties can optimise weed management. Waterlogging can, however, be a significant problem. Furthermore deep drainage (estimated with a chloride mass balance method) in standing stubble systems can be around 20% of total water inputs (rainfall + irrigation) whereas wheat stubble incorporation resulted in 7-12%. Nitrate-N leaching in standing stubble systems can be similarly high. Anecdotal observations from experiments where the standing stubble was that of a sprayed-out green wheat crop rather than that from a mature wheat crop suggests that nitrogen immobilisation may also occur, causing N imbalance within the following cotton crop.

In summary, while the rotation experiments supported by the CRDC and the Cotton Catchment Communities CRC (and its predecessor the CRC for Sustainable Cotton Production and the Australian Cotton CRC) have identified suitable cotton-rotation crop sequences under on-farm situations and identified the causes of yield decline in continuous cotton systems, other questions have arisen. These include the suitability of sowing rotation crops such as hairy vetch and corn over a long period, its performance with respect to system water use efficiency and its interaction with black root rot of cotton; management constraints related to sowing cotton into standing wheat stubble; relationship between salinity, sodicity and soil carbonates; carbon sequestration in soil; deep drainage and its role in the total water balance; and the economic and environmental consequences of plant nutrients and salts (NO_3, Cl, Na, Ca, Mg and K) leaching out of the cotton root zone on nutrient and salt balance have arisen within the past 2 years.

This report focuses on results obtained over the period 2005-2008 from 6 experiments (five irrigated, one dryland) in New South Wales and Queensland on rotation crop management. Where long-term trends are discussed, data collected since 1993 are also included.

3. Aims and Objectives

Determine the long-term effects of rotation crops and stubble management on soil quality, deep drainage and nutrient leaching; and growth, yield and profitability of succeeding cotton in grey Vertosols (grey clays).

4. Methodology

4.1 Field Experiments

4.1.1 Effects of sowing cotton into standing wheat stubble on soil quality, carbon sequestration in soil, deep drainage, nutrient leaching and profitability

Soil quality, carbon sequestration in soil, drainage and leaching and cotton growth were monitored in 2 on-going on-station experiments on rotation crop management located at ACRI (long-term rotation/tillage system experiment established in 1985 and a cover crop trial established by Dr. David Nehl in 2001, but re-laid in 2003); and two on-farm experiments (one at “Federation Farm”, near Narrabri and managed by Mr. Greg Coulton, and the other at

"Windmill Farm" near Ashleigh via Moree, part of the "Auscott-Midkin" group and managed by Mr. Justin Ramsay). The details of the individual experiments are as follows:

4.1.1.1 Tillage/rotation experiment at ACRI, Narrabri: Treatments were continuous cotton sown after either conventional or minimum tillage ("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. 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 successor 60BRF during the 2007-08 season). From 2005, the experiment was re-designed such that two irrigation regimes, "frequent" (~7-14 day 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 is 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 kg N/ha during August of each year as anhydrous ammonia before sowing cotton. 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 2006. 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 2007 to evaluate post-season soil chloride concentration. Agronomic measurements included plant mapping, root growth and lint yield and fibre quality of cotton, wheat grain yield and quality, and DM yield.

Additional measurements were also made in this site from 2001 to 2006 to quantify the effects of minimum tillage (permanent beds), wheel-traffic and time of season on furrow soil physical and chemical properties in an irrigated Vertisol. Soil was sampled with a narrow-bladed spade from the 0-5 cm depth of the base of adjacent wheel-tracked and non-wheel tracked furrows in every conventionally-tilled and minimum-tilled continuous cotton plot during the 2001-02, 2003-04 and 2005-06 cotton seasons. A single pair of wheel-tracked and non-wheel-tracked furrows was selected from each plot, and fifteen locations, spaced at 10-15 m intervals, were sampled in each furrow. The samples were pooled to make a single composite sample for individual furrows. During the 2001-02 season soil was sampled in December 2001, January 2002 and February 2002; during 2003-04 in July 2003, November 2003 and January 2004; and during 2005-06 in November 2005, January 2006 and February 2006. Although funding for this phase of the project commenced in 2005, results from all years in which soil was sampled are presented in this report.

4.1.1.2 Cover crop experiment at ACRI, Narrabri, established by Dr. Nehl: Treatments were cotton sown into (1) sprayed out wheat stubble (2) incorporated vetch stubble, (3) incorporated mustard stubble, and (4) bare fallow, arranged in a 6RCB design in plots 8 rows wide and 50 m long. This trial was established in 2001, but re-laid in 2003. The sprayed-out wheat stubble treatment was not implemented during 2005, and soil was sampled during September 2005 before cotton sowing. This experiment was discontinued by Dr. Nehl after the 2005-06 cotton season due to excessive weed growth and consequent confounding (see also our comments in the 2005 Final Report for CRC Project 45C)[1]. Soil was sampled with a

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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.

narrow-bladed spade during September 2005 from the 0-10 cm and 10-30 cm depths from five locations in each plot.

4.1.1.3 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 and April 2008. Results presented in this report relate to samples taken from 2005 to 2008. 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.

4.1.1.4 Gypsum x standing wheat stubble experiment at "Windmill Farm", near Ashley via Moree: Treatments were 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. Statistical precision was improved by establishing 4 sampling plots within each individual treatment plot. Irrigation was by sprinkler irrigation. Soil was sampled during December 2005 (baselines sampling), September 2006 and April 2007. Samples were not taken during the 2007-08 season due to funding constraints. Four 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. A supplementary sampling to evaluate post-season soil chloride concentration was conducted during May. The experiment was delayed due to poor wheat establishment during the 2005 winter. Faba bean was sown during winter 2006, sprayed out in September and cotton (cv. 43BRF) sown during the 2006-07 season. Cotton was followed by dryland wheat during 2007 winter. Due to lack of water the wheat crop failed and was incorporated in November, and followed by a rainfed sorghum crop in December 2007.

4.1.2 Comparative effects of cotton-wheat and cotton-vetch cropping systems on soil quality, carbon sequestration in soil, deep drainage, nutrient leaching and profitability

Soil quality, carbon sequestration in soil, drainage and leaching, and cotton growth and profitability were monitored in an experiment which was established in Field D1 at ACRI during 2002.

4.1.2.1 Cotton/wheat/vetch rotations experiment at ACRI, Narrabri: The experiment commenced in 2002, and crop rotations and their chronosequences from 2005 to 2008 are summarised in Table 1). 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 (if possible) after suitable rainfall events during later February or Early March and slashed/sprayed out in late August/early September. 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 most tillage operations being restricted to the bed after cotton picking. When cotton was sown, a "Roundup Ready" cotton variety (SICALA V2-RR) was used until 2005-06 season, and "Bollgard-Roundup Ready Flex" varieties thereafter (43BRF during the 2006-07 season and its successor 60BRF during the 2007-08 season). 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 rotations, both rotation and cotton phases were sown in the same year to allow evaluation of climatic variability. Rotations which did not include a vetch component (Rotations 2 and 3) received 160 kg N/ha during August of each year as anhydrous ammonia before sowing cotton and a supplementary fertiliser application during December 2006 at a rate of 80 kg N/ha as urea, whereas those which did, 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 varied from 30 (2006-07) to 60 (2007-08) kg N/ha for Rotation 4 and 80 (2006-07) to 100 (2007-08) kg N/ha for Rotation 1. The higher rates during 2007-08 season were due to the poor growth and consequently, low N fixation by the drought-affected vetch during winter 2007. Due to high N fixation during the 2005 winter (> 160 kg N/ha), no N fertiliser was applied to cotton in Rotations 1 and 4 during the 2005-06 season. 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. Phosphorus was applied only during May 2004 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. 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. Agronomic measurements included plant mapping, root growth and lint yield and fibre quality of cotton, wheat grain and DM yield, and vetch DM yield, C and N concentration. The experiment is expected to run for a period of 12 years.

4.1.3 Sowing vetch in cotton-corn rotations

4.1.3.1 On-farm experiment of strip-cropped cotton and corn, with and without vetch, near Goondiwindi: The experiment, which consisted of paired plots (800 m x 8 m) of strip-cropped cotton and (feed) corn sown with or without green manured vetch on 2-m beds, was established at "McIntyre Downs", near Goondiwindi by Mr. David Turner. Due to lack of irrigation water vetch was not sown during the 2004 and 2005 winters, and cotton was sown in both treatments during 2004 and 2005. Soil was sampled from 20 locations along parallel transects in each plot during November 2003, December 2004 and 2005 with a narrow-bladed spade from the 0-30 cm depth of each plot. No plant measurements were made in this experiment. Due to a combination of poor winter rainfall and unavailability of irrigation water this experiment was discontinued in 2006.

4.1.3.2 Effect of a winter vetch crop on soil quality in a cotton-corn rotation: This experiment was established at ACRI during December 2005 as a replacement for the abovementioned on-farm experiment at Goondiwindi. The experimental treatments were cotton-winter fallow-sweet corn-winter fallow and cotton-vetch-sweet corn-vetch sown on 1-m beds in a 4 RCB design. Individual plots were 20 m long and 4 (1-m) rows wide. Both corn and cotton phases were sown in the same year to allow evaluation of climatic variability. When cotton was sown, a "Roundup Ready" cotton variety (SICALA V2-RR) was sown during the 2005-06 season, and "Bollgard-Roundup Ready Flex" varieties thereafter (43BRF during the 2006-07 season and its successor 60BRF during the 2007-08 season). 160 kg N/ha was applied during August 2005 as anhydrous ammonia, 122 kg N/ha and 80 kg N/ha during November and December 2006, respectively, as urea, and 80 kg N/ha as urea during October 2007. Soil was sampled from five locations in each plot during November 2005 and 2006 with a narrow-bladed spade from the 0-30 cm depths. Soil was not sampled during 2007 due

Table 1. Crop rotations and chronosequences in cotton/vetch/wheat experiment in Field D1, ACRI, 2005-08
(The letters a and b denote different phases of the same rotation. Vetch$_{GM}$ = green-manured /stubble mulched vetch)

<table>
<tr><th>Rotation</th><th>2004-05 summer</th><th>2005 winter</th><th>2005-06 summer</th><th>2006 winter</th><th>2006-07 summer</th><th>2007 winter</th><th>2007-08 summer</th></tr>
<tr><td>1</td><td>Cotton</td><td>Vetch$_{GM}$</td><td>Cotton</td><td>Vetch$_{GM}$</td><td>Cotton</td><td>Vetch$_{GM}$</td><td>Cotton</td></tr>
<tr><td>2</td><td>Cotton</td><td>Fallow</td><td>Cotton</td><td>Fallow</td><td>Cotton</td><td>Fallow</td><td></td></tr>
<tr><td>3a</td><td>Cotton</td><td>Wheat</td><td colspan="2">Wheat stubble incorporated/ Fallow</td><td></td><td></td><td>Wheat stubble incorporated/ Fallow</td></tr>
<tr><td>3b</td><td colspan="2">Wheat stubble incorporated/ Fallow</td><td>Cotton</td><td>Wheat</td><td colspan="2">Wheat stubble incorporated/ Fallow</td><td>Cotton</td></tr>
<tr><td>4a</td><td>Cotton</td><td>Wheat</td><td>Standing wheat stubble/ Fallow</td><td>Standing wheat stubble/ Vetch$_{GM}$</td><td>Cotton</td><td>Wheat</td><td>Standing wheat stubble/ Fallow</td></tr>
<tr><td>4b</td><td>Standing wheat stubble/ Fallow</td><td>Standing wheat stubble/ Vetch$_{GM}$</td><td>Cotton</td><td>Wheat</td><td>Standing wheat stubble/ Fallow</td><td>Standing wheat stubble/ Vetch$_{GM}$</td><td>Cotton</td></tr>
</table>

to funding constraints. Measurements were also made of vetch, corn and cotton dry matter production, cotton lint yield and corn cob yields.

Mr. James Terry, a summer scholarship student from the University of Sydney sampled from this experiment during November and December 2006, and February 2007, and from the continuous cotton and cotton-wheat rotations in the previously-described cotton-wheat-vetch experiment to evaluate seasonal changes in soil carbon fractions (labile C as particulate organic matter, stable C, total C and microbial C). Additional measurements were also made on historical samples taken during 2002, 2004 and 2005. Soil was sampled from the 0-10 cm and 10-30 cm depths.

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

4.1.1.4 On-farm experiment of 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[1], and June 2006 and 2007. 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.

In all experiments, cotton lint yield and rotation crop dry matter and yield were measured.

4.2. Sampling & Measurements

4.2.1. Soil quality (physical and chemical properties)

Air-dried soil was passed through 2 mm-sieve and the following tests carried out: plastic limit using a drop-cone penetrometer[2]; pH (in 0.01M $CaCl_2$); electrical conductivity, $EC_{1:5}$ (in a 1:5 soil:water suspension); nitrate-N[3] (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 two sodicity indices: the "traditional"' exchangeable sodium percentage, ESP [= (exchangeable

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[1] Sampling was delayed during 2005 until project funding commenced.

[2] Weaver, T.B., and Hulugalle, N.R. 2001. Evaluating plastic limit in Vertisols with a drop-cone penetrometer. *Comm. Soil Sci. Plant Anal.*, **32**, 1457-1464.

[3] Nitrate-N was measured only at "Federation farm" and ACRI's cotton-wheat-vetch experiment (see p. 10)

Na/Σexchangeable cations) x100], and the $EC_{1:5}$/ESC ratio[1] (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.

Bulk density, ρ_b (g/cm^3) was determined on the 5-cm diameter soil cores extracted as previously described (see pp. 9-13) after oven-drying a sub-sample at 110 °C. Dispersion (after immersion in water of EC = 0.4 dS m^{-1}) was determined with a hydrometer (ASTM 152H) on air-dried soil aggregates of 1-4 mm diameter[3]. Dispersion was measured every other year, at Brigalow, both ACRI long-term experiments and Moree. Dispersion index (in g/100g) was expressed as:

$$\text{Dispersion index} = \frac{\text{Mass of soil particles} <20\ \mu\text{m released into the suspension due to immersion in water}}{\text{Mass of soil particles} <20\ \mu\text{m released into suspension after complete dispersion of sample}} \times 100$$

Aggregate stability was measured with the ASWAT test[4] in samples from Moree and Brigalow in the years when dispersion index was not measured, and in those from Goondiwindi. Additional measurements made in the furrow characteristics experiment in Field C1 at ACRI (see p. 8) were: plastic limit with the hand method on air dried soil (< 2 mm)[5] and specific volume with the kerosene saturation method on air-dried aggregates (1-10 mm diameter)[6], and the size distribution of the aggregates in undisturbed, air-dried soil. The last was determined by dry-sieving over a nest of sieves with openings of 9.5, 4, 2, 1, and 0.25 mm on a mechanical shaker at 1440 vibrations per minute for 5 minutes and expressed as their geometric mean diameter, GMD[7].

In replicated experiments, all data were analysed with analysis of variance appropriate for the specified experimental design. With respect to the study on spatial and temporal variation of furrow soil properties in tillage/rotation experiment at ACRI (see p. 9), data were analysed using a linear mixed model[8] with fixed effects evaluated using Wald statistics. The fixed model for the soil variables consisted of season (2001-02, 2003-04, 2005-06), month, tillage system (conventional tillage, permanent beds), furrow type (wheel-tracked, non-wheel-tracked) and their interactions. The random model consisted of months within seasons, and months and replications within seasons. Data was analysed in this way as tillage system and furrow type effects were confounded with season and month effects. Some variables were log10 and square root transformed, as required, to correct for non-uniform residual variance. Results are presented as predicted values for individual variables at each time of sampling for tillage systems and furrow types. A significance level of 10% was selected due to the abovementioned confounding and high variability in some of the data (CV's range of 7% to 135%). In unreplicated on-farm experiments (Goondiwindi), where soil was sampled in paired

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[1] Hulugalle, N.R., and Finlay, L.A. 2003. $EC_{1:5}$/exchangeable Na, a sodicity index for cotton farming systems in irrigated and rainfed Vertosols. *Aust. J. Soil Res.*, **41**, 761-769.

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

[3] Gee, G.W., and Bauder, J.W. 1986. Particle fractionation and particle size analysis. In '*Methods of Soil Analysis – Part 1 (2nd edition) (Ed. A. Klute)*', pp. 383-411. American Society of Agronomy, Madison, WI.

[4] McKenzie DC (Ed.). 1998. *SOILpak for cotton growers, 3rd edition*. NSW Agriculture: Orange, NSW.

[5] Kirby, J.M., 2002. Liquid and plastic limits. In '*Soil Physical Measurements and Interpretation for Land Evaluation (Eds. N. McKenzie, K. Coughlan, and H. Cresswell)*, pp. 261-270. CSIRO Publishing, Collingwood, Vic.

[6] 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.

[7] Kemper, W.D., and Rosenau, R.C., 1986. Aggregate stability and size distribution. In '*Methods of Soil Analysis – Part 1 (2nd edition) (Ed. A. Klute)*', pp. 425-42. American Society of Agronomy, Madison, WI.

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

transects, the results were analysed with linear regression analysis with data collected during the three years (2003-04 to 2005-06 seasons) of the study.

The results from the site at Brigalow, in a which a formal experimental design was not used, were analysed using Generalised Linear Models (GLMs). 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.

4.2.2. Nutrient leaching and drainage

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 "Windmill Farm"; and the soil amendment experiment at Brigalow. Nutrient leaching was measured in the tillage/rotation experiment and cotton/wheat/vetch rotations experiment at ACRI. The aim of these measurements was to evaluate deep drainage and nutrient leaching in these sites.

Nutrient leaching was monitored with the aid of 5-cm diameter ceramic-cup water samplers installed at depths of 60, 90 and 120-cm. The ceramic cup samplers were assembled from 40-mm diameter PVC pipe and P80 semi-permeable ceramic cups (SOILMOISTURE Corporation, CA, USA). Solvent cement was used to attach the ceramic cups to the PVC pipe. The PVC pipe was heated and expanded to allow the ceramic cups to be inserted and glued with ABS solvent. The samplers were cut at three lengths: 70, 100 and 130 cm (10-cm extra for surface protrusion). Soil slurry was poured into each augured hole to ensure good contact with the soil. Water was extracted at 7-10 day intervals, taken back to the laboratory, and filtered. Water samples were also taken from the head-ditch during each irrigation at each experimental site. The water samples were analysed for pH_w, EC_w (salinity), chloride by titrating with $AgNO_3$, nitrate-N (with a nitrate electrode pre-calibrated with the Kjehldahl method and from 2007 onwards with the Kjeldahl method alone), and Ca, Mg, K and Na with an atomic absorption spectrophotometer[1]. 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.

Soil was sampled, before and after the cotton season and after the wheat season, across the same transects. The cores were 120-cm long and were divided into 4 depth increments: 0-30, 30-60, 60-90 and 90-120-cm. The soil was air-dried, ground by hand and passed through a <2mm sieve, and analysed for pH in 0.01 M $CaCl_2$, $EC_{1:5}$, chloride by $AgNO_3$ titration and nitrate-N. In addition pre-season samples were analysed for exchangeable Ca, Mg, K and Na, and organic C. All soil analyses were conducted as described previously[1], except for chloride which is described in detail in the following section (see "Determining drainage with the solute mass balance model").

The values of nutrients and salts leached out of the cotton root zone (i.e. 1.2-m depth) were quantified by equating them to the value of a specific fertiliser or soil amendment. The amount of nitrate-N leached was calculated in terms of its equivalent amount in anhydrous ammonia, K in terms of muriate of potash, and Ca, Mg and Na in terms of their gypsum

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

equivalents[1]. Values of gypsum was assumed to be $75/t (with an additional spreading costs of $20/ha at a rate of 2.5-5.0 t/ha), anhydrous ammonia $1058/t and muriate of potash $0.735/kg. Chloride value was equated to the increase in yield which could be expected due to Cl being leached out of the soil profile. This was based on a soil Cl-relative cotton lint yield response curve[2].

4.2.3. Determining drainage with the chloride mass balance model

Previously published models 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:

$$DP_z = I(\frac{C_i}{\bar{C}_z}) \qquad (1)$$

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); $\bar{C}_z$ is the concentration of chloride in the drainage water at depth z (mmol/l), calculated from the mean of the soil chloride concentrations pre- and post-crop. Assuming transient state conditions, deep drainage was calculated as:

$$\bar{S}_{(0-z)t2} - \bar{S}_{(0-z)t1} = [(\frac{IC_i}{DP_z\lambda}) - \bar{S}_{(0-z)t1} - \alpha][1 - \exp(\frac{-tDP_z\lambda}{z})] \qquad (2)$$

where α and λ were calculated as:

$$\alpha = \frac{[C_{zt1}\bar{S}_{(0-z)t2} - C_{zt2}\bar{S}_{(0-z)t1}]}{[C_{zt2} - C_{zt1}]}\text{; and } \quad \lambda = \frac{C_{zt1}}{[\bar{S}_{(0-z)t1} + \alpha]}$$

$\bar{S}_{(0-z)}$ is mean soluble chloride content per unit volume of the 0-z layer (mmol/l); z is depth increment (mm); t is time (weeks). The parameters α and λ have been defined previously as the ionic nonequilibrium rate coefficient (α) and dispersivity (λ). 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:

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

where ρ_b is soil bulk density (kg/m^3); 0.814 accounts for anion exclusion (m^3/kg) and has been defined by other researchers as the distribution factor. The coefficient in equation 4 which accounts for anion exclusion was initially derived by Peter Slavich of NSW DPI for a grey Vertosol.

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[1] Hulugalle, N.R., Weaver , T.B., and Ghadiri, H. 2005. A simple method to estimate the value of salt and nutrient leaching in irrigated Vertisols in Australia. In: "*Sustainable use and Management of Soils – Arid and Semiarid Regions", Eds. A. Faz Cano, R. Ortiz Silla and A.R. Mermut. Adv. GeoEcol.*, **36**, 579-588.

[2] 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.

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.

Statistical analysis

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. 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.

4.2.4. Crop agronomy and nutrient uptake

Plant mapping was conducted at the ACRI sites and growth indices such as nodes/plant, and squares, green bolls and open bolls/m^2 recorded.

Profile water content was measured as described in a previous section in all plots in the long-term tillage rotation experiment and cotton/wheat/vetch rotations experiment at ACRI. Cotton root and root carbon turnover in the 0-100 cm depth were measured in the same experiments with a minirhizotron (Bartz Technology Corporation BTC-2 model with I-CAP image capture system) in the sub-surface and subsoil ($\geq$ 0.10 cm), and with the core-break method in the soil surface layers (0-10 cm). The roots in the images were traced on desktop computer and length estimated using the RooTracker 2.03 software. The root numbers observed with the core-break method were converted to root length by through a calibration curve derived by washing, staining and measuring the cleaned roots with Newman's line intersection method. 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 solution for a period 2-8 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 Newman's line interception method with pre-calibrated 1cm x 1 cm grid. Root length in all depths was converted to root mass through a calibration curve which related root length to root mass of washed and cleaned root samples.

N in vetch dry matter, and C and N in cotton roots were measured with a LECO analyser. After harvest in May, cotton lint fibre characteristics were measured with a HVI-Spinlab 900 series.

4.2.5. Profitability

Financial returns and profitability for each rotation were evaluated for the tillage/rotation and cotton/wheat/vetch rotation experiments at ACRI, and the gypsum x standing stubble experiment at "Windmill Farm" by comparing cumulative gross margins per hectare and per ML of irrigation water supplied. A gross margin is the gross income from an enterprise less the variable costs (costs directly attributable 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 $420/bale and a seed price of $400/tonne, and costing of operations conducted on each treatment, including weed control costs. The wheat price used was Feed $248/tonne, AH $202/tonne, PH13 $220/tonne with the current discount system for low protein and bonuses for low screenings included. Where possible, 2008 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 with price variations. Cotton price sensitivity testing was determined, using lint prices ranging from $300 to $500/bale.

5. Key Results and Discussion

5.1. Cropping systems and soil quality

5.1.1 Effects of sowing irrigated cotton into standing crop stubble

When cotton is sown into standing crop stubble (commonly, wheat) on permanent beds (Fig. 1), the standing stubble is known to reduce erosion (Fig. 2) and runoff, increase water infiltration, reduce off-field movement of pesticide residues and nutrients, and reduce heliothis moth infestation in young cotton. However, the effects of sowing irrigated cotton into standing wheat stubble on soil quality indices such as soil organic carbon, structure, exchangeable K, sodicity and salinity which are also key indicators of soil sustainability in the irrigated cotton-growing Vertosols of eastern Australia are less well known. The following section summarises the changes in soil quality and profitability caused by sowing irrigated cotton into standing wheat stubble. These results are based on measurements made in the experiments described on pp. 9-11.

Figure 1. Cotton sown into standing wheat stubble at the Australian Cotton Research Institute, near Narrabri, New South Wales

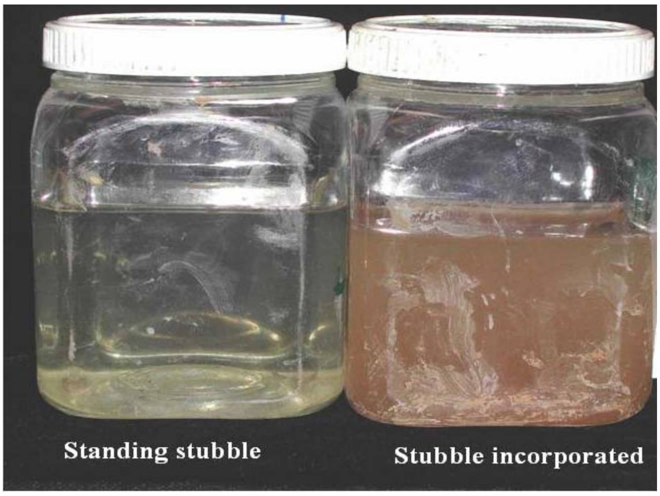

Figure 2. Runoff water from a trial, near Boggabri, NSW, where cotton was sown either into standing wheat stubble or after wheat stubble was incorporated. Photograph provided by M. Hickman

5.1.1.1 Soil properties

Soil in standing stubble systems, both on-station and on-farm, had, in general, higher SOC, and lower exchangeable Na, ESP, $EC_{1:5}$/ESC and $EC_{1:5}$ than in stubble incorporated systems. The increases in SOC, however, were usually limited to the surface 30 cm. The key differences in soil properties observed during the 2005-2008 period are summarised as follows:

- *Water harvesting*: Retention of stubble on beds and furrows facilitates harvesting of winter and early spring rainfall. At time of sowing cotton in October 2006, profile water content was 421 mm with conventionally-tilled/continuous cotton, 393 mm with minimum-tilled continuous cotton and 453 mm with minimum-tilled/cotton-standing wheat stubble ($P < 0.05$, S.E.M. = 12.85). In other words, there was an average difference of 46 mm in the 0-1.2 m depth between the two continuous cotton systems and the cotton-wheat system. Due to low winter rainfall (153 mm between 1 June and 19 October 2006), this value is smaller than in years when good rainfall was received, when values ranging from 75-100 mm were observed. This difference is partly due to more efficient water harvesting by the latter, partly to higher subsoil water holding capacity and partly to the wheat stubble reducing water evaporation because of a mulching effect. These differences were not maintained throughout the cotton season (Fig. 3) due to a combination of varying water application rates, infiltration capacities and extraction in different treatments, and clearing stubble from furrows to avoid waterlogging (see section 5.1.5). It is also evident that as the season progressed, irrigation efficiency and consequently, wetting up of the profile deteriorated. This may be due to a reduction in the rate of infiltration caused by a dispersion of furrow soil due to a moderately high value of SAR of the irrigation water in combination with a relatively low EC_w. Average seasonal SAR was 4.6±0.6 whereas EC_w was 0.35±0.06 dS/m. This observation contrasts with that made in this site during the period 2001 to 2003, when irrigation application efficiency increased as the season progressed[1].

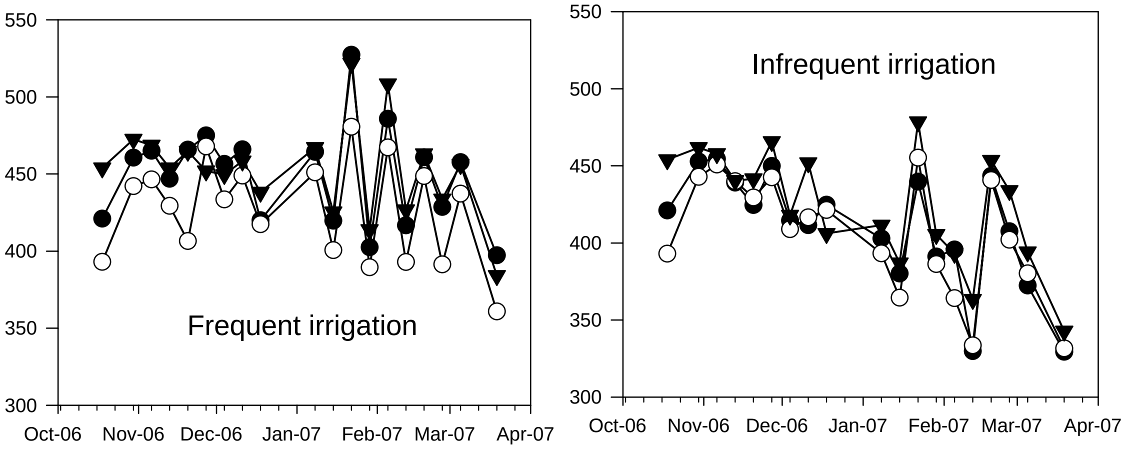

Figure 3. Effect of tillage and cropping system on variation of soil water storage during the 2006-07 cotton season, Field C1, ACRI, Narrabri. •, conventionally-tilled continuous cotton; o, minimum-tilled continuous cotton; ▼, minimum-tilled cotton-wheat

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[1] Tennakoon, S.B., and Hulugalle, N.R. 2006. Impact of crop rotation and minimum tillage on water use efficiency of irrigated cotton in a Vertisol. *Irrig. Sci.*, **25**, 45-52.

- *Soil carbon sequestration:* Past results from these and other experiments had shown that sowing cotton into standing wheat stubble resulted in higher soil organic carbon[1] within the surface 30 cm. Similar clearly defined results were not evident in all sites between 2005 and 2008 (Table 2). This may be largely due to the low and poorly-distributed winter rainfall during this period which greatly reduced wheat growth. For example, average rainfall between 1 June and 30 September at ACRI was of the order of 131 mm whereas the long-term average was approximately 300 mm. A decrease in SOC was also observed with time ($P < 0.05$) in some sites and may be due to poor winter rotation crop growth, and consequently a reduction in stubble returned to the soil (Fig. 4). Significant differences were present between conventionally-tilled and minimum-tilled treatments, although where stubble incorporation was with minimum tillage (i.e. permanent beds), soil carbon values did not differ significantly. Retaining vetch stubble as a surface mulch resulted in rotations which included vetch having higher soil organic carbon than other rotations (Fig. 4; Table 2).

Table 2. Effect of sowing cotton into standing rotation crop stubble on carbon sequestration in the 0-30 cm depth.

Site	**Cropping system**	**Soil organic C in the 0-30 cm depth (t/ha)**		
		2005	**2006**	**2007**
ACRI, Narrabri (Tillage/rotation Experiment)	Conventional tillage/continuous cotton		35	
	Minimum tillage/continuous cotton		39	
	Minimum tillage/cotton-wheat (standing stubble)		40	
	P <		0.01	
	SEM		0.6	
ACRI, Narrabri (Cover crop experiment of D. Nehl)[2]	Bare	35		
	Cotton-vetch	40		
	Cotton-mustard	41		
	Cotton-wheat	-		
	P <	0.05		
	SEM	1.2		
“Federation Farm”, Narrabri	2.5 t/ha Gypsum during 2000 fb. stubble incorporation from 2003 onwards. Between 2000 and 2003 cotton was sown into standing stubble.	22		25
	No gypsum. Cotton sown into standing stubble	20		24
	P <	ns		ns
	SEM	0.8		1.0
ACRI, Narrabri (Cotton/vetch/ wheat rotations Experiment)	Continuous cotton	27	28	24
	Cotton-vetch	32	32	26
	Cotton-wheat (stubble incorporated)	31	31	26
	Cotton-wheat (standing stubble)-vetch	31	34	29
	P (all treatments) <	ns	ns	ns
	P (vetch rotations) <	ns	0.05	0.05
	P (wheat rotations) <	ns	ns	ns
	SEM	1.5	1.3	1.0

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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.

[2] Wheat was not sown in this experiment during 2005.

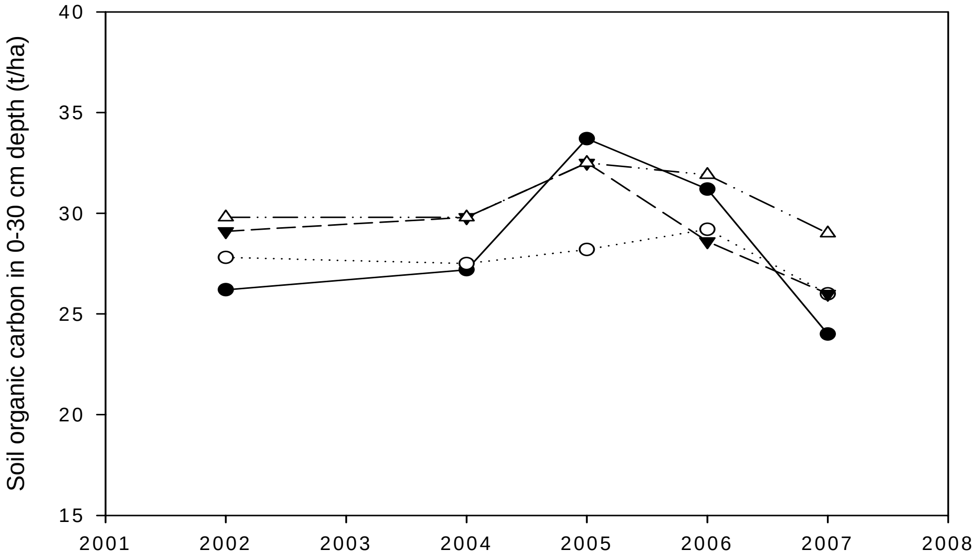

Figure 4. Variation of soil organic carbon in the 0-30 cm depth with time, Field D1, ACRI. •, Cotton-vetch-cotton; o, Cotton-winter fallow-cotton; ▼, Cotton-wheat; Δ, Cotton-wheat-vetch

- *Alleviating salinity and sodicity:* Sowing cotton into standing wheat stubble increases infiltration and hence, drainage, by reducing the rate of flow in the furrows; i.e. a "ponding" effect. This in turn facilitates leaching of excess salts (indicated by soluble Cl concentration in the soil) and exchangeable Na out of the rooting zone. An examples of this are shown in Fig. 5. (N.B. During the 2006-07 cotton season, analysis of water samples taken from the head-ditch indicated that SAR of irrigation water averaged 4.5, and 0.2 t/ha of soluble Cl entered the field in irrigation water). A similar response occurs with respect to salts but not exchangeable Na in a site where poor quality irrigation water (treated sewage effluent) was used (Fig. 6). This may be because, in spite of the previously mentioned ponding effect, the higher Na concentration in treated sewage effluent (mean SAR was 9.1) may require a higher leaching fraction than when water of low Na concentration is used for irrigation.

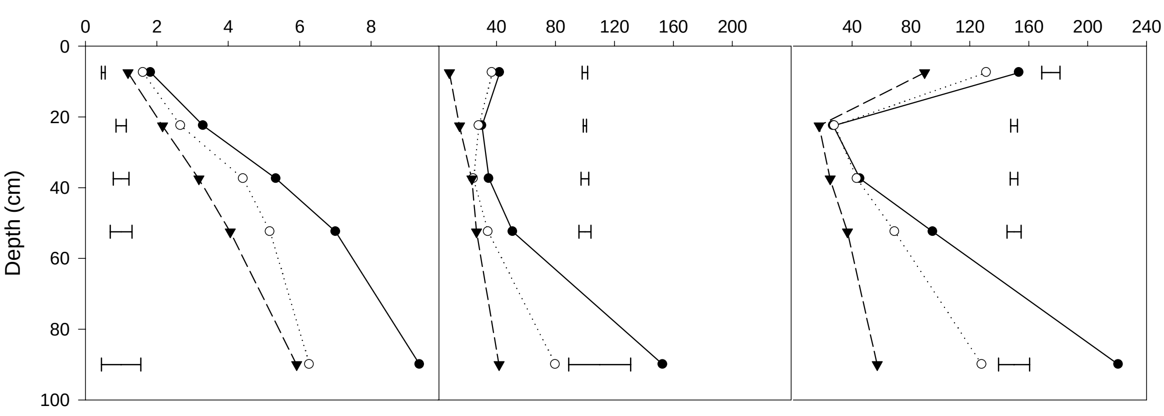

Figure 5. Effect of minimum tillage and wheat rotation crops on pre-season ESP and post- and pre-season soluble Cl in the 0-120 cm depth in Field C1, ACRI, 2006-07 season. •, conventionally-tilled continuous cotton; o, minimum-tilled continuous cotton; ▼, minimum-tilled cotton-wheat. Horizontal bars are SEM's.

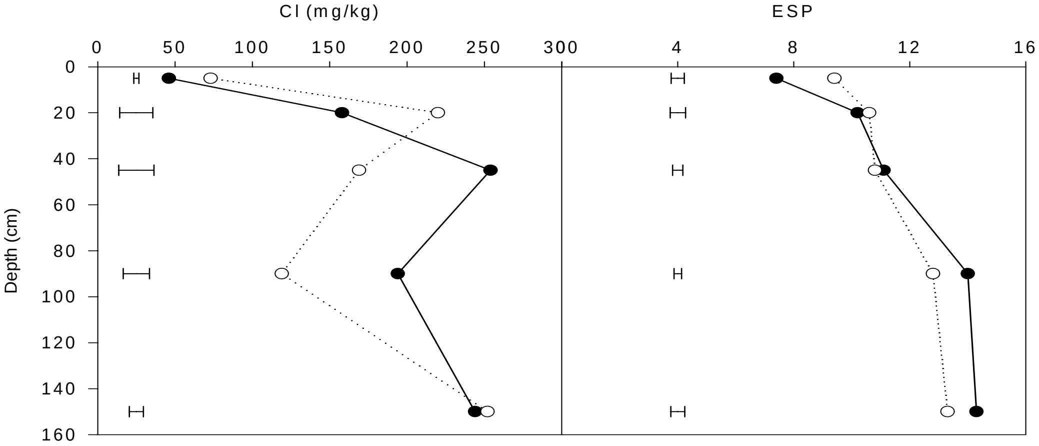

Figure 6. Effect of managing wheat stubble in a cotton-wheat rotation on soluble Cl and ESP in the 0-180 cm depth at "Federation Farm", Narrabri. Results from September 2005 and 2007 were pooled. •, incorporated wheat stubble; o, standing wheat stubble. Horizontal bars are SEM's.

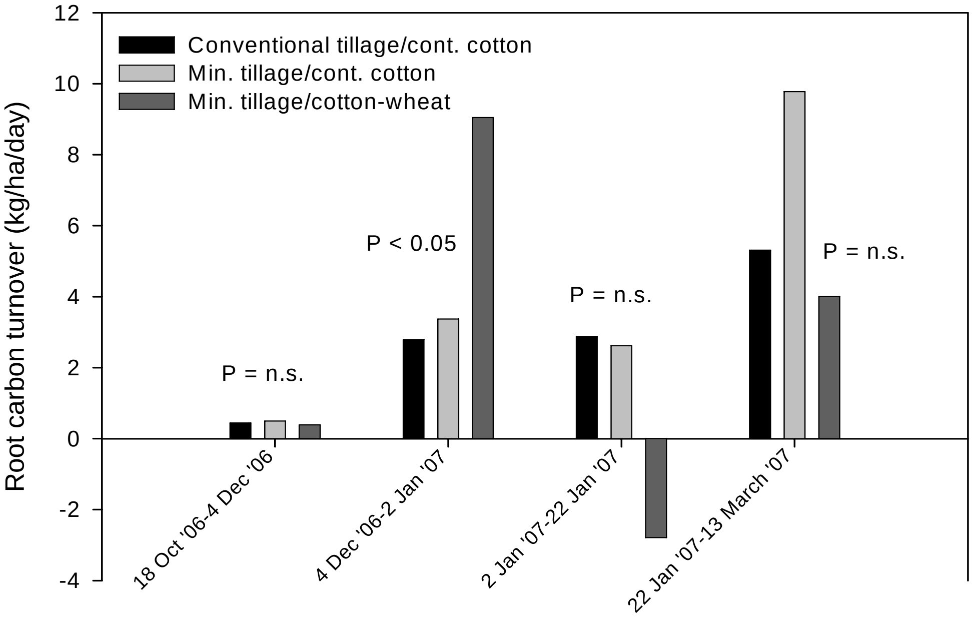

Figure 7. Effect of tillage system and crop rotation on root carbon turnover during the 2006-07 growing season, ACRI. Data was analysed after $\log_e$ transformation.

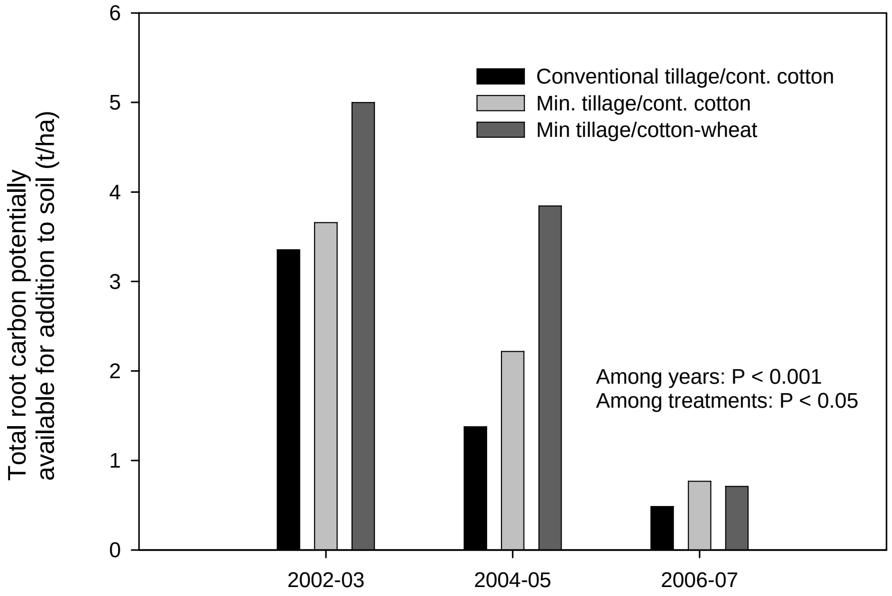

Figure 8. Effect of tillage system and crop rotation on cotton root carbon available for addition to soil on a seasonal basis, ACRI, Narrabri. Data was analysed after $\log_e$ transformation.

- *Cotton root growth and soil carbon:* Seasonal root carbon available for addition to soil carbon stocks was estimated as carbon added to the soil through root initiation and death throughout a cotton growing season. Root dynamics were measured with a minirhizotron in the frequently-irrigated treatments of tillage/rotation experiment at ACRI during the 2006-07 cotton season. Carbon contained in cotton roots at season's end was estimated to be 0.4 t/ha with conventionally-tilled continuous cotton, 0.6 t/ha with minimum-tilled continuous cotton and 0.4 t/ha with minimum-tilled cotton-wheat (P = n.s.). Carbon lost due to root death and decay during the season was 0.05 t/ha with conventionally-tilled continuous cotton, 0.13 t/ha with minimum-tilled continuous cotton and 0.29 t/ha with minimum-tilled cotton-wheat ($P < 0.05$). The potential addition of carbon to soil from cotton roots was, therefore, 0.5 t/ha with conventionally-tilled continuous cotton, 0.8 t/ha with minimum-tilled continuous cotton and 0.7 t/ha with minimum-tilled cotton-wheat ($P = 0.05$). These results differ markedly ($P < 0.001$) from previous years when carbon contribution from cotton sown after wheat was greater than either of the continuous cotton sequences (Fig. 8). This may be due to lower cotton root growth of the differing cotton varieties (see p. 9), to deterioration in water quality or both. Average SAR and EC_w of irrigation water was 0.9 and 0.4, respectively, during 2002-03, 1.5 and 0.3, respectively, during 2004-05, 1.2 and 0.35, respectively, during 2005-06 and 4.5 and 0.35, respectively, during 2006-07. The SAR and ECw values observed during 2006-07 are likely to have resulted soil structural instability, whereas the values in other years are unlikely to have caused similar problems. Significant intra-seasonal differences ($P < 0.05$) in cotton root carbon turnover among treatments occurred only between 4 December 2006 and 2 January 2007 (i.e. between late vegetative and flowering) when that under the cotton-wheat sequence was greater than those in either of the continuous cotton sequences (Fig. 7).

5.1.1.2 Cotton lint yields

At ACRI, in the tillage/rotation experiment (see p. 9) were least with continuous cotton sown after conventional-tillage (disc- and chisel ploughing followed by ridging every year) and highest with cotton-wheat where cotton was sown into standing wheat stubble after minimum tillage (Table 3). Under a "frequent" irrigation regime (control) during the 2006-07 season, sowing cotton into standing wheat stubble yielded 36% more than continuous cotton sown after conventional tillage and 30% more than continuous cotton sown after minimum tillage. Between 2000 and 2007, sowing cotton into standing wheat stubble yielded 20% more than continuous cotton sown after conventional tillage and 14% more than continuous cotton sown after minimum tillage. 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 back-to-back cotton plots by between 3 and 10%. Under an "infrequent" irrigation regime (stressed conditions), relative to the control, overall yield were, as expected, 76% lower during 2006-07. Nonetheless, cotton sown into standing wheat stubble yielded 42% and 35% more than conventionally-tilled and minimum-tilled continuous cotton, respectively. During the 2007-08 season, when the cotton-wheat rotation was not sown, there were no significant differences in lint yield between conventionally and minimum-tilled continuous cotton. Lint yield in frequently-irrigated plots (11.1 bales/ha) was, however, greater ($P < 0.01$, sem = 0.03) than that in infrequently-irrigated plots (6.3 bales/ha). Similarly, 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.

Cotton lint yield was not significantly affected by wheat stubble management (Table 4). This result differs from those from other sites[1] (see also previous paragraph) which indicated that sowing cotton into standing wheat stubble was able to significantly increase lint yield. Stubble incorporation with an aer-way cultivator under dry conditions results in less soil disturbance than with conventional methods such as disc-ploughing, and suggests that this tillage method may have negligible effects on soil characteristics such as water storage, soil structure and soil organic matter (Table 2). The co-operator did not leave the site fallow during the 2006-07 season, as is normal with a cotton-wheat rotation in northern NSW, but sowed a crop of corn with limited irrigation. Grain yield was not assessed although dry matter yield were. There were no significant effects of past experimental treatments on corn DM production. Mean corn DM yield was 4.7 t/ha. This is approximately 50-60% less than that produced by a well-watered crop.

Table 3. Effect of tillage system and wheat rotation crop on cotton lint yield (bales/ha), Field C1, ACRI, 2006-07 season. 1 bale = 227 kg.

Tillage system	Cropping system	Irrigation frequency (IF)	2006-07
Conventional	Continuous cotton	Frequent	7.3
Minimum	Continuous cotton	(7-14 day interval)	7.6
Minimum	Cotton-wheat[2]		9.9
	Mean		8.3
Conventional	Continuous cotton	Infrequent	4.1
Minimum	Continuous cotton	(14-21 day interval)	4.3
Minimum	Cotton-wheat		5.8
	Mean		4.7
P <	Treatments[3] (T)		0.01
	IF		0.05
	IF x T		ns
SEM	Treatments		0.19
	IF		0.18
	IF x T		0.27

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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.

[2] Wheat yielded 3.9 t/ha during the winter of 2005.

[3] Tillage system/cropping system combinations

Table 4. Effect of wheat stubble management on cotton lint yield (bales/ha), "Federation Farm", Narrabri, 2005-06 and 2007-08 seasons.

Stubble management	2005-06	2007-08	Mean
Stubble incorporation	11.5	12.5	12.0
Standing stubble	11.1	13.4	12.3
P <	ns	ns	
SEM	0.38	0.64	

As noted previously, wheat sown in the experiment at "Windmill Farm" established poorly, and consequently the wheat stubble management treatments were not imposed. Stubble in all plots was incorporated. Gypsum application during March 2006 resulted in a non-significant increase in cotton lint yield. Mean lint yields during 2006-07 were 12.4 bales/ha with gypsum application and 11.9 bales/ha in the control. Profitability, however, was reduced by gypsum application. Cumulative gross margins with gypsum application was \$5013/ha and without gypsum, \$5433/ha. Gypsum application resulted in higher concentrations ($P < 0.05$) of exchangeable Ca concentration in the subsoil than that in the control (Figure 9).

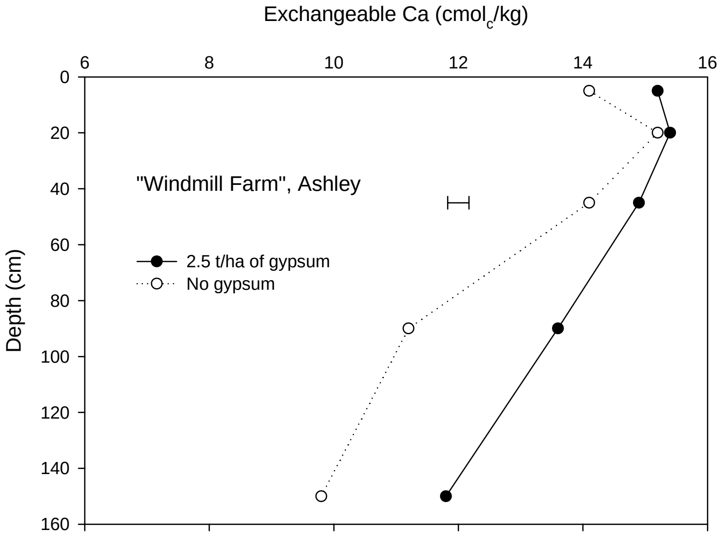

Figure 9. Effect of gypsum application on exchangeable Ca concentration, "Windmill Farm", Ashley, September 2006. Horizontal bar is SEM (treatment x depth)

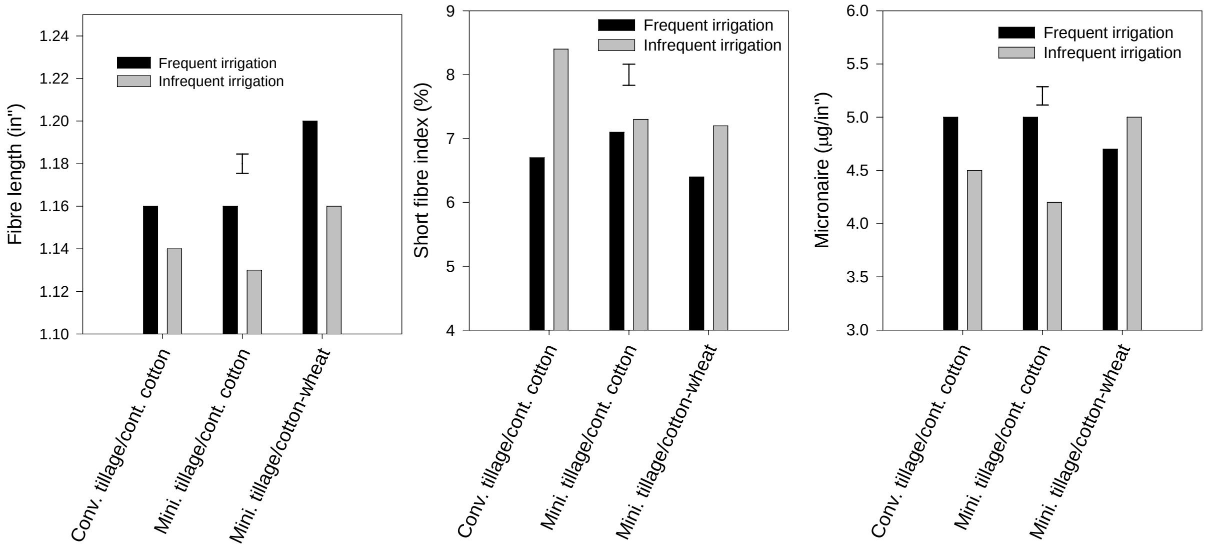

Figure 10. Effect of tillage system, wheat rotation crop and irrigation frequency on cotton lint fibre length, short fibre index and micronaire, Field C1, ACRI, Narrabri, 2006-07 season. Vertical bar is SEM (tillage system/cropping system x irrigation frequency).

In tillage/rotation experiment at ACRI during the 2006-07 season, cotton lint from the minimum-tilled cotton-wheat rotation had the longest fibre length ($P < 0.05$), whereas highest ($P < 0.05$) short-fibre index[1] was present lint from infrequently-irrigated conventionally-tilled continuous cotton (Fig. 10). Micronaire was least ($P < 0.05$) in both continuous cotton treatments under infrequent irrigation. The values were of the order where price penalties could be imposed. Significant differences in micronaire did not occur among the other four treatments. Other fibre quality indices were not affected by either tillage system/cropping system combination or irrigation frequency. Mean uniformity index (%) was 84.1, strength (g/tex) 32.0 and elongation (%) 4.0.

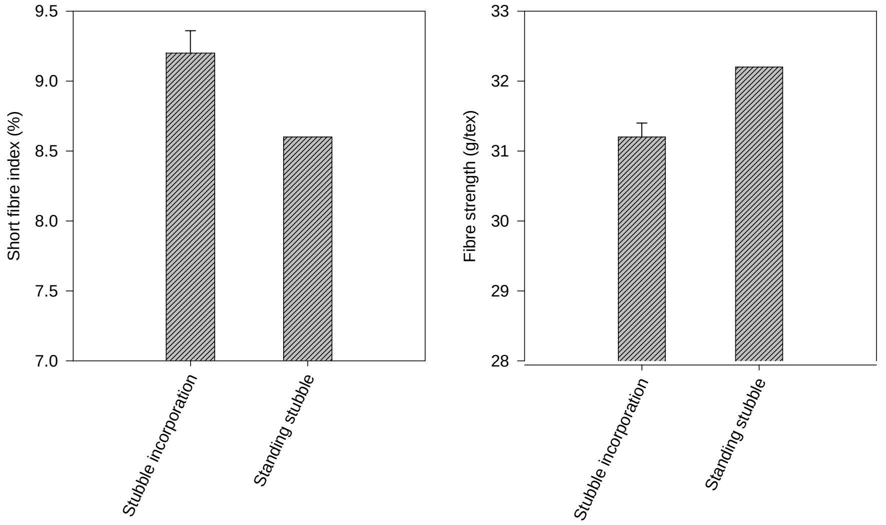

Figure 11. Effect of wheat stubble management system on short fibre index and fibre strength of cotton lint, "Federation Farm", Narrabri, 2005-06 season

At "Federation Farm" during the 2005-06 season, in comparison with sowing cotton into standing wheat stubble, incorporating wheat stubble resulted in a cotton lint which had a significantly higher ($P < 0.05$) short fibre index and lower strength ($P < 0.01$) (Fig. 11). Other fibre quality indices were not significantly affected. Mean fibre length was 1.20 in", micronaire 4.6 µg/in", uniformity index 82.9% and elongation 3.8%. No fibre quality index was significantly affected by either of the wheat stubble management practices during 2007-08, presumably due to the frequent rainfall and cool conditions during reproductive growth. During 2007-08 mean values of fibre length was 1.20 in", micronaire 4.1 µg/in", short fibre index 7.6%, strength 29.9 g/tex, elongation 2.4% and uniformity index 83.0%.

Gypsum application at "Windmill Farm" significantly increased ($P < 0.05$) elongation (6.1%) relative to the control (5.6%) during 2006-07, but had no effect on other lint fibre quality indices. Mean fibre length was 1.17 in", micronaire 4.5 µg/in", short fibre index 7.8%, strength 31.3 g/tex, and uniformity index 82.9%.

5.1.1.4 Resilience of profitability to changes in input costs

In this section recent economic results (2000-2008) from the tillage/rotation experiment at ACRI are presented and the consequences of increases in fuel and fertiliser prices on profitability, measured as gross margins, are discussed. This experiment compared either conventional or minimum tillage under continuous cotton (8 cotton crops since 2000), and minimum tillage under a cotton-wheat rotation (4 cotton and 4 wheat crops since 2000) where

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[1] Percentage of fibres by weight which are less than 0.5 in" in length.

cotton was sown into standing wheat stubble. In order to compare the different treatments in the current price context, where possible, 2008 prices have been used for inputs such as fuel, fertiliser, herbicides (including defoliants) and pesticides. In addition prices for cotton lint was set at $420/bale and seed at $400/t. Wheat prices for various grades were taken as feed $248/t, AH $202/t, and PH13 $220/t.

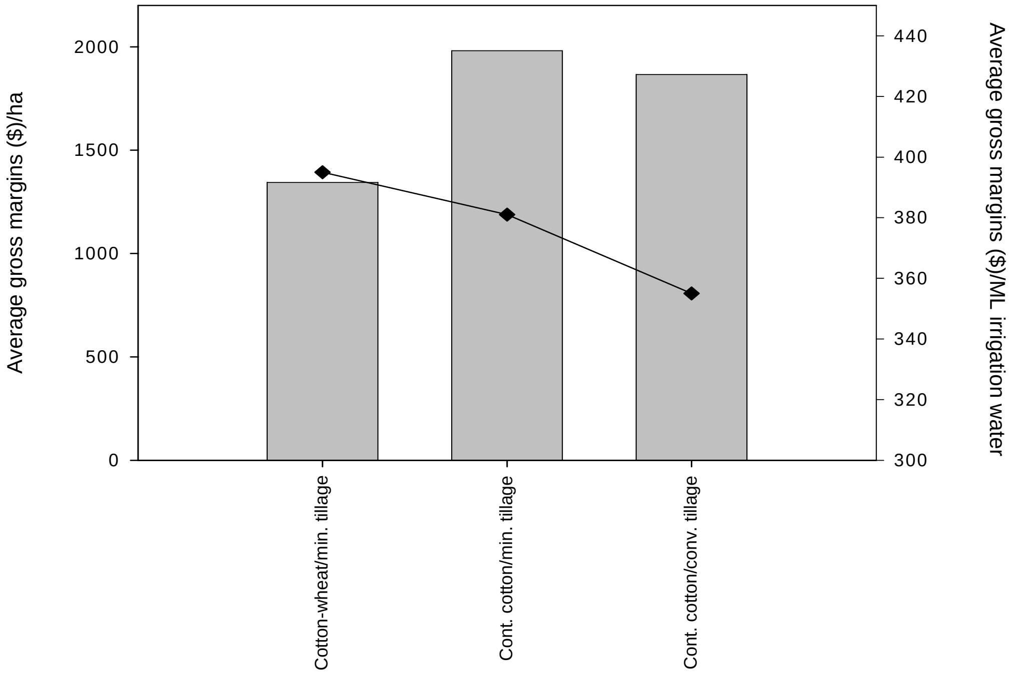

Figure 12. Effect of tillage and cropping system on average gross margins 2000-08, Field C1, ACRI. 1 bale of cotton lint = $420

We compared these systems on a per field basis, e.g. assuming a field was continuously farmed under the particular system, as might be the case if there was sufficient water to irrigate all the available land and secondly, as part of a whole farm where there is only sufficient water to fully irrigate half of the available land. The latter opens the possibility for systems which only have cotton every second year (e.g. cotton-wheat-fallow-cotton) on a per field basis, to have a cotton crop every year though in a different field following a wheat rotation each time. This system is probably more typical of many farms, especially under drought conditions with limited allocation of irrigation water.

Comparisons on a field basis

Basic Gross Margin Comparisons

Using a cotton price of $420/bale, minimum-tilled cotton-winter fallow-cotton returned the highest average annual gross margin ($1981/ha). This was 6% higher than the conventionally-tilled cotton-winter fallow-cotton (8 cotton crops) ($1866/ha) and 47% higher than the minimum-tilled cotton-wheat ($1343/ha).

In the case of gross margin/ML of irrigation water and using a cotton price of $420/bale, minimum-tilled cotton-wheat gave a 11% higher return ($395/ML) than conventionally-tilled cotton-winter fallow-cotton ($355/ML) (Fig. 12). Minimum-tilled cotton-winter fallow-cotton was 7% higher ($381/ML) than that which was conventionally-tilled.

Impact of input and output price changes

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

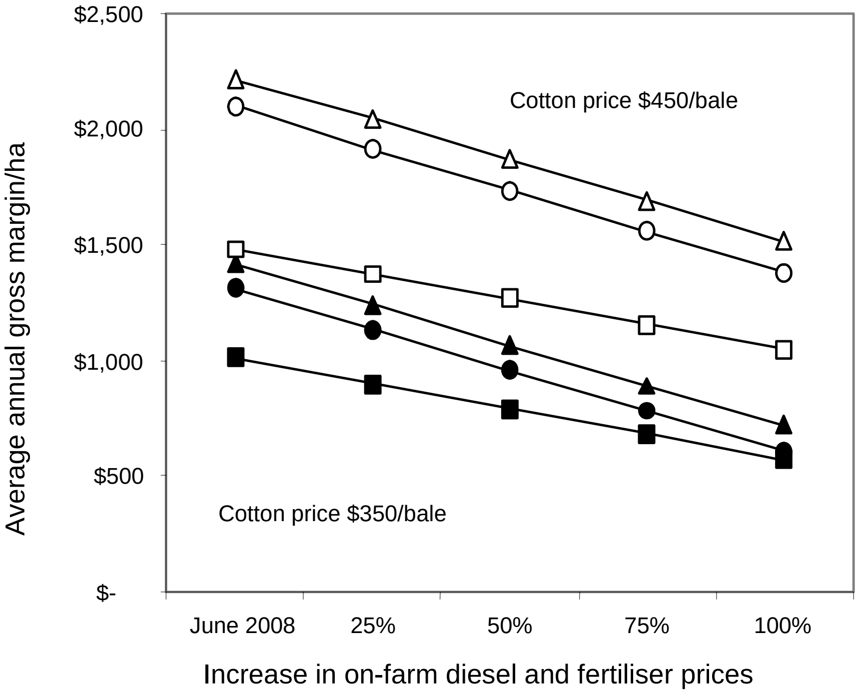

Figure 13. Impact of cotton lint price and fuel/fertiliser prices increases on rotation returns Triangles- minimum-tilled continuous cotton on beds, Circles-conventionally-tilled continuous cotton and Squares- minimum-tilled cotton-wheat

Price changes included using cotton lint prices of $450 and $350/bale, a cotton seed price of $400/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 June 2008 price of $1.86/litre at the bowser (which is equivalent to $1.31/litre on-farm, ex-GST and less off-road diesel rebate), bowser fuel prices used were $2.33 ($1.73 on-farm), $2.79 ($2.16 on-farm), $3.25 ($2.57 on-farm) and $3.72 ($3.00 on-farm). The base price of the major fertiliser used, anhydrous ammonia, was $1140/tonne. All other input costs were not altered. Rising world fuel prices may also affect other inputs such as insecticides, herbicides, growth regulators and other nutrients, but the magnitude of this is very complex and will differ between products and companies.

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 of the cotton monoculture systems by the increase in diesel and fertiliser costs and so appears to be more resilient to such increases (Fig.13). This is due to a lower frequency of cotton crops in the cotton-wheat sequence compared with cotton monoculture, and therefore lower overall input costs. The relative profitability of the rotations also changes as cotton price increases, due to the increase in the price of cotton relative to wheat.

Reduced water applications

In 2005/06, the treatments were split into a ”normal” and low irrigation frequencies. After 3 years, the lower irrigation frequencies are well behind the average irrigation frequencies due to poor cotton yields (Table 4).

Table 4. Comparison of “normal” and low irrigation frequencies, Field C1, ACRI, 2005-08

	Minimum-tilled cotton-wheat		**Minimum-tilled Continuous cotton**		**Conventionally-tilled continuous cotton**	
	Normal irrigation frequency	Low Irrigation frequency	Normal irrigation frequency	Low Irrigation frequency	Normal irrigation frequency	Low irrigation frequency
Average gross margin ($)/ha	1343	283	1981	437	1866	560
Average lint yield (bales/ha)	9.5	5.77	8.01	4.52	7.80	4.56

Whole-farm impact

In recent times water has been the limiting factor on total area on-farm under irrigation, rather than land. The average gross margin results reported thus far here show the relative profitabilities in the experiment where the same system was used in the same field over time, but growers need to consider the whole-farm impacts of these rotations also, since cotton-winter fallow-cotton is a one year 'cycle' of continuous cotton (cotton-winter fallow), whereas cotton-wheat is in fact, a 2 year rotation of cotton-wheat-summer fallow-winter fallow.

This can be demonstrated by applying the average yield results for the experiment on rotations on permanent beds to a farm of 1000 ha. Average water use during the trial was 5 ML/ha for cotton and 1 ML/ha for wheat. The average crop yields and in-crop costs from the experiment have been used to calculate the example, with $40/ha winter fallow costs and $182/ha summer fallow costs.

Assuming the annual water allocation for the farm of 6000 ML, the comparative farm plan for cotton-winter fallow-cotton is 1000 ha of cotton in summer and 1000ha of fallow in winter (total water required 5000 ML/year), and for cotton-vetch-cotton, 1000ha of cotton in summer and 1000 ha of vetch in winter. For cotton-wheat, the ‘normal’ farm plan would be 500 ha cotton and 500 ha wheat stubble fallow in summer, and 500ha wheat and 500ha pre-cotton fallow in winter (water required 3000 ML/year with wheat using 1 ML/ha).

The basic assumption in the limited water scenario is that the annual water allocation is cut by 50% for whatever reason to 3000 ML/year. This leaves the cotton-winter fallow-cotton and cotton-vetch-cotton plans with only enough water for 600ha cotton (60% of the area). For the cotton-wheat plan, allowing 5 ML/ha for the cotton and 1 ML/ha for the wheat, 3000 ML is enough for 500ha of cotton and 500 ha of wheat so the cotton-wheat plan can still carry on with the same areas. Using the average yields and costs from the trial and $420/bale for cotton and $200/t for wheat, cotton-wheat has the advantage over both continuous cotton systems in this water-limited situation. When water is not limiting, in absolute financial terms, cotton-winter fallow-cotton will generate the higher total farm gross margin. Over the longer term, however, this higher profitability is accompanied by declining soil fertility, crop health and cotton yields/hectare. Also, a cotton-wheat rotation uses less water over the same area than a cotton-winter fallow-cotton ‘rotation’, freeing up water to be carried over to following seasons or able to be sold under temporary seasonal transfers, where such arrangements are possible.

5.1.2 Effects of tillage system, trafficking and time of season on furrow soil properties in continuous cotton systems

5.1.2.1 Effects of tillage system and trafficking

Due to the confounding described previously (see p. 13), results of analyses reported relate to the interactions between season and month (S x M), season, month and tillage system (S x M x T), season, month and furrow type (S x M x F), and season, month, tillage system and furrow type (S x M x T x F). Significant effects of S x M x T did occur, however, with respect to pH ($P < 0.10$) and SOC ($P < 0.10$), and of S x M x F with respect to $EC_{1:5}$ ($P < 0.05$) and plastic limit ($P < 0.001$) (Table 7). Significant S x M x T x F effects were not present for any variable, indicating the absence of interactions between tillage system and furrow type at any time.

Table 7. REML variance components analysis for interactions between season, month, tillage system and furrow type for furrow soil properties.

Soil property	**Season (S) x Month (M) x Tillage system (T)**	**Season (S) x Month (M) x Furrow type (F)**	**S x M x T x F**
pH (0.01M $CaCl_2$)	$P < 0.10$	n.s.	n.s.
$EC_{1:5}$ (dS/m)	n.s.	$P < 0.05$	n.s.
Plastic limit (g/g)	n.s.	$P < 0.001$	n.s.
$\log_{10}$ GMD (mm)	n.s.	$P < 0.10$	n.s.
Soil organic carbon (g/100g)	$P < 0.10$	n.s.	n.s.
Exchangeable Ca ($cmol_c$/kg)	n.s.	n.s.	n.s.
Exchangeable Mg ($cmol_c$/kg)	n.s.	n.s.	n.s.
Exchangeable K ($cmol_c$/kg)	n.s.	n.s.	n.s.
ESP	n.s.	n.s.	n.s.
Specific volume (m^3/Mg)	n.s.	n.s.	n.s
$\log_{10}$ Dispersion index	n.s.	n.s.	n.s.

The surface 50 mm of furrows under minimum tillage had generally lower pH and higher SOC (Table 8). While these trends are similar to those in the beds in this site, the magnitude of the differences between tillage systems is smaller. Within beds, relative to conventional tillage, pH in minimum tilled plots was 2% lower, and SOC 14% higher[1]. In the present study, in furrows, average pH of in minimum tilled plots was 3% lower than conventional tillage during 2001-02, was the same during 2003-04 and 1% lower during 2005-06, averaging 1% over the three seasons. Similarly, SOC in furrows of minimum tilled plots was 8% higher on average than in conventionally-tilled furrows during 2001-02, and 4% higher during 2005-06, averaging 6% for these two seasons. In addition, compared with conventionally-tilled beds, exchangeable K and specific volume of aggregates were higher and ESP lower with minimum tillage, whereas in the present study, significant differences were absent in furrows. This is probably because runoff, leaching and erosion due to both rainfall and irrigation is higher in furrows than under beds or in the plant line.

Applying the above values into appropriate pedotransfer functions from the literature enables the saturated hydraulic conductivity, K_s (terminal infiltration rate) to be estimated. For example, inserting the values of ESP (Fig. 1) and silt content (26 g/100g and 21 g/100g during 2001-02 and 2005-06, respectively) into the pedotransfer function derived by Vervoort *et al.* (2006)[2] ($\text{Log } K_s = 3.413 + 0.049\text{silt} - 0.0057(\text{silt x ESP})$) indicates that average seasonal K_s in conventionally-tilled and permanent bed furrows was of the order of 82 and 88 mm/h,

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

[2] Vervoort, R.W., Cattle, S., and Minasny, B., 2003. The hydrology of Vertosols used for cotton production: I. Hydraulic, structural and fundamental soil properties. *Aust. J. Soil Res*. **41**, 1255-1272.

respectively, during 2001-02 and 70 and 72 mm/h, respectively, during 2005-06. These values suggest that differences in hydraulic conductivity between tillage systems were small.

Table 8. Effect of tillage system on soil pH and organic carbon. s_d, standard error of the difference between means

Season	Month	pH (0.01M $CaCl_2$)		SOC (g/100g)	
		Conventional Tillage	**Minimum tillage**	**Conventional Tillage**	**Minimum tillage**
2001-02	December	6.4	6.1	0.89	0.98
	January	7.4	7.3	0.72	0.83
	February	7.1	7.1	0.89	0.98
	Mean	7.0	6.8	0.86	0.93
2003-04	July	7.3	7.2	-	-
	November	7.3	7.4	-	-
	January	7.4	7.3	-	-
	Mean	7.3	7.3	-	-
2005-06	November	6.9	7.0	0.85	0.90
	January	6.9	6.8	0.86	0.85
	February	6.8	6.6	0.75	0.80
	Mean	6.9	6.8	0.82	0.85
s_d (Season x month x tillage system)		0.12		0.079	

Wheel-tracked furrows generally had lower values of plastic limit and higher $EC_{1:5}$ than non-wheel-tracked furrows (Table 9). Relative to non-wheel-tracked furrows, average $EC_{1:5}$ in wheel-tracked furrows was 16% higher during 2001-02, 4% higher during 2003-04 and 24% higher during 2005-06. Differences in plastic limit although significant, were quite small, with seasonal averages differing by 0.01 g/g or less. Except during 2001-02, aggregates in wheel-tracked furrows had a higher GMD than those in non-wheel-tracked furrows (Table 9). In comparison with non-wheel-tracked furrows, mean seasonal GMD of soil aggregates was 0.3 mm higher in wheel-tracked furrows during 2003-04 and 1.6 mm higher during 2005-06. The unusually high values observed in both furrow types during February 2002, an indicator of soil structural collapse, may have been caused by a period of intensive rainfall which occurred after irrigation during late January 2002 and the subsequent extended inundation. Soil structural breakdown can occur due to raindrop impact and when entrapped air breaks out of soil aggregates during flooding.

Applying irrigation water only to non-wheel-tracked furrows may have resulted in higher rates of leaching, runoff and erosion than in wheel-tracked furrows, resulting in higher ionic concentrations in the latter. For the same reason, wetting and drying intensities may also have been greater in non-trafficked furrows, resulting in smaller soil aggregates being formed (Semmel *et al.*, 1990; Pillai and McGarry, 1999). Larger aggregates in wheel-tracked furrows may also have been due to trafficking reducing the efficacy of the wetting/drying process. However, surface sealing in both furrow types may have minimised potential differences, by minimising differences in runoff and erosion (Silburn and Glanville 2002). K_s estimated as described previously (Vervoort et al., 2006) was similar in both furrow types. K_s, averaged over the 2001-02 and 2005-06 seasons, was 79 mm/h in wheel-tracked and 77 mm/h in non-wheel-tracked furrows.

Table 9. Effect of wheeled traffic on furrow soil $EC_{1:5}$ and plastic limit. s_d, standard error of the difference between means.

Season	Month	$EC_{1:5}$ (dS/m)		Plastic limit (g/g)		GMD (mm)	
		Non-wheel-tracked	Wheel-tracked	Non-wheel-tracked	Wheel-tracked	Non-wheel-tracked[1]	Wheel-tracked
2001-02	December	0.13	0.15	0.24	0.23	1.7 (0.2281)	1.9 (0.2825)
	January	0.25	0.30	0.23	0.22	1.5 (0.1614)	0.9 (-0.0267)
	February	0.18	0.21	0.25	0.23	8.3 (0.9186)	7.5 (0.8755)
	Mean	0.19	0.22	0.24	0.23	3.8 (0.4360)	3.5 (0.3771)
2003-04	July	0.22	0.22	0.21	0.21	2.1 (0.3221)	2.1 (0.3221)
	November	0.23	0.25	0.23	0.18	1.0 (-0.0116)	1.5 (0.1844)
	January	0.30	0.31	0.20	0.25	0.6 (-0.2033)	0.8 (-0.1103)
	Mean	0.25	0.26	0.21	0.21	1.2 (0.0357)	1.5 (0.1321)
2005-06	November	0.16	0.16	0.27	0.28	0.8 (-0.0766)	2.2 (0.3488)
	January	0.16	0.17	0.30	0.29	1.3 (0.1278)	3.9 (0.5856)
	February	0.20	0.31	0.30	0.28	1.6 (0.2123)	2.5 (0.4029)
	Mean	0.17	0.21	0.29	0.28	1.3 (0.0878)	2.9 (0.4458)
s_d (Season x month x furrow type)		0.031		0.012		(0.08881)	

In summary, pH was lower and SOC higher in furrows under minimum tillage than those under conventional tillage, whereas $EC_{1:5}$ was higher, and plastic limit lower in wheel-tracked than in non-wheel-tracked furrows. Soil aggregates were also smaller in the latter. Differences were small between conventionally-tilled and permanent bed furrows, and between wheel-tracked and non-wheel-tracked furrows, and are consistent with the small differences in plant available water (6%), water infiltration (4%) and irrigation application efficiency (1%) reported by Tennakoon and Hulugalle (2006)[2] in this same site.

5.1.2.2 Effect of season and time of season

Significant effects of season, independent of tillage system or furrow type, were also present with respect to pH ($P < 0.001$), $EC_{1:5}$ ($P < 0.001$), plastic limit ($P < 0.001$), geometric mean diameter of aggregates (GMD) ($P < 0.001$), exchangeable Na ($P < 0.05$), ESP ($P < 0.05$), dispersion index ($P< 0.001$) and specific volume of soil aggregates ($P < 0.10$) (Figs. 1 and 2). The significant differences in plastic limit among 2001-02, 2003-04 and 2005-06 seasons may not be a real difference but an operator effect. Campbell (1976) notes that even with the best quality control, the hand method of determining plastic limit suffers from operator subjectivity. In this study, the measurements were made by three different operators in the three years. The variations in $EC_{1:5}$, pH and ESP among seasons may be related to the quality of the irrigation water in each season. For example, Mean pH_w of irrigation water was 8.2 during 2001-02 and 2005-06, and 7.5 during 2003-04. This in turn, may be related to the drought conditions which prevailed during 2002. Annual rainfall during 2002 was 275 mm and 2003 495 mm, whereas the average for 1999, 2000, 2001, 2004 and 2005 was 725 mm. The consequences of these variations in soil properties are reflected in the differences in K_s between seasons; *viz*. 86 mm/h during 2001-02 and 71 mm/h during 2005-06.

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[1] Values in parentheses are $\log_{10}$ transformed values

[2] Tennakoon, S.B., and Hulugalle, N.R. (2006). Impact of crop rotation and minimum tillage on water use efficiency of irrigated cotton in a Vertisol. *Irrig. Sci.*, **25**, 45-52.

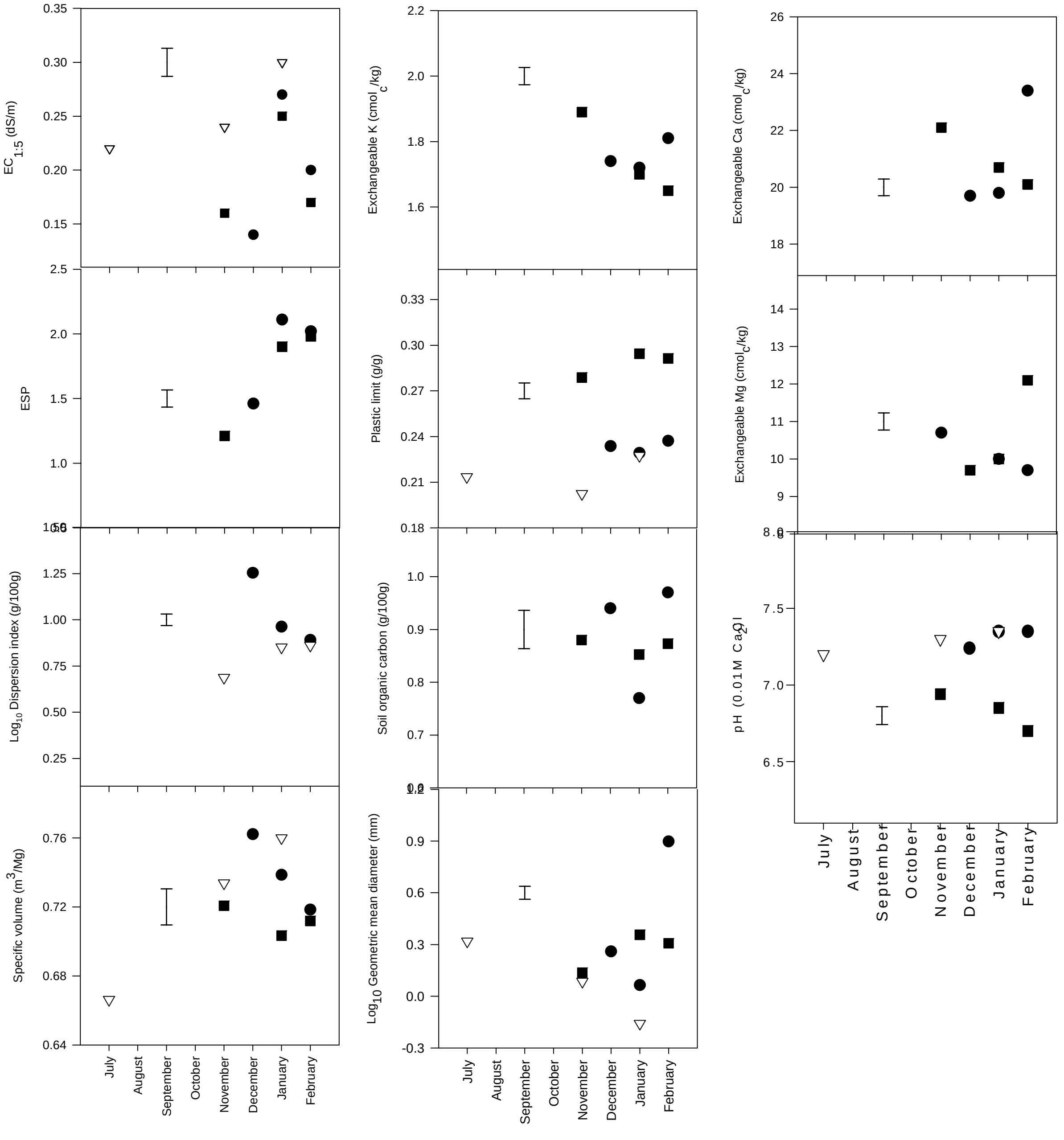

Figure 14. Variation of EC$_{1:5}$, exchangeable Ca, Mg and K, ESP, plastic limit, dispersion index, pH, specific volume, SOC and GMD of air-dried soil aggregates with time during the cotton growing seasons of 2001-02 (●), 2003-04 (□) and 2005-06 (■). Vertical bar is

Significant, but generally small intra-seasonal changes occurred with respect to GMD ($P < 0.001$), SOC ($P < 0.01$), exchangeable Ca ($P < 0.001$), Mg ($P < 0.001$) and K ($P < 0.01$), and dispersion index, DI ($P < 0.05$) (Fig. 14). As noted previously, GMD remained relatively stable throughout the season except during 2001-02, when, presumably due to the combined effects of raindrop impact and flooding during January 2002, a sharp increase occurred in February. Exchangeable K decreased with time in all years (Fig. 1). This was probably caused by losses in runoff and erosion, and uptake by the cotton. Cotton is a crop with a high potassium requirement, with average seasonal uptake in Australian Vertisols being of the order of 200 kg/ha. Exchangeable Ca increased during 2001-02 and decreased during 2005-06, whereas the reverse occurred for exchangeable Mg. SOC decreased between December and January in 2001-02 and 2005-06, and increased thereafter. The initial decrease in SOC may be due to mineralization, which is high in irrigated soils in this region during January due to warm soil temperatures. The increase in SOC by February was probably due to increased rates of leaf litter addition and root turnover, which peaks in irrigated cotton during January.

In summary, although intra-seasonal changes did occur with respect to some of the soil physical and chemical properties measured, they do not appear to be sufficient to cause or be related to the seasonal improvements in irrigation efficiency and infiltration reported in this site by Tennakoon and Hulugalle (2006)[1]. As irrigation water was of good quality for the period 2001-2006 and the soil in this site was non-saline and non-sodic, major causes of seasonal changes in water penetration may be depth of cracking and the intensity of wetting and drying and formation of surface seals rather than interactions between the soil physical and chemical factors measure in this study. It may also be that a significant proportion of water absorption occurs not through the furrow bottom, from which soil was sampled during this study, but through the sides of the beds. Inter-seasonal differences were, however, significant, and could affect hydrological processes in this soil. These differences were probably related to annual variations in irrigation water quality.

In conclusion, furrow soil in continuous cotton systems sown with minimum tillage had lower pH and higher SOC than that under conventional tillage. In comparison with non-wheel-tracked furrows, $EC_{1:5}$ and GMD were higher in wheel-tracked furrows, and plastic limit lower. Differences were small between conventionally-tilled and minimum-tilled furrows, and between wheel-tracked and non-wheel-tracked furrows. Management practices such as minimum tillage and traffic management appear to have caused relatively minor changes to surface soil physical and chemical properties in furrows. Inter- and intra-seasonal changes also occurred with respect to soil physical and chemical properties in furrows. Intra-seasonal changes were small and are unlikely to cause significant changes to soil hydrological processes. Interactions between surface soil physical and chemical factors in furrows may not, therefore, play a major role in influencing water application efficiency and infiltration within a season. Inter-seasonal differences were, however, significant, and could affect hydrological processes in this soil.

5.1.3 Comparative effects of cotton-wheat and cotton-vetch rotations

5.1.3.1 Rotation crop growth and yield

Inclusion of vetch in the crop rotation increased wheat grain yields during the 2003-07 period by approximately 0.35 t/ha and water use efficiency (grain yield/seasonal water input) by 1.3 kg/ha/mm (Fig. 15). Water use efficiency was 7.6 kg/ha/mm in cotton-wheat (stubble incorporated) plots and 8.9 kg/ha/mm in cotton-wheat (standing stubble)-vetch plots. Protein concentration of wheat grain from cotton-wheat-vetch rotations remained relatively constant under variable seasonal water availability whereas in cotton-wheat rotations it decreased with increasing availability of water. The level of screenings increased faster with cotton-wheat than with cotton-wheat vetch as water stress increased. These observations suggest that sowing a vetch rotation crop may benefit subsequent wheat crops, even though a cotton crop was sown between the vetch and the following wheat.

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[1] Tennakoon, S.B., and Hulugalle, N.R. (2006). Impact of crop rotation and minimum tillage on water use efficiency of irrigated cotton in a Vertisol. *Irrig. Sci.*, **25**, 45-52.

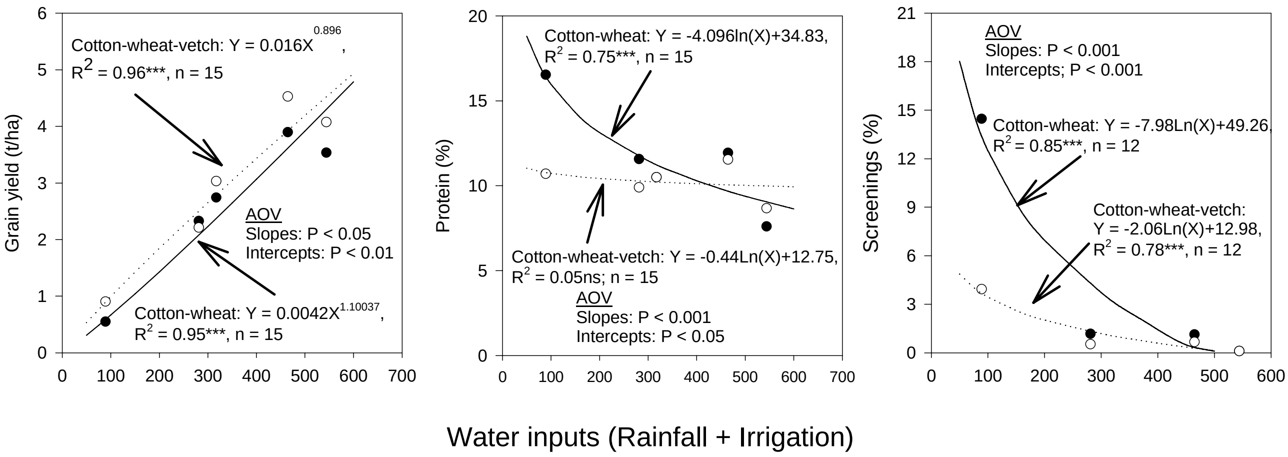

Figure 15. Effect of seasonal water inputs and crop rotation on wheat grain yield and quality, Field D1, ACRI, Narrabri. ●, cotton-wheat (stubble incorporated); ○, cotton-wheat (standing stubble)-vetch

Table 10. Effect of crop rotation (mean ± SEM) on above-ground dry matter production, N in above-ground dry matter, N concentration and N fixation by vetch, Field D1, ACRI, 2003-07.

Rotation	Dry matter production (t/ha)	N concentration (%)	N in above-ground dry matter (kg/ha)	N fixation (kg/ha)
Cotton-vetch	3.6 ± 0.44	3.5 ± 0.14	120.4 ± 17.55	109.9 ± 15.48
Cotton-wheat-vetch	5.0 ± 0.49	4.0 ± 0.16	202.8 ± 19.62	167.8 ± 17.31
P <	0.05	0.05	0.01	0.05

Average dry matter production, N concentration in plant tissues, N uptake and N fixation by vetch in the cotton-vetch rotation from 2003 to 2007 was significantly lower than that by vetch in the cotton-wheat-vetch rotation (Table 10). The differences in above-ground dry matter, tissue N concentration, N uptake content in above-ground dry matter and N fixation were influenced by both in-crop water inputs and crop rotation. This was such that higher values were present in plots sown with the cotton-wheat-vetch sequence when seasonal water inputs were between 225 and 400 mm with peak values occurring around 300 mm (Fig. 16). Thereafter values of these parameters decreased sharply and approached those in the cotton-vetch rotation. Inclusion of a wheat rotation crop may have facilitated both N uptake and N fixation by the vetch. The mechanism may involve release of nutrients by the decomposing wheat stubble and their extraction by the following vetch crop. Microbial decomposition of the wheat stubble may have been further enhanced by the single superphosphate (and hence, additional supplied of P and S) applied during May 2004. The increase in nutrient availability and uptake by the vetch may in turn have resulted in higher N fixation. The fall in N uptake, fixation and concentration with increasing water inputs may reflect both higher rates of N leaching and volatilisation leading to less N availability under wet conditions, and waterlogging, both of which can result in reduced nutrient uptake and growth by vetch. The above results also underscore the likelihood that vetch can respond to enhanced nutrient availability, particularly in a rotation system which includes wheat. This is an issue which has been little researched.

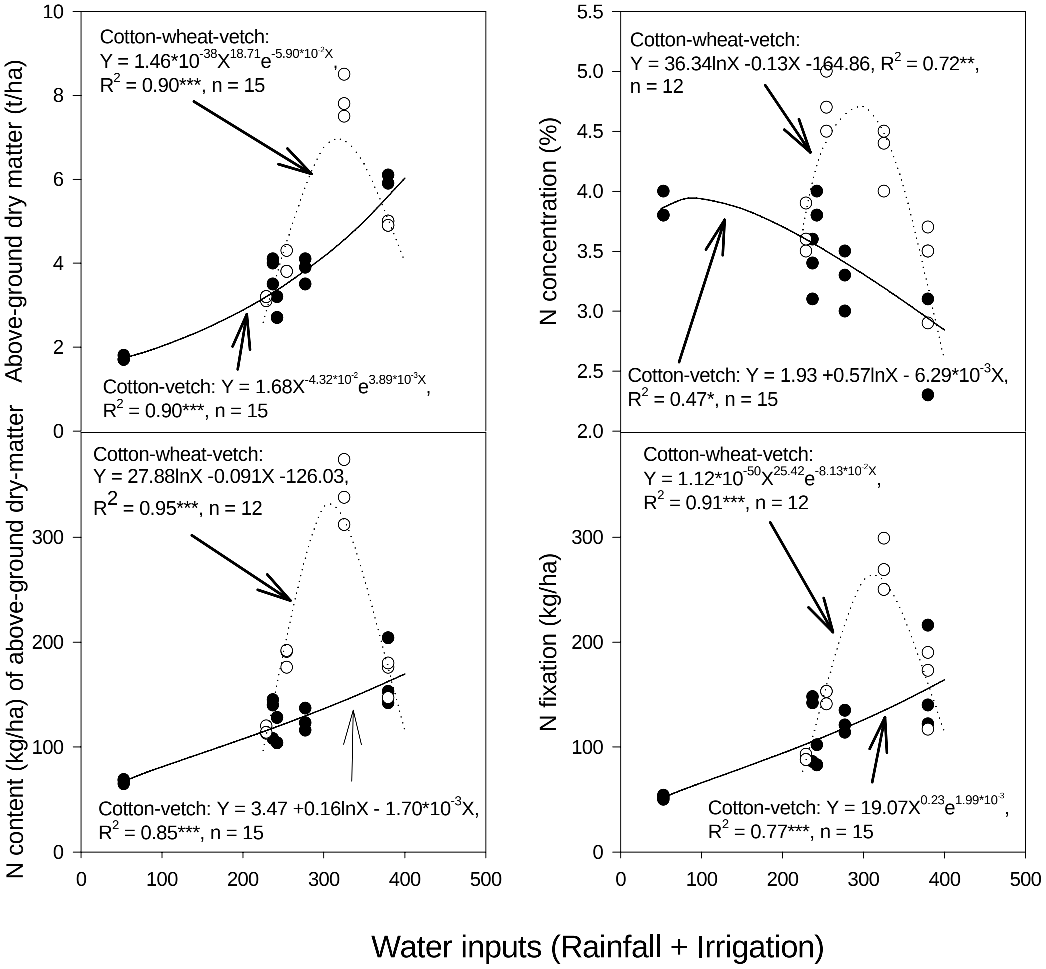

Figure 16. Effect of seasonal water inputs and crop rotation on above-ground dry matter production, N uptake, N concentration and N fixation by vetch, Field D1, ACRI, 2003-07. ●, cotton-vetch; ○, cotton-wheat (standing stubble)-vetch

5.1.3.2 Cotton growth and yield

Cotton growth parameters are shown in Figure 17 for the 2006-07 (hot, dry season) and 2007-08 (cool, wet season). In general, highest values of squares, green and open bolls per unit area occurred with rotations which include a wheat crop. Lowest number of green bolls during the 2006-07 season occurred with cotton-vetch.

Soil water storage during cotton growing seasons was generally higher in cropping systems which included a wheat rotation crop. The better soil water storage with wheat rotation crops may be because they were able to increase the number of pores which are involved in water storage. Cereal crops such as wheat can significantly improve soil structure in compacted soils[1]. Cotton yield generally reflected these differences (Table 11) except during 2005-06 when growth and yield was confounded damage caused by high numbers of *Helicoverpa* moths (Fig. 19). Retention of stubble as surface mulch also facilitated water conservation, and was evident during the 2007-08 season when a regular rainfall distribution occurred from mid-November until early February.

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[1] 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.

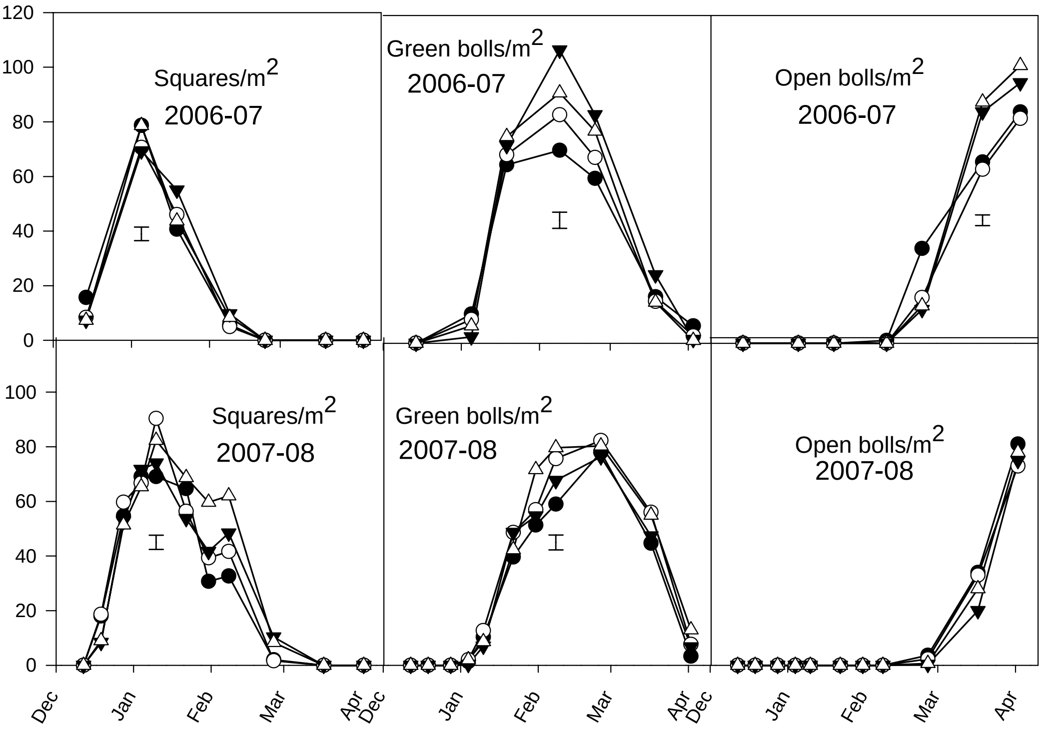

Figure 17. Effect of crop rotation on squares, green bolls and open bolls per square meter in cotton crops grown during the 2006-07 and 2007-08 season, Field D1, ACRI, Narrabri. ●, Cotton-vetch; ○, Cotton-winter fallow; ▼, Cotton-wheat (stubble incorporated); △, Cotton-wheat (standing stubble)-vetch. Vertical bars are SEM's (Treatment x date).

Rainfall during fallow and duration of the winter crop also influenced fallow soil water storage such that immediately before pre-irrigation it was least in the cotton-vetch rotation. Good winter and early spring rainfall (2005-06) resulted in cotton-wheat, cotton-winter fallow and cotton-wheat-vetch having much higher stored water than cotton-vetch whereas a dry winter and spring (2006-07) resulted in cotton-wheat having the highest stored water due to it having a summer fallow in addition to winter and early spring fallows, whereas differences among the other three rotations were small.

Table 11. Effect of crop rotation on cotton lint yield (bales/ha) in Field D1, ACRI, 2005-06, 2006-07 and 2007-08 cotton seasons.

Rotation	Rotation crop stubble management	2004-05	2005-06	2006-07	2007-08	Mean
Cotton-vetch	Retained *in situ*	7.9	9.7	8.7	10.9	9.3
Cotton-winter fallow	-	8.1	7.6	8.4	11.9	9.0
Cotton-wheat	Incorporated	10.1	8.1	10.7	11.6	10.1
Cotton-wheat-vetch	Retained *in situ*	11.1	8.7	10.5	10.7	10.3
P <		0.05	ns	0.001	ns	
SEM		0.66	0.65	0.20	0.32	

Cotton lint yields did not differ during 2005-06 and 2007-08 among treatments (Table 11), probably due to the confounding effects of the damage caused by high numbers of *Helicoverpa* moths during 2005-06 (Fig. 19), and frequent rainfall combined with cool/cloudy conditions during January and much of February 2008 during the 2007-08 season. Averaged over the four seasons, however, cotton lint yields were higher by 12% in cropping systems which included a wheat rotation crop by (Table 11). As discussed previously, the higher yields with wheat rotation crops may largely be because they improved soil water storage.

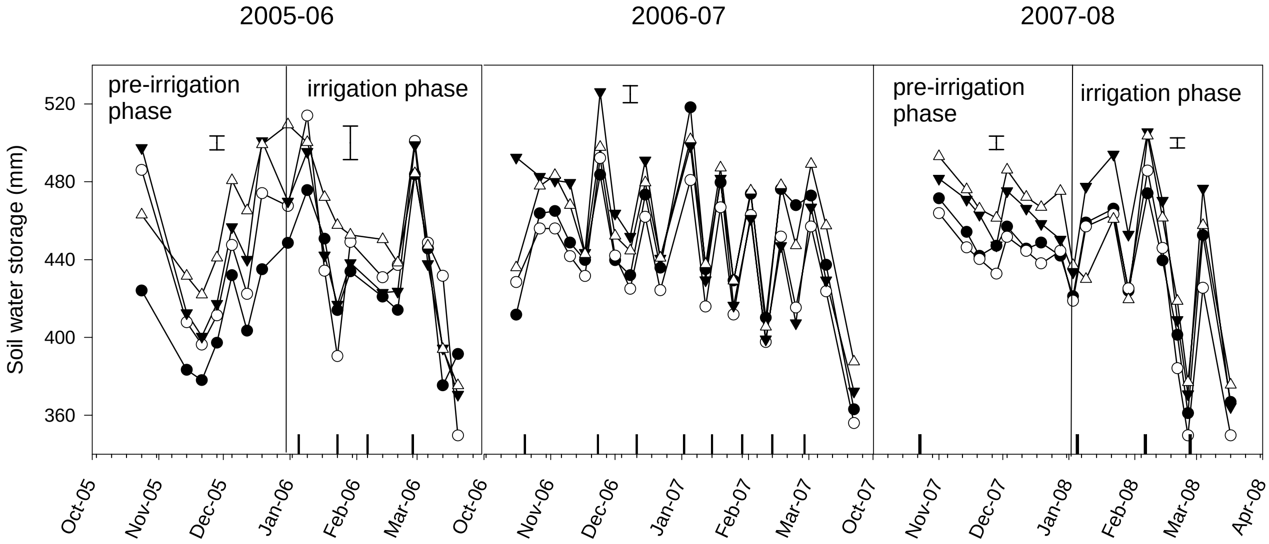

Figure 18. Effect of crop rotation on seasonal variation of soil water storage to a depth of 1.2 m during the cotton growing seasons of 2005-06. 2006-07 and 2007-08, Field D1, ACRI. ●, Cotton-vetch; ○, Cotton-winter fallow; ▼, Cotton-wheat (stubble incorporated); △, Cotton-wheat (standing stubble)-vetch. Vertical bars in the body of the figure are SEM's (Treatment x date). Data was analysed by grouping measurements according to pre-irrigation and irrigation phases, except during 2006-07 when, due to low rainfall, the

None of the cotton lint fibre quality indices measured were significantly affected by crop rotation during 2004-05, 2005-06 and 2007-08 seasons, and only uniformity was significantly ($P < 0.05$) higher in rotations which included vetch during the 2006-07 season. Uniformity index (%) was 83.8 with cotton-vetch, 82.6 with cotton-winter fallow, 82.5 with cotton-wheat and 84.1 with cotton-wheat-vetch (SEM = 0.34, $P < 0.05$). Mean values of non-significant fibre quality indices are summarised in Table 12.

Table 12. Cotton lint fibre quality indices, Field D1, ACRI

Season	Elongation (%)	Length (in")	Micronaire (µg/in")	Short fibre index (%)	Strength (g/tex)	Uniformity index (%)
2004-05	4.4	1.12	4.5	11.3	30.4	82.4
2005-06	3.4	1.14	4.5	9.3	33.5	82.4
2006-07	4.1	1.12	4.9	8.1	30.7	-
2007-08	1.2	1.20	4.2	7.1	31.4	84.1

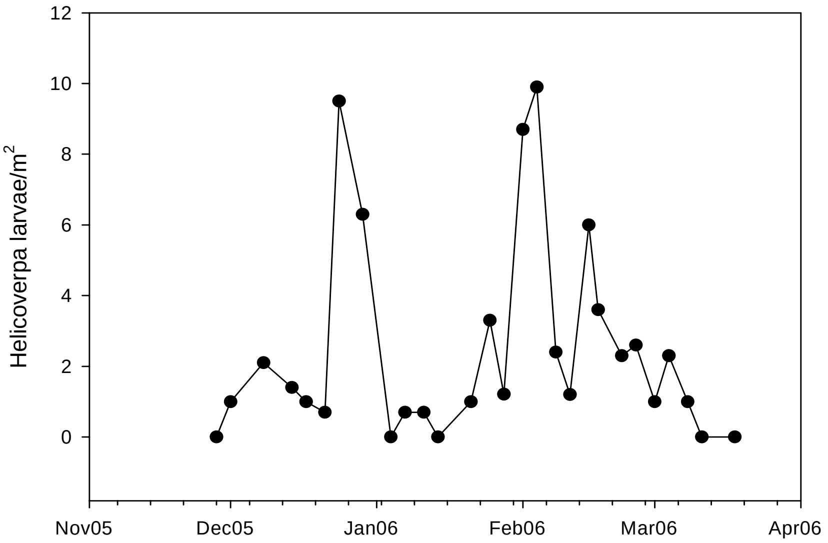

Figure 19. Variation of *Helicoverpa* larvae, Field D1, ACRI, 2006-07 cotton season. Threshold value for significant crop damage is 2.

5.1.3.3 Soil properties

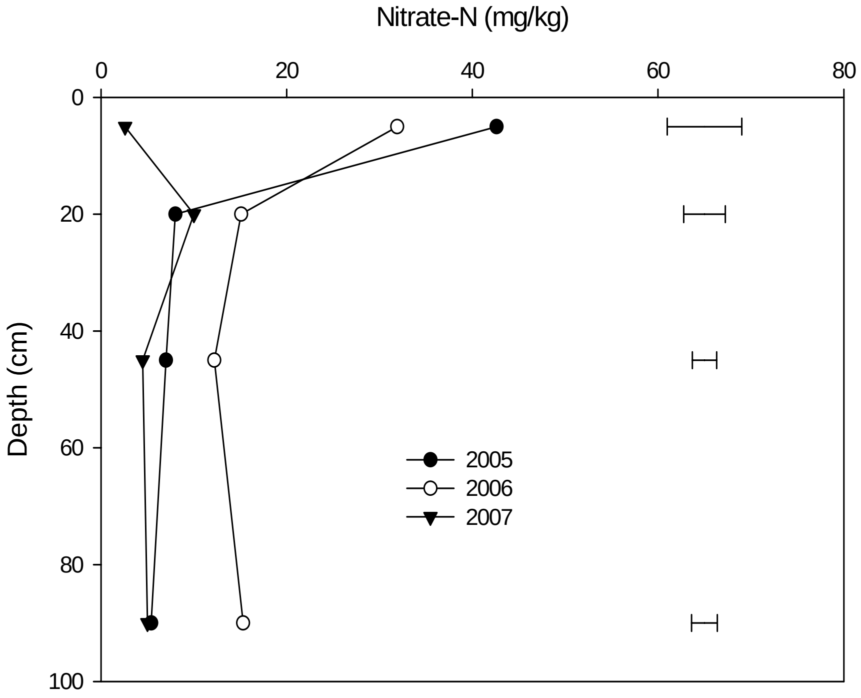

Figure 20. Variation of nitrate-N concentration with depth, Field D1, ACRI, 2005 to 2007. Pooled data for cotton-vetch and cotton-wheat-vetch. Horizontal bars are SEM's.

The cotton/wheat/vetch rotation experiment was established during 2002 in Field D1 at ACRI. At that time, the site was characterized by extensive subsoil compaction, low soil organic carbon ($\leq$ 0.5 g/100g at depths > 30 cm) and subsoil sodicity (ESP at depths > 30 cm was > 8)[1].

Significant differences in soil properties among rotations were restricted to $EC_{1:5}$, soluble Cl, nitrate-N, SOC, exchangeable K and Na, ESP and $EC_{1:5}$/ESC. Nitrate-N was higher in the surface 30 cm with cotton-winter fallow and cotton-wheat than in the other rotations (Table 13). This was because cotton-winter fallow and cotton-wheat, neither of which included a vetch component, received N fertiliser as anhydrous ammonia before sowing. Highest values of nitrate-N occurred in the 30-60 cm depth of the cotton-wheat rotation and may be due to faster leaching of applied N fertiliser relative to cotton-winter fallow. The faster leaching may, in turn, be related to greater porosity of subsoil in plots sown with wheat. In the rotations which included a vetch component, nitrate-N concentration increased significantly in all depths ($P < 0.01$) and between 2005 and 2006 (Fig. 20). This may be due to fixed N being released from decomposing vetch stubble between 2005 and 2006. Subsequently, however, nitrate-N values decreased, presumably due to water stress brought about by the low rainfall and unavailability during the 2007 winter.

Given that rainfall was low and irrigation water was unavailable, and consequently, vetch growth and N fixation was relatively poor during the 2007, it is unlikely that this increase was entirely due to N-fixation by the vetch. The dry conditions may have minimised N losses through volatilisation and leaching, resulting in N accumulating in the 10-30 cm and 30-60 cm depths between 2006 and 2007. At this stage of the experiment, therefore, nitrogen-fixation by vetch does not appear to have resulted in significant nitrate-N accumulation in the soil.

Cl concentration was highest in the surface 10 cm in the cotton-vetch rotation, followed by the cotton-wheat-vetch, cotton-winter fallow and cotton-wheat and may be related to the length of their respective fallow periods, and thus minimisation of leaching. In other words, the longer the fallow period, the more likely there is to be salt leaching out of the soil surface regions. Cl concentrations were, however, lower in the 10-60 cm depth in rotations which included a wheat crop, and as previously noted, may be related to the better soil structure under wheat, and thus, faster leaching. $EC_{1:5}$ differed significantly among rotations and depths and is most likely caused by its close relationship to soluble Cl and nitrate-N ((R^2= 0.36, $P < 0.001$, n = 144). Similarly $EC_{1:5}$/ESC was also related to soluble Cl and nitrate-N (R^2= 0.56, $P < 0.001$, n = 144).

ESP in the 0-30 cm depth was significantly higher in rotations which included a vetch crop (Table 13) and again may be related partly to the different fallow periods, and consequently different leaching patterns in the surface regions and to the greater availability of nutrients (i.e. N). However, ESP throughout the soil profile may also be related to variations in soil organic matter, even though SOC differed significantly in the surface 10 cm and in the 30-60 cm depth, where differences although significant, were small. Stepwise regression analysis indicated that ESP was significantly related to SOC and soluble Cl (used as a surrogate for soluble Na) ($R^2 = 0.57$, $P < 0.001$, n = 144). This relationship has been described previously by many authors[2], and involves solubilisation of native calcium carbonates by H^+ released by (a) crop stubble and soil organic matter mineralisation, and (b) ionisation of carbonic acid formed by dissolution of carbon dioxide, a product of microbial respiration. This causes the release of Ca^{2+} which displaces Na from the exchange complex, which may then either be

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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.

[2] Chorom, M., and Rengasamy, P. (1997). Carbonate chemistry, pH, and physical properties of an alkaline sodic soil as affected by various amendments. *Aust. J. Soil Res*. **35**, 149-161.

leached with incoming rainfall or remain within the soil solution. The efficacy of this process is greatly improved by increasing the amount of available nutrients such as N, which can be done by sowing a leguminous crop, P and S (see also discussion on vetch growth and wheat stubble decomposition, section 5.3.1.1).

Exchangeable K differed significantly ($P < 0.05$) among rotations only in the 0-10 cm depth. Exchangeable K (in cmol_c/kg) was 1.4 with cotton-vetch, 1.5 with cotton-winter fallow, 1.5 with cotton-wheat and 1.6 with cotton-wheat-vetch. Values also decreased with time (years). Mean values among years were 1.5, 1.6 and 1.3 cmol_c/kg during 2005, 2006 and 2007, respectively.

Table 13. Soil properties under cotton/vetch/wheat rotations, Field D1, ACRI. Cotton stubble was incorporated but rotation stubble was managed as indicated in table. Results are averages for 2005, 2006 and 2007 from cotton phase of each rotation 2-3 weeks before sowing cotton.

Depth (cm)	**Rotation**	**Stubble management**	**$EC_{1:5}$ (dS/m)**	**Nitrate-N (mg/kg)**	**ESP**	**Cl (mg/kg)**	**SOC (g/100g)**	**$EC_{1:5}$/ESC**
0-10	Cotton-vetch	*In situ mulch*	0.27	22.6	2.5	60.8	1.05	0.37
	Cotton-winter fallow	-	0.45	126.5	1.9	32.2	0.95	0.74
	Cotton-wheat	Incorporated	0.44	113.0	1.7	26.7	0.96	0.81
	Cotton-wheat-vetch	*In situ mulch*	0.26	28.9	2.0	39.5	1.06	0.41
	P <		0.01	0.001	0.01	0.01	0.05	0.01
	SEM		0.029	20.25	0.09	3.13	0.025	0.049
10-30	Cotton-vetch	*In situ mulch*	0.23	10.5	4.5	47.8	0.63	0.15
	Cotton-winter fallow	-	0.36	91.5	3.6	42.7	0.61	0.32
	Cotton-wheat	Incorporated	0.39	114.8	3.1	33.5	0.62	0.39
	Cotton-wheat-vetch	*In situ mulch*	0.23	11.7	3.8	33.3	0.60	0.18
	P <		0.01	0.001	0.10	0.05	ns	0.10
	SEM		0.018	17.21	0.27	3.58	0.016	0.056
30-60	Cotton-vetch	*In situ mulch*	0.30	7.6	7.4	84.4	0.49	0.11
	Cotton-winter fallow	-	0.33	8.7	6.4	72.7	0.50	0.15
	Cotton-wheat	Incorporated	0.27	22.8	5.8	49.3	0.52	10.4
	Cotton-wheat-vetch	*In situ mulch*	0.26	8.2	6.4	39.8	0.52	0.12
	P <		0.01	0.001	ns	0.05	0.05	ns
	SEM		0.010	2.72	0.49	8.22	0.007	0.014
60-120	Cotton-vetch	*In situ mulch*	0.36	6.1	12.0	111.8	0.45	0.09
	Cotton-winter fallow	-	0.33	11.5	10.7	122.0	0.47	0.10
	Cotton-wheat	Incorporated	0.32	13.5	10.2	98.8	0.51	0.09
	Cotton-wheat-vetch	*In situ mulch*	0.38	11.0	11.0	117.2	0.46	0.10
	P <		ns	ns	ns	ns	ns	ns
	SEM		0.023	2.23	0.87	7.92	0.021	0.006

5.1.3.4 Cotton root growth and soil carbon

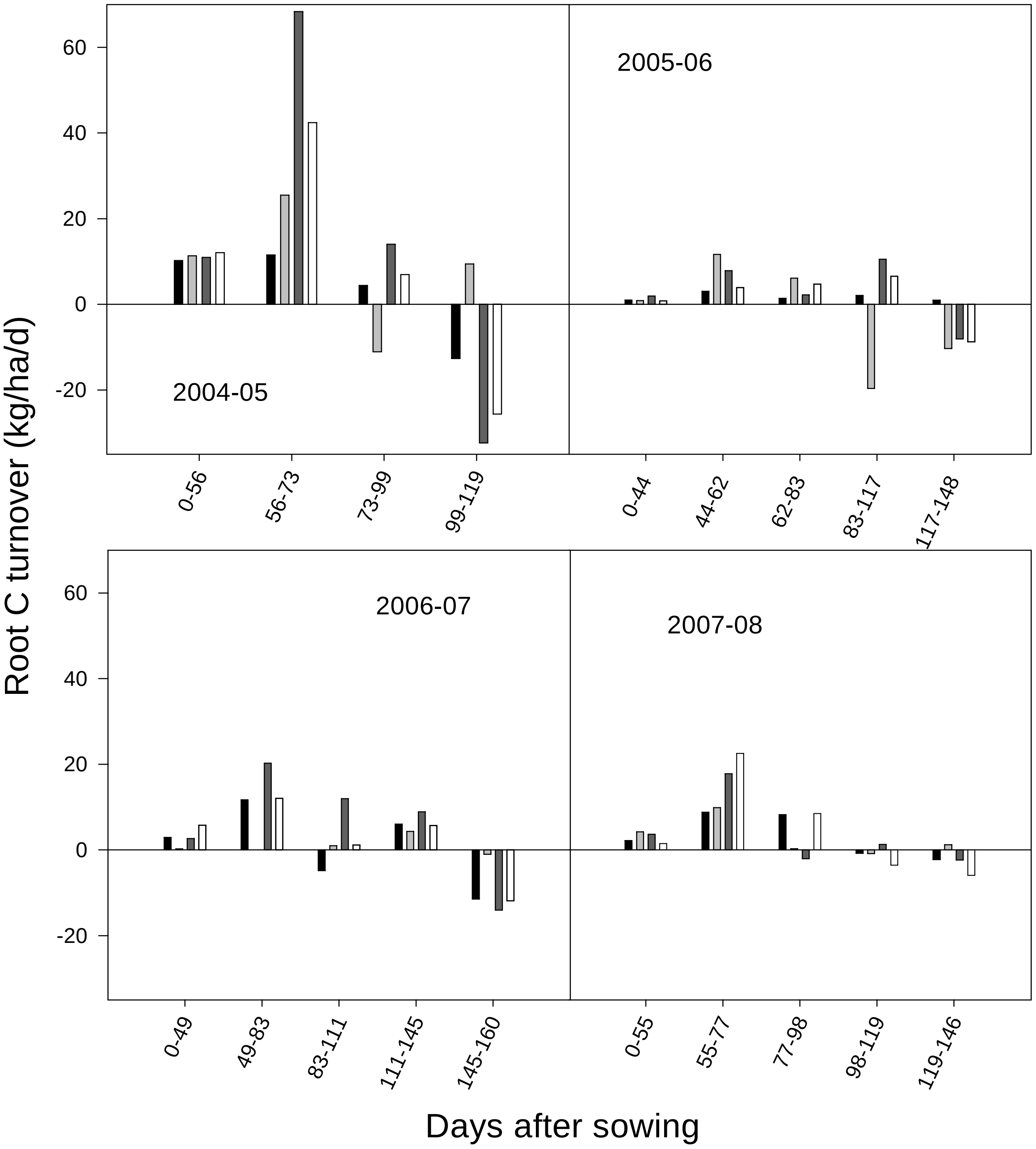

Figure 21. Effect of crop rotation on intra- and inter-seasonal variation in cotton root carbon turnover, Field D1, ACRI, Narrabri. Black: cotton-vetch; Light grey: cotton-winter fallow; Dark grey: cotton-wheat; White: cotton-wheat-vetch.

Table 14. Statistical significance of crop rotation effects on intra-seasonal variation in cotton root carbon turnover results presented in Fig. 21. Data were analysed after $\log_e$ transformation. DAS, days after sowing

2004-05	**P <**
0-56 DAS	ns
56-73 DAS	0.05
73-99 DAS	ns
99-119 DAS	0.05

2005-06	**P <**
0-44 DAS	ns
44-62 DAS	0.05
62-83 DAS	ns
83-117 DAS	ns
117-148 DAS	ns

2006-07	**P <**
0-49 DAS	0.05
49-83 DAS	0.01
83-111 DAS	ns
111-145 DAS	ns
145-160 DAS	ns

2007-08	**P <**
0-55 DAS	0.01
55-77 DAS	ns
77-98 DAS	0.05
98-119 DAS	ns
119-146 DAS	ns

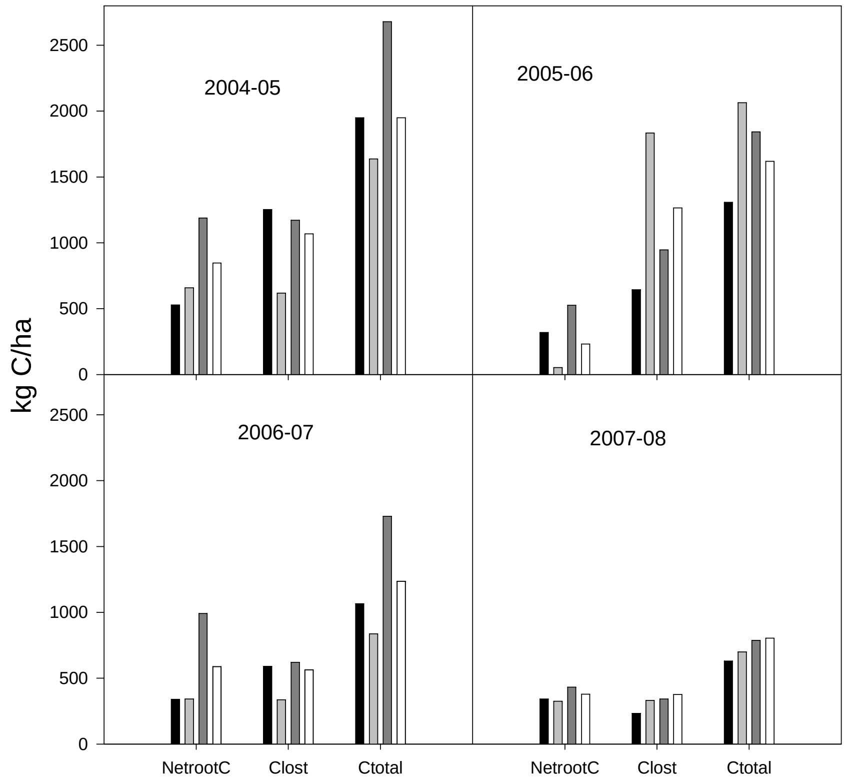

Figure 22. Effect of crop rotation on cotton root carbon available for addition to soil on a seasonal basis, Field D1, ACRI, Narrabri. Data was analysed after $\log_e$ transformation. Black: cotton-vetch; Light grey: cotton-winter fallow; Dark grey: cotton-wheat; White: cotton-wheat-vetch. NetrootC: carbon in roots remaining at end of season; Clost: C added to soil during season due to root death and decay; Ctotal: carbon potentially available for addition to soil = sum of NetrootC and Clost

Intra-seasonal cotton root carbon turnover patterns measured between 2004 and 2008 suggest that there is a period of active root growth during late vegetative growth (~60-90 DAS) followed by a decline as flowering and boll-filling commence (Fig. 21). In some years, when there is late season rainfall after boll-filling, a short-lived flush of root activity mat take place. This is usually followed by a rapid decline in root numbers and root death. In most years it is during vegetative growth that statistically significant differences in turnover occur (Table 14). The present results suggest that cotton-wheat and cotton-wheat-vetch have the highest average root turnover rates (Fig. 21). During 2004-05, 2006-07 and 2007-08 the total amount of carbon available for addition to soil from cotton roots on a seasonal basis, Ctotal was in the order of cotton-wheat $\geq$ cotton-wheat-vetch > cotton-vetch = cotton-winter fallow ($P < 0.01$) (Fig. 22), although differences were small during 2007-08. This is probably a reflection of the differences in soil properties under the various rotations (i.e. soil water storage, structure etc.). Between 2004 and 2008, average Ctotal ranged from 850 to 2000 kg C/ha. This is approximately 50-60% of that added from above-ground dry matter and is higher than had been previously assumed. Ctotal also decreased significantly ($P < 0.001$) from 2004-05 to 2007-08. This may be due to the application of single super phosphate during the winter of 2004 stimulating cotton root growth during 2004-05. As the amount of P available decreased with time, cotton root growth may, consequently, have also decreased. Alternatively, decrease in Ctotal may be reflect the different cotton varieties used; i.e. Roundup-Ready varieties during 2004-05 and 2005-06, and Bollgard II-Flex varieties during 2006-07 and 2008-08.

The amount of carbon added to soil through intra-seasonal root death and decay, Clost, also varied with time in all rotations. During 2005-06 a large proportion of Ctotal comprised of Clost (averaged among all treatments it was of the order of 70% in comparison with other years when it ranged from 44-50%), and may be related to the damage caused by the high *Helicoverpa* numbers (Fig. 19). Insect damage may, therefore, influence root functions such as water and nutrient extraction.

5.1.3.5 Resilience of profitability to changes in input costs

In this section recent economic results (2003-2008) from the crop rotation experiment in Field D1, ACRI are presented and the consequences of increases in fuel and fertiliser prices on profitability, measured as gross margins, are discussed. In order to compare the different treatments in the current price context, where possible, 2008 prices have been used for inputs such as fuel, fertiliser, herbicides (including defoliants) and pesticides. In addition prices for cotton lint was set at $420/bale and seed at $400/t. Wheat prices for various grades were taken as feed $248/t, AH $202/t, and PH13 $220/t.

The cropping systems were compared on a per field basis, e.g. assuming a field was continuously farmed under the particular system, as might be the case if there was sufficient water to irrigate all the available land and secondly, as part of a whole farm where there is only sufficient water to fully irrigate half of the available land. The latter opens the possibility for systems which only have cotton every second year (e.g. cotton-wheat-fallow-cotton) on a per field basis, to have a cotton crop every year though in a different field following a wheat rotation each time. This system is probably more typical of many farms, especially under drought conditions with limited allocation of irrigation water.

Basic Gross Margin Comparisons

At a cotton price of $420/bale, average annual gross margins were in the order of cotton-winter fallow-cotton ($2035/ha) > cotton-vetch-cotton ($1890/ha) > cotton-wheat-vetch ($1349/ha) > cotton-wheat ($1311/ha) (Fig. 23). In terms of gross margin/ML of irrigation water, profitability was in the order of cotton-wheat ($423/ML) > cotton-wheat-vetch ($403/ML) > cotton-winter fallow-cotton ($407/ML) > cotton-vetch-cotton ($403/ML) (Fig. 23). On the basis of the results so far, the inclusion of vetch between cotton crops has not been profitable. This is because cotton yield in the cotton-vetch-cotton rotation (8.2 bales/ha) was lower than that in cotton-winter fallow-cotton (8.5 bales/ha). This contrasts with previous research which found that cotton-vetch-cotton was more profitable than cotton-winter fallow-cotton (Williams *et al.*, 2005[1]). However, sowing vetch after wheat in a cotton-wheat rotation has increased profitability relative to cotton-wheat alone, similar to that reported by Williams *et al.* (2005).

Impact of input and output price changes

When the fuel and fertiliser price changes mentioned previously (see section 5.1.1.4) were applied, the relative profitability of the rotations changed similarly (Fig. 24). The rotations with a higher frequency of cotton crops (cotton-winter fallow-cotton, cotton-vetch) gave better returns with a higher cotton price, but with a lower cotton price relative to wheat, the gap between the continuous cotton and cotton/wheat rotations was lower. The cotton-wheat and cotton-wheat-vetch rotations were also less sensitive to falling cotton prices due to lower overall costs and the lower proportion of cotton in the rotation.

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[1] Williams, E., Rocheaster, I., and Constable, G. (2005). Using legumes to maximise profits in cotton systems. *Australian Cottongrower*, **26(6)**, 43-44, 46.

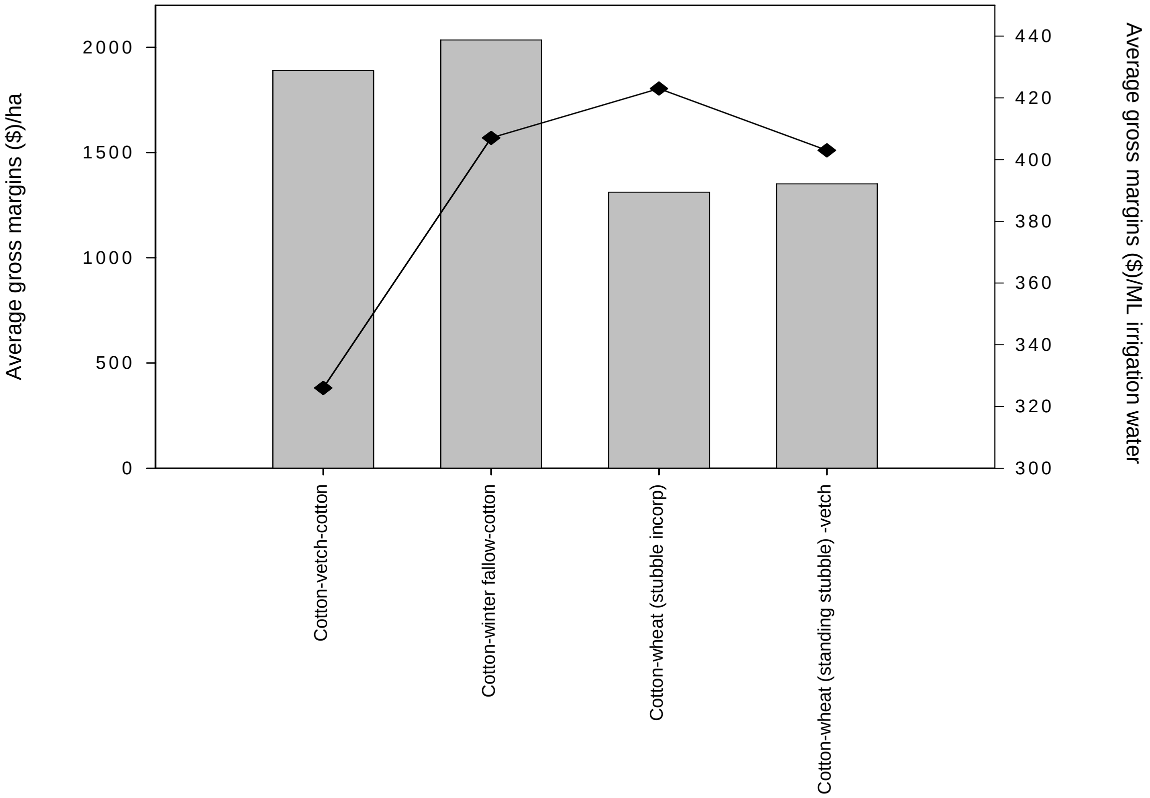

Figure 23. Effect of cropping system on average gross margins 2003-08, Field D1, ACRI. 1 bale of cotton lint = $420. Results for the 2002-03 season were exclude due to possible confounding with previous experiments in this site.

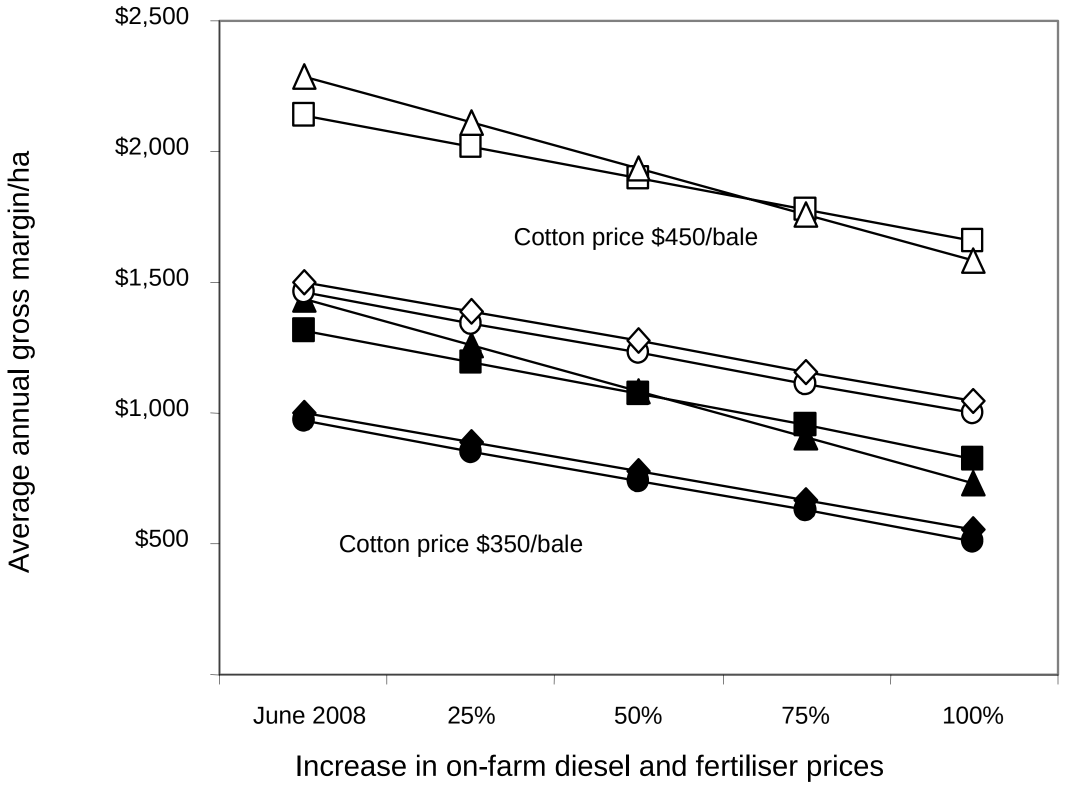

Figure 24. Impact of cotton lint price and fuel/fertiliser prices increases on rotation returns. Triangles- cotton-cotton, Circles- cotton-wheat, Diamonds- cotton-wheat-vetch and Squares- cotton-vetch

Whole-farm impact

In recent times water has been the limiting factor on total area on-farm under irrigation, rather than land. The average gross margin results reported thus far here show the relative profitabilities in the experiments where the same system was used in the same field over time, but growers need to consider the whole-farm impacts of these rotations also, since cotton-winter fallow-cotton is a one year 'cycle' of cotton-winter fallow, whereas cotton-wheat is in fact a 2 year rotation of cotton-wheat-summer fallow-winter fallow.

This can be demonstrated by applying the average yield results for the experiment on rotations on permanent beds to a farm of 1000 ha. Average water use during the trial was 5 ML/ha for cotton, 1 ML/ha for vetch and wheat. The average crop yields and in-crop costs from the experiment have been used to calculate the example, with $40/ha winter fallow costs and $182/ha summer fallow costs.

Assuming the annual water allocation for the farm of 6000ML, the comparative farm plans would be for cotton-winter fallow-cotton, 1000ha of cotton in summer and 1000ha of fallow in winter (total water required 5000 ML/year), and for cotton-vetch-cotton, 1000ha of cotton in summer and 1000ha of vetch in winter. For cotton-wheat, the ‘normal’ farm plan would be 500ha cotton and 500ha wheat stubble fallow in summer, and 500ha wheat and 500ha pre-cotton fallow in winter (water required 3000 ML/year with wheat using 1 ML/ha). For cotton-wheat-vetch, the ‘normal’ farm plan would have 500ha pre-cotton vetch in winter instead of fallow, (requiring 3500 ML/year if the vetch received 1 ML/ha as in the experiment).

The basic assumption in the limited water scenario is that the annual water allocation is cut by 50% for whatever reason to 3000ML/year. This leaves the cotton-winter fallow-cotton and cotton-vetch-cotton plans with only enough water for 600ha cotton (60% of the area). For the cotton-wheat plan, allowing 5 ML/ha for the cotton and 1 ML/ha for the wheat, 3000ML is enough for 500ha of cotton and 500 ha of wheat so the cotton-wheat or cotton-wheat-vetch plan can still carry on with the same areas. Using the average yields and costs from the trial and $420/bale for cotton and $200/t for wheat, cotton-wheat has the advantage over both continuous cotton systems (cotton-winter fallow-cotton and cotton-vetch-cotton) in this water-limited situation, but cotton-wheat-vetch in turn has an advantage over cotton-wheat (Table 15). Cotton-vetch-cotton is, however, less profitable than cotton-winter fallow-cotton. In the experiment, the vetch received 1 ML/ha irrigation, but for this reduced allocation example we have assumed that the water is allocated between the cotton and wheat component only.

When water is not limiting, in absolute financial terms, cotton-winter fallow-cotton will generate the higher total farm gross margin. Over the longer term, however, this higher profitability is accompanied by declining soil fertility, crop health and cotton yields/hectare. Also, a cotton-wheat rotation uses less water over the same area than a cotton-winter fallow-cotton ‘rotation’, freeing up water to be carried over to following seasons or able to be sold under temporary seasonal transfers, where such arrangements are possible.

However, financial comparison of rotations can be an involved issue, especially since it is likely that machinery needs, labour needs and infrastructure maintenance and therefore overhead costs, will be different. Gross margins cannot indicate these differences and whole farm budgets for the individual circumstances are more useful when comparing different rotations that will involve overhead costs.

Table 15. Comparison of water limited farm plans for four cotton rotation systems.

A) Cotton-cotton plan	GM/ha	Area (ha)	Water use (ML)	Gross margin
cotton	$ 2,398	600	3000	$ 1,438,756
summer fallow	$(182)	400	0	-$ 72,800
winter fallow	$(40)	1000	0	-$ 40,000
ML water used and Farm gross margin			3000	$ 1,325,956

B) Cotton-vetch-cotton plan	GM/ha	Area (ha)	Water use (ML)	Gross margin
cotton	$ 2,454	600	3000	$ 1,472,297
summer fallow	$(182)	400	0	-$ 72,800
vetch	$(196)	600	-	-$117,600
winter fallow	$(40)	400	0	-$ 16,000
ML water used and Farm gross margin			3000	$ 1,265,897

C) Cotton-Wheat plan	GM/ha	Area (ha)	Water use (ML)	Gross margin
cotton	$ 3,010	500	2500	$ 1,505,113
summer fallow	$(182)	500	0	-$ 91,000
winter fallow before cotton	$(40)	500	0	-$ 20,000
wheat	$230	500	500	$114,885
ML water used and Farm gross margin			3000	$ 1,508,998

D) Cotton-Wheat-Vetch plan	GM/ha	Area (ha)	Water use (ML)	Gross margin
cotton	$ 3,218	500	2500	$ 1,608,899
summer fallow	$(182)	500	0	-$ 91,000
vetch before cotton	$(196)	500	-	- 98,000
wheat	$241	500	500	120,297
ML water used and Farm gross margin			3000	$ 1,540,196

Difference between cotton-vetch and cotton monoculture (B-A)	-$ 60,059
Difference between cotton-wheat and cotton monoculture (C-A)	$183,042
Difference between cotton-wheat-vetch and cotton monoculture (D-A)	$214,240
Difference between cotton-wheat-vetch and cotton-wheat (D-C)	$31,198
Difference between cotton-wheat and cotton-vetch-cotton (C-B)	$243,101
Difference between cotton-wheat-vetch and cotton-vetch-cotton (D-B)	$274,299

5.1.3.6 Managing vetch in cotton-vetch and cotton-wheat-vetch rotations

While sowing cotton into standing wheat or vetch stubble retained on beds and in furrows has many advantages, disadvantages related to crop management such as blocking of "gas knives" by stubble during injection of anhydrous ammonia as fertiliser, waterlogging during irrigation and suffocation of cotton seedlings by vetch stubble regrowth exist. Solutions to the first two issues were developed during the previous phases of this research[1,2] and are briefly summarised below.

Blocking of "gas knives" by wheat stubble during application of anhydrous ammonia can be avoided by attaching coulter discs to the front bar of the gas rig, in front of the gas tines, to cut through wheat stubble. A press wheel, which follows the tine, seals the soil and leaves a rolled surface ready for planting. The gas tines and press wheels are fastened onto the back

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[1] 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.

[2] 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.

bar of the gas rig. During the pass of the rig, the only stubble disturbed is that on the top of the bed. After anhydrous ammonia has been injected, a 10-cm wide stubble-free strip, remains on top of the beds.

Waterlogging during irrigation events can be avoided by retaining the stubble in the furrows only until the start of the irrigation season. At this point, except for a 2 m long strip in the furrows at the tail drain end of the field, the point of a sweep is run through the furrow to a depth of about 10-cm to clean out the stubble from the furrow bottom. This increases the rate of water flow through the field. However, the retained 2-m strip slows water flow just enough to settle out dispersed clay and silt. Salts, nutrients and pesticides adsorbed onto clay particles are deposited in the furrow and do not move off field with runoff.

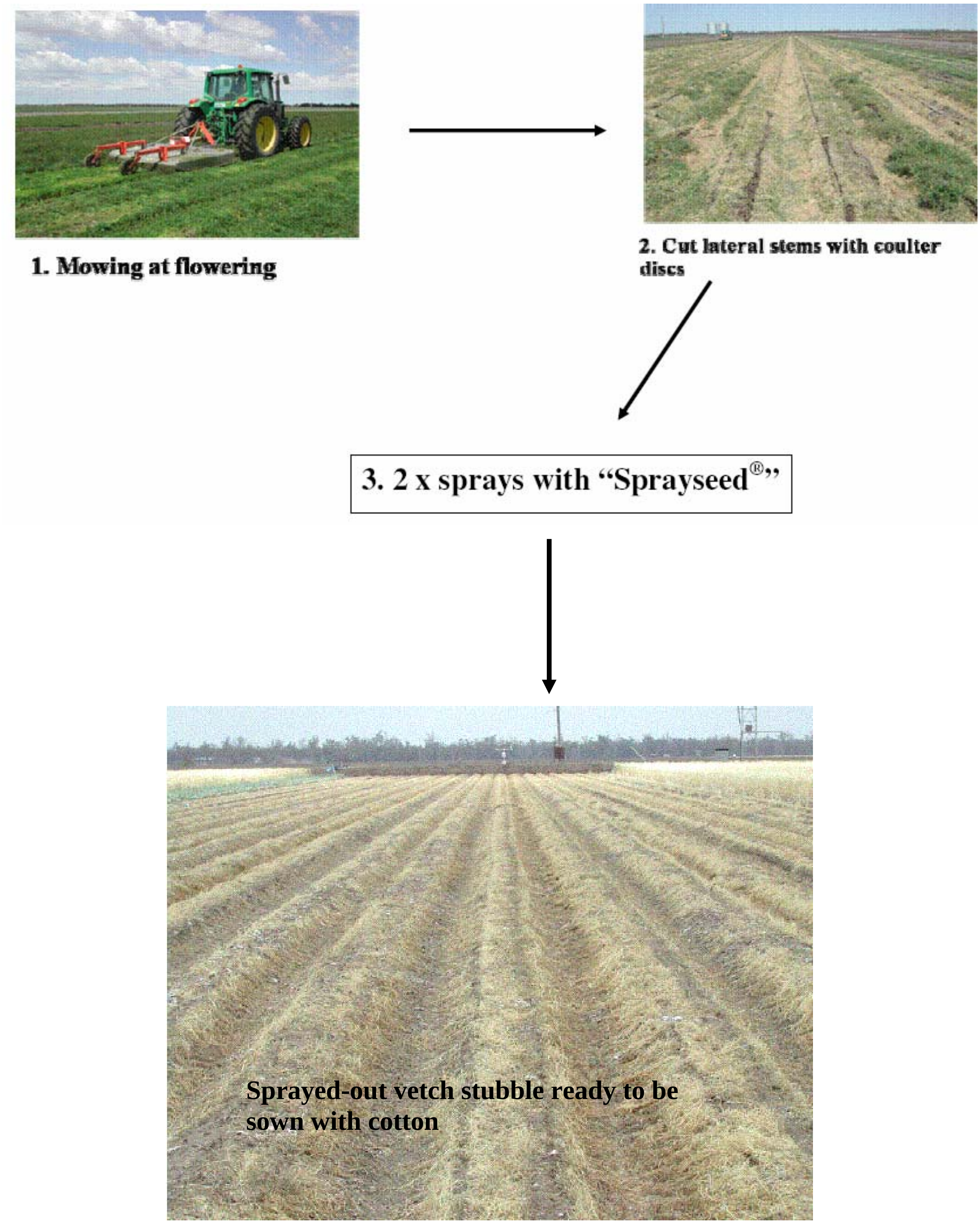

Figure 23. Process of controlling vetch before sowing cotton

Regrowth of vetch can be best controlled by mowing/slashing the vetch at 50% flowering, followed by running a set of coulter discs along the plant line to cut off the runners, and finally 1-2 applications of Sprayseed® (a.i. 135 g/litre paraquat + 115 g/litre diquat) at a rate of 2.5 L/ha (Fig. 23).

During the past 3 years, we experimented with modifying available machinery and implements such that the latter steps could be combined into a single operation which would minimise trafficking, fuel use and labour requirements while at the same time significantly reducing the amount of Sprayseed® required. The resulting modification achieved this by spraying the herbicide in a ~20 cm wide strip within the vetch plant line, thus reducing application amounts by ~70-80% and labour by ~40% while at the same time controlling vetch to the same extent as application with a boom-spray (Fig. 24). However, this resulted in no herbicide being applied to the furrows, and consequently, weed growth in furrows was not controlled. A second modification was, therefore made which enabled weeds growing within the furrow to be controlled but with a cheaper and less toxic herbicide. This is characterised by two tanks, which contain either Sprayseed® or Roundup®, connected to two separate spray lines, which enables these herbicides to be applied simultaneously either to the furrow or to the vetch plant line on the bed surface (Fig. 25).

Figure 24. Simultaneously cutting off vetch runners and applying Sprayseed®

Fig. 25. Modified implement to simultaneously cut vetch runners and apply Sprayseed® to bed surfaces and Roundup® to furrows.

5.1.3.7 Black root rot of cotton

Measurements made by Mr. Chris Anderson, NSW DPI plant pathologist, during January 2008 indicated that spore density was significantly lower ($P < 0.05$) when a wheat crop was included in the rotation, but not vetch. Mean colony counts/g dry soil was 3.0 in plots of cotton-winter fallow and cotton-vetch and 0.5 in cotton-wheat and cotton-wheat-vetch plots. However, these values are considered to be low and unlikely to affect cotton growth and yield.

5.1.4 Sowing vetch in cotton-corn rotations

Soil sampled between 2003 and 2005 from the experiment at "McIntyre Downs", near Goondiwindi, showed that the cotton-corn rotation was characterised by decreasing SOC, exchangeable K, $EC_{1:5}$, $EC_{1:5}$/ESC whereas exchangeable Mg and Na, and ESP were relatively stable (Table 17). During the same period, soil properties in the cotton-corn-vetch rotation were such that SOC, exchangeable K and $EC_{1:5}$/ESC increased, exchangeable Mg and Na decreased, and $EC_{1:5}$ did not change significantly.

As both plots were sown with cotton from 2003 until the terminations of measurements in 2005, the abovementioned differences were probably caused by the vetch which was incorporated in 2003. Decomposition of vetch residues may have released significant amounts of soluble nutrients such as K and nitrates, and consequently increased electrolyte concentrations, and hence, $EC_{1:5}$ in the soil solution. The $EC_{1:5}$ values, therefore, reflect the changes in nutrient availability rather than changes in salinity. The increased availability of soluble K may also have caused K to become adsorbed on the clay surfaces and displace exchangeable Na. Exchangeable Na and K in the cotton-corn-vetch sequences was closely related ($R^2 = 0.62$***, n = 40). A similar substitution may also have occurred with respect to exchangeable Mg. Consequently, exchangeable K and $EC_{1:5}$/ESC increased and exchangeable Na and Mg, and ESP decreased in the cotton + corn-vetch sequence. ESP may also have decreased due to the previously mentioned solubilisation of native $CaCO_3$ by decomposing vetch residues (see section 5.1.3.3), although significant changes in exchangeable Ca and pH were not observed. Exchangeable Ca in the cotton-corn and cotton-corn-vetch sequences averaged 21.6 and 22.1 cmol$_c$/kg, respectively, and pH 7.4 and 7.5, respectively. Structural stability, measured during 2004 and 2005 with the ASWAT test, resulted in ASWAT scores of 0 in both cropping systems, indicating very flocculative soils under both rotations.

Table 17. Effect of sowing vetch in strip-cropped cotton + corn on quality of a grey clay at "McIntyre Downs", Goondwindi, 2003-2005.

Crop rotation	Year	$EC_{1:5}$	SOC	Exchangeable cations (cmol$_c$/kg)			ESP	$EC_{1:5}$/ESC
		(dS/m)	(g/100g)	Mg	K	Na		
Cotton + corn	2003	0.23	1.08	8.9	0.9	1.0	3.2	0.24
	2004	0.11	0.71	10.3	0.8	1.2	3.4	0.09
	2005	0.15	0.82	9.0	0.6	1.1	3.6	0.14
Slope		-0.06	-0.14	-0.18	-0.13	0.04	0.19	-0.07
R^2 (n = 40)		0.42***	0.52***	0.02ns	0.34***	0.02ns	0.09ns	0.32***
Cotton + corn-vetch	2003	0.16	0.72	10.6	0.6	1.3	3.9	0.13
	2004	0.31	0.87	9.1	0.9	0.8	2.4	0.36
	2005	0.22	0.93	8.0	0.9	0.8	2.5	0.30
Slope		0.05	0.10	-1.31	0.15	-0.29	-0.74	0.10
R^2 (n = 40)		0.07ns	0.53***	0.61***	0.39***	0.44***	0.39***	0.23**
P <:								
Slopes		0.001	0.001	0.001	0.001	0.001	0.001	0.001

Corn and cotton yields, and dry matter production were not affected by sowing vetch in the experiment at ACRI, although large variations in corn growth occurred among years. Mean yields are summarised in Table 18. Vetch growth was poor during the experiment, averaging 0.9 and 1.1 t/ha during the winters of 2006 and 2007, and was due to the low rainfall and unavailability of irrigation water. The poor growth of the vetch may have resulted in the absence of any treatment effects on cotton and corn yields. N concentration in vetch tissues was similar during 2006 and 2007, and averaged 4.2%. N in above-ground vetch dry matter was 36 kg N/ha during 2006 and 47 kg N/ha during 2007.

Table 18. Mean yields of corn and cotton during 2005-06, 2006-07 and 2007-08 seasons. Cotton lint and corn cob yields were not measured during 2005-06.

Season	Cotton lint yield (bales/ha)	Corn cob yield (FW, t/ha)	Corn dry matter production (stubble+ husks, t/ha)
2005-06	-	-	20.8
2006-07	7.9	2.3	11.4
2007-08	7.2	11.2	8.9

Soil properties during November 2006 in the ACRI experiment were not significantly affected by including vetch in the rotation, and may be due to the poor growth of vetch during this experiment. Mean values of the soil properties which did not differ significantly are summarised in Table 19. pH, however, was affected by the summer crop sown in 2005-06; *viz.* it averaged 7.4 in cotton and 7.1 in corn plots ($P < 0.001$, SEM = 0.03). This may be related to differences in light organic matter fraction. Mr. James Terry, a summer student from the University of Sydney, who analysed soil sampled from this and adjacent experiments for organic matter fractions and related soil properties, reported that previous crops of corn resulted in a higher concentrations (0.8%) of light carbon (particulate organic carbon) than either cotton or wheat (0.4%). This in turn was related to root density of the following cotton ($R^2 = 0.51$**) and microbial biomass ($R^2 = 0.68$**)[1].

Table 19. Mean values of non-significant soil properties in the 0-30 cm depth of the corn-cotton-vetch experiment at ACRI, Narrabri, November 2006

Soil property	Value
$EC_{1:5}$ (dS/m)	0.30
SOC (g/100g)	0.86
$EC_{1:5}$/ESC	0.37
Ca/Mg	1.6

Soil property	Value
Exch. Ca ($cmol_c$/kg)	25.2
Exch. Mg ($cmol_c$/kg)	16.0
Exch. K ($cmol_c$/kg)	1.8
Exch. Na ($cmol_c$/kg)	0.9
ESP	1.9

In summary, including vetch in a cotton-corn rotation appears to have had significant benefits to overall soil quality at “McIntyre Downs” near Goondiwindi whereas it had a negligible effect at Narrabri. The different responses in the two locations are most likely related to the growth of the vetch crop. Although the vetch appeared to benefit soil quality at Goondiwindi, these results should be treated with some caution as they are based on measurements conducted over a three year period, even though the cotton/corn-vetch sequence had been in place since 2001. The on-going drought during the 2003-2007 period may also have resulted in some confounding, as it resulted in vetch growing poorly at Narrabri and not being sown at Goondiwindi.

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

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 9.4 bales/ha and sorghum grain during 2007-08 9.4 t/ha. Key changes in soil properties were that application of manure resulted in a higher exchangeable K and SOC concentration in the

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[1] Terry, J.H. (2007). Cotton yield and soil carbon under continuous cotton, cotton-corn, cotton-vetch-corn and cotton-wheat rotations. B.Sci. (Agric.) Hon. Thesis, University of Sydney, 102 pp.

surface and a small decrease in ESP (relative to the control of ripping alone) at depth (Table 21). Similar decreases in ESP also occurred with either gypsum or deep incorporation of P, K and Zn, or the combination of the two, albeit to a lesser extent than manure. Extremely small (< 5%), although statistically significant, changes also occurred with respect to exchangeable Ca and Mg (data not shown). Overall the changes with application of any of the amendments were small, and suggests that for discernible yield increases to occur frequent applications may be required. The positive responses to manure also suggest that long-term cropping-related K depletion and SOC decline could be minimised by regular application of cattle manure. The suggested time interval could be of the order of 5 years.

Table 21. Effect of applying soil amendments during 2005 on average exchangeable K, soil organic C and ESP, Brigalow, 2005-2007.

Amendment	**0-10 cm**	**10-30 cm**	**30-60 cm**	**60-120 cm**	**P <**	**SEM**
Exchangeable K, cmol$_c$/kg[1]						
Ripping alone	0.8(0.91)	0.3 (0.53)	0.2 (0.42)	0.1 (0.33)	(0.001)	(0.020)
Deep incorporation of P and K	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)	0.3 (0.56)	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	0.41
Deep incorporation of P and K	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		
Soil organic C (g/100g)						
Ripping alone	0.73	0.60	0.49	0.36	0.05	0.0273
Deep incorporation of P and K	0.72	0.63	0.45	0.34		
Deep incorporation of P, K and Zn	0.74	0.68	0.45	0.35		
Manure	0.87	0.64	0.48	0.35		
Gypsum	0.73	0.69	0.50	0.34		
Gypsum and deep incorporation of P, Zn and K	0.71	0.66	0.46	0.33		

5.2 Deep drainage and nutrient leaching

5.2.1 Effects of tillage systems, crop rotations, soil amendment and stubble management on deep drainage

Deep drainage in the soil profile to a depth of 120 cm was estimated with either the steady-state or transient state chloride mass balance model after testing whether water flow occurred under steady or transient state conditions as described by Weaver *et al.* (2005)[2]. The estimated drainage for irrigated cotton and rotation crops in Fields D1 and C1 at ACRI and "Federation Farm", near Narrabri, and dryland conditions at Brigalow are shown in Figs. 26-30. The main features of these results are summarised as follows:

- Drainage was generally greater where cotton was sown into standing wheat stubble compared with stubble incorporation and when soil water profiles were similar when cotton was sown (Figs. 26-27). This is due to the higher water infiltration and lower evaporation in the former management practice. Similarly a high irrigation frequency results in greater drainage throughout the root zone, but not out of the root zone (i.e. 120

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[1] Values in parentheses are sqrt transformed values

[2] Weaver, T.B., Hulugalle, N.R., and Ghadiri, H. 2005. Comparing deep drainage estimated with transient and steady state assumptions in irrigated Vertisols. *Irrig. Sci.*, **24**, 183-191.

cm depth). This may be related to different drainage pathways under the two irrigation frequencies: viz. dominance of preferential (crack) flow in the infrequently irrigated treatments whereas mass flow may play a larger role in drainage in the frequently irrigated treatments. Drainage did not differ during 2007-08 among stubble management systems at “Federation Farm” (Fig. 27). This was probably due to a combination of very frequent irrigation and frequent rainfall during the irrigation season confounding drainage.

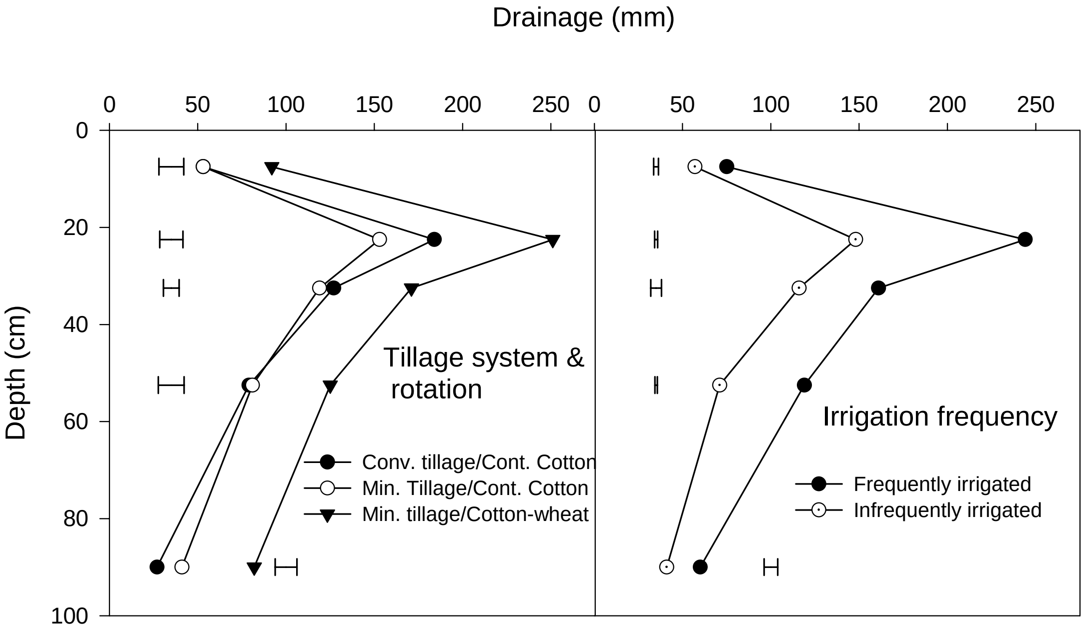

Figure 26. Effect of tillage system, rotation and irrigation frequency on deep drainage, Field C1, ACRI, Narrabri. Horizontal bars are SEM’s

- Management practices which improved soil structure such as permanent beds (minimum tillage), cereal rotation crops and gypsum increased drainage (Figs. 26-30). During the past three years wheat rotation crops and gypsum increased drainage more than minimum tillage alone. The combination of minimum tillage and wheat appeared to have synergistic effect on drainage (Fig. 26, 29 and 30).

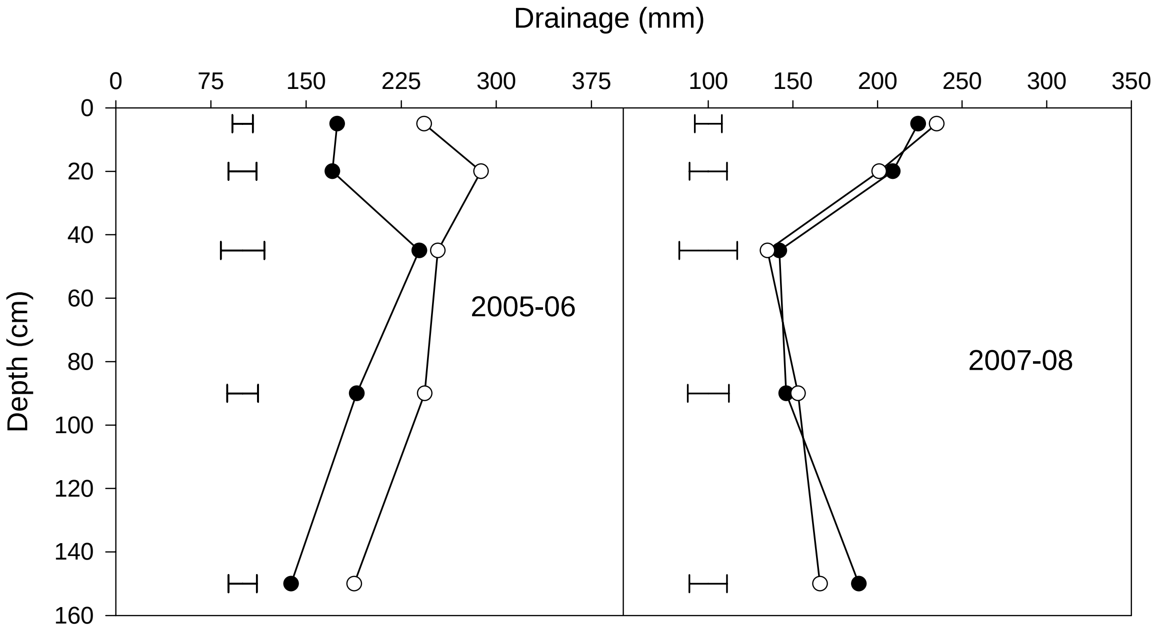

Figure 27. Effect of stubble management on deep drainage, “Federation Farm”, Narrabri. ●, stubble incorporated; ○, standing stubble. Horizontal bars are SEM’s.

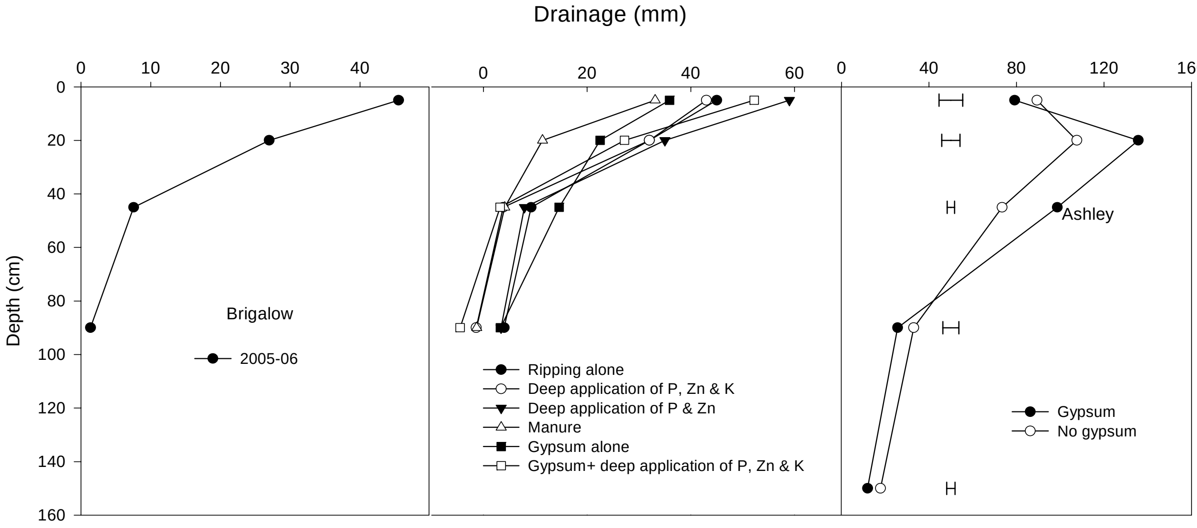

Figure 28. Drainage in the soil profile at Brigalow (July 2005 to June 2006 and June 2006 to 2007) and Ashley via Moree (Cotton season of 2006-07).

- Drainage was least in fallow plots at Narrabri (Figs. 28-29) and dryland plots at Brigalow (Fig. 28). Application of amendments did not affect drainage at Brigalow during 2005-06 but drainage during the 2006-07 season was less in plots which had been treated with a source of K ($P < 0.05$, analysed after a transformation of sqrt (D(z)+10)). This may be due to K resulting in better growth and hence, greater water extraction.

- In field D1 at ACRI, drainage measured between 2005 and 2008 (Figs. 29 and 30) was a function of water inputs (irrigation + rainfall), crop sown during the period under consideration and the rotation sequence in place. For instance, during the winter of 2005 (Fig. 29), among plots sown with a crop, those under wheat had higher drainage than those sown with vetch. During the 2006 winter, however, among cropped plots, drainage was least with cotton-vetch whereas subsurface and subsoil drainage did not differ in the other three treatments; *viz*. cotton-wheat (wheat phase), cotton-wheat-vetch (wheat and vetch phases). There was negligible drainage during the 2007 winter due to low rainfall and the unavailability of irrigation. The negative values in some depths during 2007 winter suggest that some upward flux, albeit very low, may have occurred.

  During the 2005-06, 2006-07 and 2007-08 cotton seasons (Fig. 30), drainage patterns were similar, with rotations which included a wheat crop having higher subsoil (> 30 cm) values than those which did not, although differences among treatments were small during 2007-08. The small differences among cropped treatments during the 2007-08 cotton season may be due to the frequent rainfall during December and January. In addition, the cotton-wheat-vetch rotation received one less irrigation due to better soil water storage. In years when the major source of water was irrigation (i.e. 2006-07), higher values of drainage occurred in ex-wheat plots from 10 cm onwards. It appears, therefore, that wheat may be able to create a larger number of drainage pores than vetch can, and that over time in a system which includes both crops, the drainage patterns created by the wheat roots will become dominant.

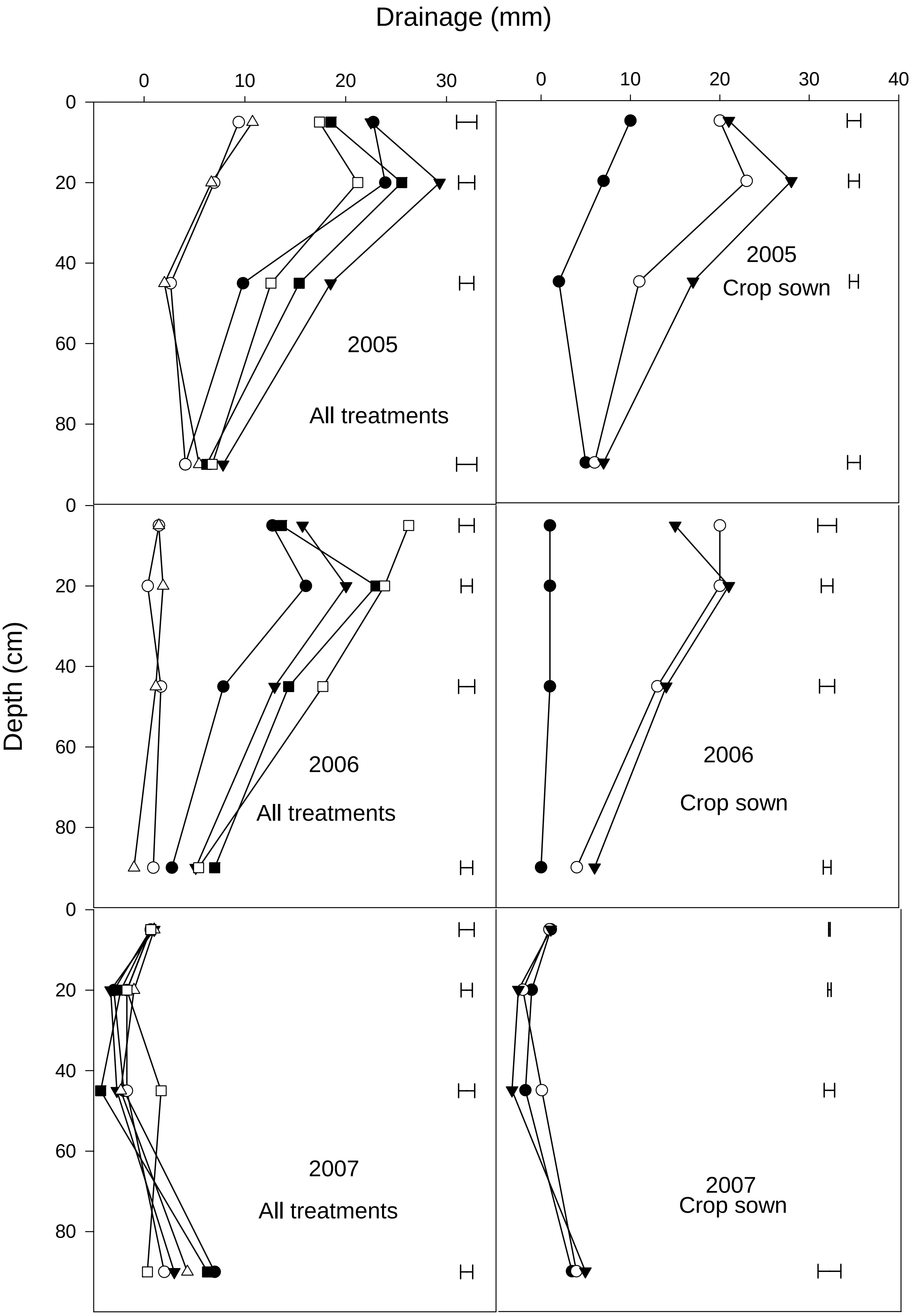

Figure 29. Effect of crop rotation on deep drainage during the winters of 2005, 2006 and 2007, Field D1, ACRI, Narrabri. **<u>All treatments</u>**: ●, Cotton-vetch (vetch phase); ○, Cotton-winter fallow (fallow phase); ▼, Cotton-wheat (wheat phase); △, Cotton-wheat (fallow phase); ■, Cotton-wheat-vetch (wheat phase); □, Cotton-wheat-vetch (vetch phase). **<u>Crop sown</u>**: ●, Fallow; ○, Vetch; ▼, Wheat. Horizontal bars are SEM's.

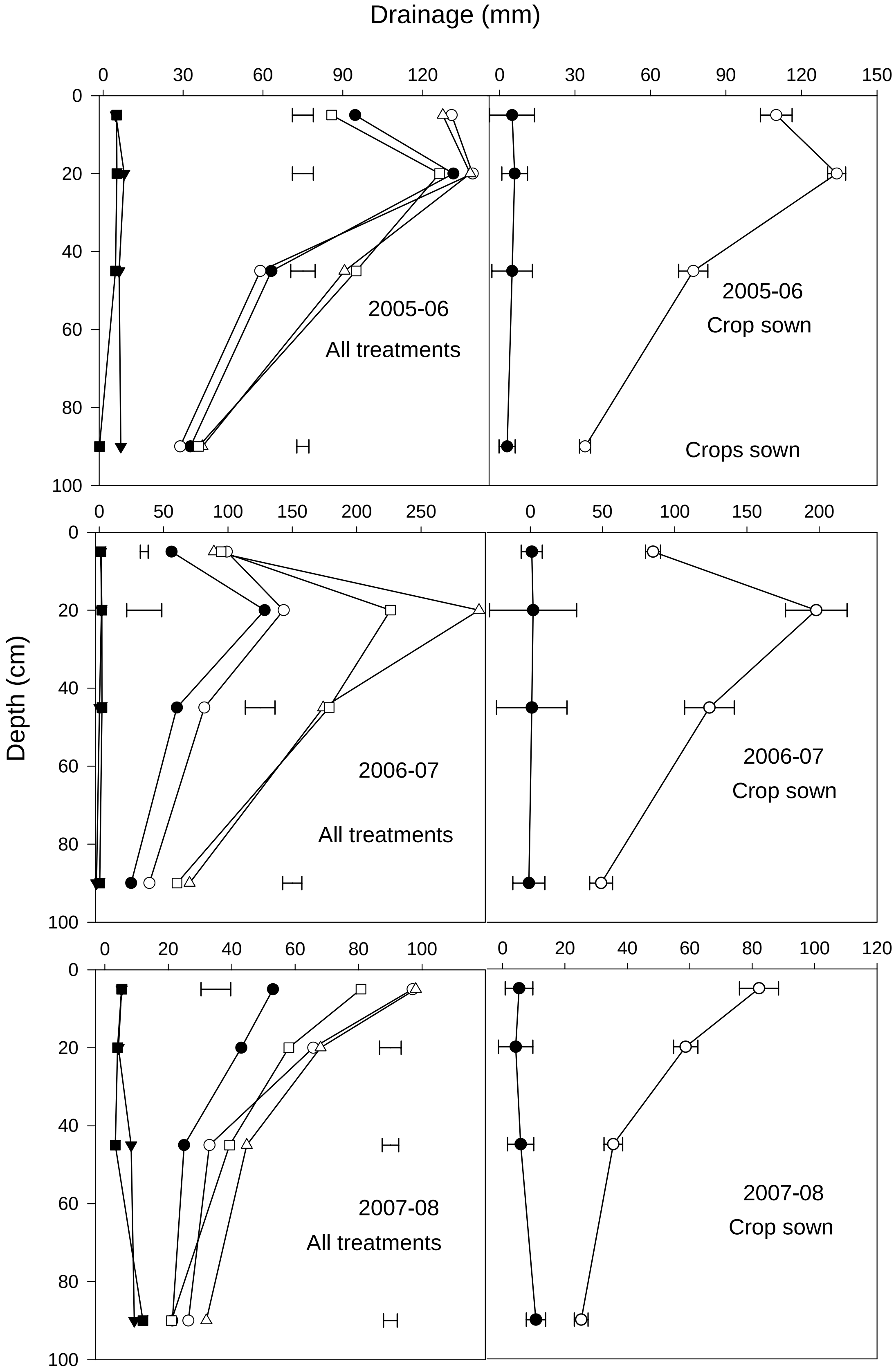

Figure 30. Effect of crop rotation on deep drainage during the cotton seasons of 2005-06, 2006-07 and 2007-08, Field D1, ACRI, Narrabri. **All treatments**: ●, Cotton-vetch (cotton phase); ○, Cotton-winter fallow (cotton phase); ▼, Cotton-wheat (fallow phase); △, Cotton-wheat (cotton phase); ■, Cotton-wheat-vetch (fallow phase); □, Cotton-wheat-vetch (cotton phase). **Crop sown**: ●, Fallow; ○, Cotton. Horizontal bars are SEM's.

5.2.2 Irrigation water quality

At ACRI irrigation water quality during 2005-06 was characterised by low values of SAR and EC_w, and low to moderate Cl concentrations during the cotton season of 2005-06 (Table 22). During 2006-07 and 2007-08, however, EC_w ($P < 0.001$), SAR ($P < 0.001$) and Cl concentration ($P < 0.05$) of irrigation water were significantly higher, with the greatest increases in EC_w and SAR occurring between 2005-06 and 2006-07. The values of EC_w and SAR observed during 2006-07 and 2007-08 suggest that structural deterioration (instability)[1] may have occurred during these seasons. The deterioration in irrigation water quality is probably related to factors such as reduced availability of river water and increasing use of bore water for irrigation; increased concentration of salt in river water, particularly sodium, due to drought; higher salt concentrations in bore water; and virtual absence of rain during the 2006-07 season which could have diluted salt concentrations in water supplies. 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.

In comparison with ACRI, irrigation water (treated sewage effluent) at “Federation Farm” had high SAR, EC_w, and soluble Cl concentration (Table 22). This has resulted in increasing soil salinity and sodicity (see section 5.1.1.1). Nitrate-N and K concentration and pH_w were also much higher than at ACRI. The high nitrate-N concentration implies that application of additional N as fertiliser is unnecessary. The values given in table 21 suggests that if irrigation efficiency is of the order of 75%, this is equivalent to a seasonal application of ~165-200 kg N/ha. High nitrate-N concentrations in irrigation water when combined with additional nitrates from fertiliser suggest the occurrence of high rates of N leaching (which have been documented in this site[2]) and movement into groundwater, nitrate-N accumulation in soil[2] and nitrous oxide emissions. In spite of the relatively high EC_w, the high SAR also suggests that soil structural stability may be poor in this site. Mean dispersion index (g/100g) during September 2007 was 10 in the 0-10 cm depth, 14 in the 10-30 cm depth, 13 in the 30-60 cm depth, and 16 in the 60-120 cm depth. 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.

5.2.3 Nutrient and salt leaching

Nutrient and salt leaching out of the cotton root zone (120 cm) were not significantly affected by irrigation frequency in the tillage/rotation experiment in Field C1 at ACRI but were highest with cotton-wheat under minimum-tillage, plots, less so with continuous cotton under minimum tillage, and least with continuous cotton under conventional tillage (Table 23). Calcium, chloride and sodium were the major constituents of the leachate. The above-mentioned differences reflected the drainage under the cropping systems but not that under the two irrigation frequencies. It may be that leaching (and drainage) in the infrequently-irrigated treatments were dominated by preferential flow pathways (i.e. cracks) but under frequent irrigation, mass flow may play a larger role. Consequently, a few drainage events which follow preferential flow pathways could account for a major proportion of the nutrient and salt leaching under infrequent irrigation, with seasonal drainage having no correlation to it. Under frequent irrigation, however, mass flow may influence nutrient and salt leaching more. Correlation analysis of salts and nutrients leached, and seasonal drainage indicated that

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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

[2] Hicks, A. 2002. The effect of effluent irrigation and gypsum on the soil properties of a Vertisol and growth of cotton. B. Sc. (Agric.) Thesis, University of Sydney, Sydney, NSW.

frequent irrigation was significantly ($P < 0.05$) correlated to seasonal drainage whereas the infrequent irrigation was not.

In Field D1 at ACRI, except for nitrate-N, there were no significant differences among rotations with respect to nutrient and salt leaching during 2005-06, 2006-07 and 2007-08 (Table 23). Nitrate-N was highest with cotton-vetch during 2005-06 and 2006-07, and may be related to a higher frequency of soil cracks and root pores created by the vetch facilitating leaching during the cotton season. Crack frequency may have been highest in cotton-vetch due to the low winter rainfall during the 2005-07 period and virtual absence of a pre-cotton fallow period in this treatment (2-3 weeks between spraying out vetch and sowing cotton) compared with 4-6 week with cotton-wheat vetch, 5 months with cotton-winter fallow and 11 months with cotton-wheat. There were no significant differences among rotations in the amounts of any of the nutrients or salts leached out of the root zone during 2007-08 and may be related to the frequent rainfall during that season. Except for nitrate-N and K, the amounts of other nutrients and salts leached during 2007-08 were much less than in other years, and may be related to the fact that due to the frequent rainfall less irrigation was applied. Consequently, nutrient and salt imports in irrigation water were less as was drainage out of the 120 cm depth.

Estimated costs of leaching indicated that during the 2006-07 season, the net benefit (benefits - costs = [values of Na, Cl and Mg[1]]-[values of nitrates, Ca and K]) of leaching/ha was highest with minimally-tilled cotton-wheat in Field C1 at ACRI (Table 24). These results concur with those obtained in previous years which indicated that relative to continuous cotton systems, leaching associated with a cotton-wheat rotation was most beneficial. This is primarily due to the leaching of high amounts and Na and Cl, and low amounts of nitrate-N.

In Field D1 at ACRI, a net cost occurred during 2005-06 with respect to the rotations which include a vetch crop whereas net benefits were greater in the same treatments during 2006-07 (Table 24). During 2007-08, except for cotton-wheat, net costs occurred with all treatments. Even with cotton-wheat, the net benefit was very small ($1.87/ha). In comparison with 2005-06 and 2007-08, average net benefits were also higher in 2006-07, presumably due to the lower nitrate-N, and higher Na and Cl amounts leached. This may be related to the poorer irrigation water quality in 2006-07 relative to 2005-06 (Table 22). Leaching of salts out of the root zone is, therefore, more beneficial when irrigation water contains high concentrations of Na and Cl.

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[1] As Mg can be a dispersive ion, its leaching was taken to be a “benefit”)

Table 22. Irrigation water quality during the cotton seasons of 2005-06, 2006-07 and 2007-08 at ACRI (Fields C1 and D1), and "Federation Farm", Narrabri. SAR, sodium adsorption ratio.

Season	Date	Site	Cl	K	Ca	Mg	Na	Nitrate-N	SAR	pH_w	EC_w
						(mg/L)					(dS/m)
2005-06	23-Dec-05	Cotton/vetch/wheat rotation experiment Field D1, ACRI, Narrabri	18	4	26	12	35	4	1.4	8.5	0.27
	05-Jan-06		20	4	14	9	51	3	2.6	8.8	0.25
	23-Jan-06		16	3	20	11	29	3	1.3	8.2	0.26
	06-Feb-06		15	3	22	9	20	3	0.9	8.0	0.23
	27-Feb-06		18	4	21	14	38	130	1.6	8.1	0.25
		Seasonal sum (kg/ha)	87	18	103	55	173	143			
	24-Dec-05	Stubble management experiment "Federation Farm", Narrabri	66	11	22	9	141	30	6.4	8.3	0.51
	05-Jan-06		100	14	28	13	212	27	8.3	8.4	0.63
	11-Jan-06		121	14	22	9	250	56	11.3	8.7	0.69
	24-Jan-06		110	14	20	8	216	55	10.1	9.1	0.54
	06-Feb-06		103	12	15	7	186	22	10.1	9.2	0.82
	09-Mar-06		99	13	21	8	194	30	9.1	9.2	0.71
		Seasonal sum (kg/ha)	599	77	127	54	1200	220			
2006-07	24-Oct-06	Tillage/rotation experiment Field C1, ACRI, Narrabri	21	3	27	14	67	25	2.6	7.5	0.32
	22-Nov-06		22	3	21	13	104	19	4.4	7.9	0.40
	12-Dec-06		31	3	25	16	125	10	4.8	7.8	0.40
	03-Jan-07		20	3	18	14	134	21	5.7	7.9	0.40
	16-Jan-07		21	3	21	13	108	20	4.5	7.9	0.30
	30-Jan-07		21	3	22	14	109	3	4.4	7.8	0.40
	14-Feb-07		25	5	31	22	136	12	4.6	7.8	0.50
	28-Feb-07		32	5	23	23	108	5	3.8	7.8	0.40
		Seasonal sum (kg/ha)	193	29	189	129	892	115			
	20-Oct-06	Cotton/vetch/wheat rotation experiment Field D1, ACRI, Narrabri	21	4	33	15	93	25	3.4	7.8	0.38
	23-Nov-06		11	4	18	13	109	15	4.8	8.0	0.40
	11-Dec-06		28	3	13	13	104	3	4.9	8.0	0.30
	02-Jan-07		26	4	19	17	109	5	4.4	7.9	0.40
	15-Jan-07		21	4	22	15	106	4	4.2	8.0	0.40
	29-Jan-07		17	4	18	15	101	33	4.2	7.9	0.40
	12-Feb-07		21	5	31	22	131	15	4.4	7.9	0.50
	27-Feb-07		25	5	34	25	115	27	3.6	7.8	0.50
		Seasonal sum (kg/ha)	170	32	188	134	867	128			
2007-08	23-Oct-07	Cotton/vetch/wheat rotation experiment Field D1, ACRI, Narrabri	24	3	11	11	95	33	4.8	8.4	0.36
	05-Jan-08		29	3	11	9	60	33	3.2	9.1	0.36
	06-Feb-08		21	4	16	12	93	38	4.2	8.6	0.31
	27-Feb-08		31	5	20	20	69	38	2.6	8.4	0.34
		Seasonal sum (kg/ha)	105	15	58	53	317	142			
	05-Oct-07	Stubble management experiment "Federation Farm", Narrabri[1]	114	20	12	8	327	97	18.0	8.9	0.90
	04-Jan-08		135	9	15	7	364	52	19.7	9.1	0.93
	15-Jan-08		63	5	7	2	280	20	23.4	9.1	0.64
	31-Jan-08		89	17	15	8	236	27	11.9	8.6	0.80
	22-Feb-08		111	15	12	6	284	46	17.0	9.1	0.86
	10-Mar-08		119	20	14	9	292	47	15.1	8.9	1.24
	20-Mar-08		121	20	25	14	300	40	12.0	9.3	1.30
		Seasonal sum (kg/ha)	751	107	99	54	2082	329			

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[1] Replicate 1 was not irrigated on 5 October 2007, and 15 January and 20 March 2008 due to rainfall during irrigation

Table 23. Nutrient and salt movement out of the 120 cm depth (kg/ha) in Field C1 and D1, ACRI, Narrabri during the cotton growing seasons of 2005-06, 2006-07 and 2007-08. Results were analysed after (100+$\log_e$) transformation.

Site	Cropping system	Season	NO_3-N	Cl	Ca	Mg	K	Na
Tillage/rotation experiment, Field C1, ACRI, Narrabri	Conventional tillage/Continuous cotton	2006-07	2	36	11	7	1	39
	Minimum tillage/Continuous cotton		4	50	34	14	2	54
	Minimum tillage/Cotton-wheat (standing stubble)		17	298	115	76	29	383
		P <	0.01	0.05	0.05	0.01	ns	0.01
Cotton/vetch/wheat rotation experiment, Field D1, ACRI, Narrabri	Cotton-vetch	2005-06	77	154	19	16	3	142
	Cotton-winter fallow		15	90	11	12	2	85
	Cotton-wheat (stubble incorporated)		19	144	10	13	2	137
	Cotton-wheat (standing stubble)-vetch		16	38	8	4	1	30
	All treatments	P <	0.05	ns	ns	ns	ns	ns
	Cotton-vetch	2006-07	20	293	47	80	6	428
	Cotton-winter fallow		5	110	9	17	2	155
	Cotton-wheat (stubble incorporated)		4	147	20	18	2	154
	Cotton-wheat (standing stubble)-vetch		9	279	15	31	3	385
	All treatments	P <	0.05	ns	ns	ns	ns	ns
	Cotton-vetch	2007-08	38	54	1	6	5	66
	Cotton-winter fallow		7	17	0	3	2	27
	Cotton-wheat (stubble incorporated)		4	34	1	7	8	28
	Cotton-wheat (standing stubble)-vetch		15	46	1	10	6	50
		P <	ns	ns	ns	ns	ns	ns

Table 24. Values[1] ($/ha) of nutrients and salts leached out of the 120 cm depth in field C1 and D1, ACRI, Narrabri during the cotton growing seasons of 2005-06 to 2007-08. Fertiliser and gypsum prices are those of 3 April 2008.

Site	Cropping system	Season	NO_3-N	Ca	Mg	K	Na	Cl[2]	Net benefit
Tillage/rotation experiment, Field C1, ACRI, Narrabri	Conventional tillage/Continuous cotton	2006-07	2.58	2.49	3.92	1.40	6.95	11.21	15.59
	Minimum tillage/Continuous cotton		5.16	12.11	4.99	2.81	9.62	15.56	10.09
	Minimum tillage/Cotton-wheat (standing stubble)		21.93	40.97	27.07	40.72	68.22	92.75	84.43
Cotton/vetch/wheat rotation experiment, Field D1, ACRI, Narrabri	Cotton-vetch	2005-06	99.35	6.77	5.70	4.21	25.29	31.96	-47.38
	Cotton-winter fallow		19.35	3.92	4.27	2.81	15.14	18.68	12.01
	Cotton-wheat (stubble incorporated)		24.51	3.56	4.63	2.81	24.40	29.88	28.03
	Cotton-wheat (standing stubble)-vetch		20.64	2.85	1.42	1.40	5.34	7.89	-10.24
	Cotton-vetch	2006-07	25.80	16.74	28.50	8.42	76.23	91.20	144.95
	Cotton-winter fallow		6.45	3.21	6.06	2.81	27.61	34.24	55.44
	Cotton-wheat (stubble incorporated)		5.16	7.12	6.41	2.81	27.43	45.75	64.50
	Cotton-wheat (standing stubble)-vetch		11.61	5.34	11.04	4.21	68.57	86.84	145.29
	Cotton-vetch	2007-08	48.48	0.24	2.07	7.05	11.84	16.93	-24.93
	Cotton-winter fallow		8.64	0.08	0.99	2.57	4.84	5.17	-0.29
	Cotton-wheat (stubble incorporated)		5.04	0.23	2.46	11.02	5.07	10.65	1.87
	Cotton-wheat (standing stubble)-vetch		19.86	0.29	3.59	8.01	8.91	14.29	-1.36

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[1] Anhydrous ammonia = $1058/t; Gypsum = $75/t, spreading costs = $20/t; muriate of potash = $735/t.

[2] Non-Bollgard II-RR cotton: removal of 1 t/ha of chloride is equivalent to a yield increase of 0.5 bales/ha of lint; Bollgard II-RR cotton: removal of 1 t/ha of chloride is equivalent to a yield increase of 0.75 bales/ha of lint; 1 bale of cotton was $415 on 1 April 2008.

6. Conclusions

- Sowing cotton into standing wheat rotation crop stubble facilitated drainage and leaching of salts, and water conservation through rainfall harvesting. Leaching of nutrients such as nitrates was also higher. Due to drought, wheat growth was poor, and consequently carbon sequestration did not differ significantly from control treatments. Under restricted water availability and on a whole-farm basis minimum-tilled cotton-wheat was more profitable than continuous cotton, whereas with unlimited water or on an individual field basis the reverse was true. Frequent irrigation (7-10 day interval) improved cotton lint yield and fibre quality, and profitability (measured as gross margins). In comparison with infrequent irrigation (10-14 day interval), frequent irrigation (7-10 day interval) doubled cotton lint yield and profitability (measured as gross margins), and improved fibre quality. Growers would, therefore, be better off reducing the area of cotton sown and giving it sufficient water rather than reducing irrigation frequency over a larger area. Within soil layers in the cotton root zone, drainage with frequent irrigation was greater than that with infrequent irrigation. Drainage out of the crop root zone was, however, similar under both irrigation frequencies and may be related to differing drainage pathways.
- Vetch in a cotton-wheat-vetch sequence responded positively in terms of growth and N fixation to phosphate fertiliser (single superphosphate) whereas vetch in a cotton-vetch sequence did not. N fixation by vetch in the former rotation was also higher due to a longer growth period (sown in Late-February vs. later May) and wetter soil profile at sowing (sown into fallow vs. sowing immediately after cotton). Wheat grain yield and quality was improved by including vetch in the rotation (i.e. cotton-wheat-vetch) relative to cotton-wheat rotations. Cotton yield was highest when a wheat crop was included in the rotation. However, in comparison with cotton-wheat where stubble was incorporated, the cotton-wheat (standing stubble)-vetch sequence required less N fertiliser (due to N fixation by the vetch) and irrigation water (due to better subsoil water storage and presumably, reduction of evaporation by the *in situ* mulch). Average annual gross margins/ha (i.e. on an individual field basis) or when unlimited water was available were in the order of cotton-winter fallow-cotton > cotton-vetch-cotton > cotton-wheat-vetch > cotton-wheat whereas gross margins/ML of irrigation water was in the order of cotton-wheat > cotton-wheat-vetch > cotton-winter fallow-cotton > cotton-vetch-cotton. Under restricted water availability and on a whole-farm basis profitability was in the order of cotton-wheat-vetch > cotton-wheat > cotton-winter fallow-cotton > cotton-vetch-cotton, , although differences between the latter two rotations were small (~$4). Adding vetch to a cotton-wheat rotation appears marginally more profitable but adding vetch to a continuous cotton rotation is marginally less profitable.
- The amount of C added to soil C stocks by the roots of Bollgard II-Roundup Ready Flex varieties was less than that added by non-Bollgard II varieties. Above-ground stress such as insect pressure also reduced cotton root growth and C addition to soil, whereas minimum tillage and wheat rotation crops increased them. In comparison with above-ground dry matter, however, contribution by cotton root material to soil C stocks is small.
- Sowing corn in rotation with cotton increased concentrations of the light carbon fraction but not total soil carbon. A close relationship was present between the light carbon fraction and microbial activity. Microbial activity and hence, nutrient cycling may be improved by including corn as rotation crop. Including vetch in a cotton-corn rotation increased SOC and exchangeable K, and decreased exchangeable Na concentrations.
- Furrow soil in continuous cotton systems sown with minimum tillage had lower pH and higher SOC than that under conventional tillage. In comparison with non-wheel-tracked furrows, $EC_{1:5}$ and geometric mean diameter of aggregates were higher in wheel-tracked furrows, and plastic limit lower. Differences were small between conventionally-tilled and

minimum-tilled furrows, and between wheel-tracked and non-wheel-tracked furrows. Large inter- and small intra-seasonal changes also occurred with respect to soil physical and chemical properties in furrows. Interactions between surface soil physical and chemical factors in furrows may not, therefore, play a major role in influencing water application efficiency and infiltration within a season. Inter-seasonal differences could, however, affect hydrological processes.

- In a K-deficient dryland Vertosol with high subsoil salinity and sodicity, only application of cattle manure (16 t FW/ha) resulted in a sustained improvement in soil quality. This was characterised by an increase in exchangeable K and SOC in the surface 10 cm, and a decrease in exchangeable Na in the subsoil. Application of gypsum and/or inorganic fertilisers had no effect on soil quality. Crop yield and quality were unaffected by any of the treatments. More frequent application of manure may, therefore, be required to cause significant yield increases.

7. Suggested areas of future research

- Three and four crop rotation systems for irrigated cotton production. Some possible combinations are: cotton-cereal-legume, cotton-cereal-legume-cereal and cotton-oilseed-cereal-legume.
- Incorporation of high value crops into irrigated cotton-based cropping systems. Examples of high value crops are selected vegetable crops and “energy” crops for biofuel production.
- Comparative soil quality effects of managing rotation crop stubble. Some examples are: high and low-temperature stubble burning, shallow and deep incorporation and *in-situ* mulching of cereal, legume and oilseed rotation crop stubble. Information is also lacking on the interactions which may occur between irrigation systems such a sprinkler, furrow and drip with the abovementioned stubble management systems, and their consequences on soil quality.
- Identify wheat and other rotation crop varieties which are able to rapidly extend their root systems into the subsoil of Vertosols with constraints such as poor structure, salinity and sodicity. An example of this is the experimental wheat variety “Vigour 18” which is reported to be able to extend its roots into poorly-structured subsoils at a faster rate than conventional wheat varieties (Watt *et al*., 2005[1]). This would enable the rotation crops to recover nutrients leached below the root zone of the cotton crop.
- 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.
- Managing the higher drainage rates under cotton sown into standing wheat stubble in conjunction with soil ameliorants such as gypsum and mineral rock dusts to rapidly ameliorate subsoil sodicity. An experiment was established during this project but due to poor establishment of the wheat, the results were inconclusive.
- Identify drainage and leaching losses under irrigated cereal crops with high fertiliser rates. Given the interest in these management systems and the commencement of a project which is studying the agronomy of high input irrigated cereals sown in rotation with cotton, quantifying nutrient and water losses in drainage is important in the context of managing scarce water and expensive nutrient supplies, and maintaining groundwater quality.

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[1] Watt, M., Kirkegaard, J., and Rebtzke, R. 2005. A wheat genotype developed for rapid leaf growth copes well with the physical and biological constraints of unploughed soil. *Func. Plant Biol*. **32**, 695–706

- Identify amounts and quality of C added to soil by different rotation crops and types of rotation crops (e.g. C3 vs. C4 crops) and the associated greenhouse gas emissions.
- Nutrient requirements of vetch under different rotation systems.
- 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 and greenhouse gas emissions, detailed economic analyses and their potential for use as biochar.
- A cotton grower-driven on-farm research program focussing on the costs and benefits involved in the adaptation of the cotton-wheat-vetch crop sequence with *in-situ* stubble retention. Issues which will require study include economic costs, machinery modifications, and traffic, water and fertiliser management.
- In many alkaline soils a significant proportion of atmospheric carbon sequestered is not in an organic form, but in an inorganic form (i.e. as Ca and Mg carbonates). It is possible that this can be modified through irrigation, particularly through irrigation with treated sewage effluent or alkaline irrigation water, and a study to investigate this is suggested.
- Effects of sowing rotation crops after cotton on farm and cotton industry economic indicators such as the economic incentives for adopting new cotton rotations, and farm level and industry- and community/catchment wide economic modelling of the impact of research and extension activities.

8. Suggested/planned extension activities

- A high rate of turnover of cotton industry extension staff results in a “bleeding” of expertise with respect to soils capability. 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. Support and funding would, however, be required from the CRDC.
- Presentations to industry groups at workshops. Some examples are the “hands-on workshops” at the ACGRA cotton conference, accreditation and annual meetings of the Australian Cotton Consultants, CRDC’s farming systems forum and local grower groups organised by cotton industry development officers or consultants.
- Field tours and farm walks
- Being part of the extension network’s soils and farming systems focus team and providing technical support to the Cotton IDO’s 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 the Australian Cotton CRC and 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.

9. New methods and techniques

- Methodology for particle size analysis was modified such that saline water (EC_w = 1.2-1.4 dS/m) could be used. A relationship was developed between hydrometer readings made in saline and non-saline water.
- 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 “Sprayseed”) 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 “Sprayseed” applied (see pp. 43-45 of this report). Further modifications to this implement are on-going.

10. Problems encountered

- Wheat sown at “Windmill Farm” failed to establish during 2005-06 due to waterlogging and again in 2007-08 due to drought. While the effects of applying gypsum were evident with respect to exchangeable Ca and drainage, the interactive effects of the standing stubble and gypsum could not be clarified.
- Inaccurate results of exchangeable cations from the NSW DPI analytical laboratory at Wollongbar was a major problem during 2005-06. Subsequently the samples were sent to the State Chemistry Laboratory in Victoria for analyses. Unfortunately this sequence of events was a carbon copy of that which occurred during 2002.
- Control of volunteers and regrowth “Roundup Ready” cotton remains a major problem. Except for “Buctril” (Bromoxynil), most herbicides suggested by the weed scientists were ineffective. Suitable minimum tillage implements (centre-busting tines) were also not readily available at ACRI. Consequently weed control costs remain high.

11. Outcomes

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

- Identified the cropping sequence of cotton-wheat-vetch with *in-situ* stubble mulching as one which can reduce cotton’s N fertiliser and irrigation water requirements while maintaining yields, thus improving WUE, fertiliser use efficiency and profitability. Similar benefits also occur with respect to wheat grain yield and quality.
- Identified the practice of irrigating with treated sewage effluent as having some risk with respect to soil health; *viz.* increases in salinity, sodicity, pH and accumulation and leaching of nitrates[1] relative to untreated soil. The leaching of nitrates can also potentially degrade groundwater quality.
- Confirmed that management systems which include *in situ* mulch can reduce salinity and sodicity by facilitating infiltration and leaching.
- Under conditions of restricted water availability whole farm profitability can be improved by increasing complexity of cropping systems (i.e. sowing rotation crops).
- Identified management practices (minimum tillage, vetch rotation crops, manure) which could sequester more soil carbon than conventional practices.
- Nutrient cycling may be facilitated by including corn in the rotation.
- Identified manure as a soil amendment which could alleviate K deficiency.

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[1] Results of pH and nitrates were not presented in this report. They were presented in the 2006 mid-year report to the Cotton CRC.

- Developed machinery attachments for managing crops and soil in furrow-irrigated Vertosols with *in situ* mulch.

12. 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 1.04.13

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
J. Terry	B.Agr.Sci. (Hons.)	University of Sydney, Sydney, NSW	2006-07	Cotton yield and soil carbon under continuous cotton, cotton-corn and cotton-wheat rotations
A. Deveraux	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 three work experience students. They were:

- Joseph Radford, The Armidale School, Armidale (July 2005)
- Kalinga Hulugalle, Narrabri High School, Narrabri (December 2006)
- Rebecca Grey, Wee Waa High School (May and June 2006). Rebecca’s work experience program was part of her HSC syllabus which required her to gain experience in a working laboratory and knowledge of the methodology used in that laboratory. Her placement was requested by Mrs. Sharon Grellman, head science teacher at Wee Waa High School.

13. 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 2005 to 30 June 2008, including those “in press”) are given below. The hyperlinks for those items which have been published on-line are also provided.

13.1 Technical journals

1. **Hulugalle, N.R., Weaver, T.B., Ghadiri, H., and Hicks, A.** (2006). Changes in soil properties of an eastern Australian Vertisol irrigated with treated sewage effluent due to gypsum application. *Land Degrad. Develop*., 17, 527-540.
2. **Hulugalle, N.R., Weaver, T.B., and Finlay, L.A.** (2006). Residual effects of cotton-based crop rotations on soil properties of irrigated Vertosols in central-western and north-western New South Wales. *Aust. J. Soil Res*., 44, 467-477.
3. **Tennakoon, S.B., and Hulugalle, N.R.** (2006). Impact of crop rotation and minimum tillage on water use efficiency of irrigated cotton in a Vertisol. *Irrig. Sci*., 25, 45-52.
4. **Hulugalle, N.R., Weaver, T.B., Finlay, L.A., Hare, J., and Entwistle, P.C.** (2007). Soil properties and crop yields in a dryland Vertisol sown with cotton-based crop rotations. *Soil Till. Res*., 93, 356-369.
5. **Hulugalle, N.R., McCorkell, B.E., Weaver, T.B., Finlay, L.A., and Gleeson, J.** (2007). Soil properties in furrows of an irrigated Vertisol sown with continuous cotton (*Gossypium hirsutum* L.) *Soil Till. Res*., 97, 162-171.

6. **Hulugalle, N.R., and Scott, F.** (2008). A review of the changes in soil quality and profitability accomplished by sowing rotation crops after cotton in Australian Vertosols from 1970 to 2006. *Aust. J. Soil Res*., 42, 173-190.

13.2 Conference & workshop papers

1. **Luelf, N., Tan, D., Hulugalle, N., Knox, O., Weaver, T., Field, D.** (2006). Root turnover and microbial activity in cotton farming systems. In "Ground-breaking stuff", Proc. 13th Australian Agronomy Conference, 10-14 September, Perth, WA, (Eds. Turner N.C., Acuna T. and Johnson, R.C.). Australian Society of Agronomy, Perth, WA. [CD-ROM]
2. **Hulugalle, N., and Scott, F.** (2006). Rotations - maintaining our soil quality and profitability. Proc. 13th Australian Cotton Conference, 8-10 August 2006, Broadbeach, Qld., Australia. (Australian Cotton Grower's Research Association, Orange, NSW, Australia). [CD-ROM].
3. **Hulugalle, N.R., and Scott, F.** (2006). Rotation crops for cotton sown on permanent beds in irrigated Vertisols. Proc. 17th Triennial Conference of the International Soil Tillage Research Organisation, 28 August- 3 September 2006, Kiel, Germany, pp. 687-691 (ISTRO, Kiel, Germany). [CD-ROM].
4. **Hulugalle, N.R., McCorkell, B.E., and Hickman, M.** (2006). Changes in soil salinity, sodicity and organic carbon due to sowing irrigated cotton into standing or incorporated wheat stubble in a saline/sodic Vertosol. Proc. Joint Conference of Australian Society of Soil Science Inc., and Australian Soil and Plant Analysis Council, 3-7 December 2006, Adelaide, SA, Australia, p. 31. (ASSSI, Adelaide, Australia).
5. **Hulugalle, N.** (2007). Sowing rotation crops in cotton farming systems. Proc. Healthy Soils Regional Forum, 7, 8 and 13 November 2007, Narrabri, Goondiwindi and Hillston", pp. 43-46, (ed. H. Squires). (Cotton Catchment Communities CRC, Narrabri, NSW).

13.3 Cotton industry magazines and extension publications[1]

1. **Hulugalle, N., Tann, C., Weaver, T., and Fitt, G.** (2006). Permanent beds, soil disturbance and heliothis moth emergence. Aust. Cottongrower, 27(4), 49-51.
2. **Hulugalle, N., and Scott, F.** (2006). Relative profitability of irrigated cotton rotation systems in NSW. Aust. Cottongrower, 27(5), 57-59.
3. **Scott, F., and Hulugalle, N.R.** (2007). Rotations and permanent beds to fight the cotton cost-price squeeze. Aust. Cottongrower, 28(2), 41-45.
4. **CSD (Cotton Seed Distributors) Extension and Development Team, and Hulugalle, N.** (2006). Delving deeper into the high yielding crops. Aust. Cottongrower, 27(5), 16-22.
5. **Hulugalle, N.R., Weaver, T., Tann, C., and Fitt, G**. (2006). Permanent beds, soil disturbance and heliothis moth emergence. In "Lower Namoi 2006 Field Day Book", pp. 59-60, (Eds. T. Farrell and A. Dunlop). (NSW DPI/CRDC/Cotton Catchment Communities CRC, Narrabri, NSW).
6. **Maas, S., and Chapman, V.** (2005). AG15 update. A natural resource management newsletter for irrigated cotton and grains growers. Issue 3, September 2005, 2 pp.
7. **Squires, H.** (2007). Bore water quality and rotations in sustainable farming systems: A 'Beechworth' Merah North case study. http://www.cottoncrc.org.au/files/cac94804-a820-46f5-8d19-998200ba58e8/Healthy%20Soils-Sustainable%20Farming.pdf.

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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.

8. **Squires, H.** (2007). Crop rotations in a dryland cotton farming system: A Warra, Darling Downs, case study. http://www.cottoncrc.org.au/files/aaeac27b-239f-427c-836a-998200b82d38/Healthy%20Soils-Dryland.pdf.
9. **Karlen, D.L** (2006). ISTRO-Info, October 2006 issue, p. 6. Quarterly newsletter of the International Soil Tillage Research Organisation.
10. **Spotlight** (2008). New rotation: New system. Spotlight on Cotton R & D, Autumn/March 2008, P. 5.
11. **Maas, S., and Pendegast, L.** (2008). Can soil organic carbon content be increased by sowing rotation crops? Cotton Tales (Central Queensland) 2007-08, no. 21.
12. **Ceeney, S.** (2008). Can soil organic carbon content be increased by sowing rotation crops? ;Trial Opportunity - Are you interested in investigating the rates of carbon sequestration under different cotton farming systems on your farm? Cotton Tales (Macquarie Valley) 2007-08, no. 19.

13.4 Presentations

Presentations by N. Hulugalle

1. Field presentation on rotation experiments and ACRI to participants in training course organised by FarmOz Pty Ltd, 9 August 2005
2. Presentation to Elders Agronomists on research currently being conducted on rotations, 2 September 2005.
3. Field presentation to ACRI Farm staff on current soil management research program, 27 October 2005.
4. Presentation entitled: “Comparing cotton-wheat and cotton-vetch rotations: A new long-term experiment” at Australian Cotton CRC’s Final conference, 7-9 August 2005.
5. Field presentation to National Water Initiatives staff on tillage and rotation systems research at ACRI, 9 November 2005.
6. Field presentation on tillage and rotation systems research at ACRI to Israeli scientists, Igal Flash and Gad Forer, 9 March 2006.
7. Field presentation on tillage and rotation systems research at ACRI to Professor David Coleman of the University of Georgia, USA, 14 March 2006.
8. Field presentation on tillage and rotation systems research at ACRI to Cotton CRC Board of Directors, 20 March 2006.
9. Field presentation on tillage and rotation systems research at ACRI to Cotton Consultants Association of Australia members on 16 May 2006.
10. Oral paper entitled “Rotations - maintaining our soil quality and profitability” presented at ACGRA Cotton Conference, Brisbane, Qld., 10 August 2006.
11. Oral paper entitled “Rotation crops for cotton sown on permanent beds in irrigated Vertisols” presented at 17th Triennial Conference of International Soil Tillage Research Organisation, Kiel, Germany, 1 September 2006.
12. Field presentation on tillage and rotation systems research at ACRI to a delegation of politicians, administrators and researchers from Tajikistan on 17 November 2006
13. Oral Poster paper entitled “Changes in soil salinity, sodicity and organic carbon due to sowing irrigated cotton into standing or incorporated wheat stubble in a saline/sodic Vertosol” presented at Australian Soil Science Society Conference, Adelaide, SA, 4 December 2006.

14. Field presentation on tillage and rotation systems research at ACRI to Turkish agronomists and farmers 28 February and 2 March 2007.
15. Field presentation on tillage and rotation systems research at ACRI to Graham Thompson of Cotton South Africa, 13 March 2007.
16. Oral paper entitled "Sowing rotation crops in cotton farming systems" presented at Healthy Soils Regional Forum, Narrabri, NSW, (7 November 2007) and Goondiwindi, Qld. (8 November 2007).
17. Field presentation on tillage and rotation systems research at ACRI to Greg Hamilton of WA Department of Agriculture, South Perth, WA, on 13 November 2007.

Presentations by T. B. Weaver

1. Presentation entitled: "Movement of Organochloride Pesticides in Vertisols" at Australian Cotton CRC's Final conference, 7-9 August 2005.

Presentations by L. Finlay

1. Presentation on working as a technical support staff at ACRI to Regional High School students during visit on 14 March 2008.

Presentations by co-operating researchers

1. Presentation entitled "Root turnover and microbial biomass in cotton farming systems" by Dr. Daniel Tan of the University of Sydney at the 13th Australian Agronomy Conference held in Perth, 10-14 September 2006.
2. Presentation by Mr. James Terry entitled "Cotton yield and soil carbon under continuous cotton, cotton-corn and cotton-wheat rotation" at the University of Sydney, October 2007.
3. Presentation by Miss A. Devereux entitled "Quantifying the effects of maize rotation on cotton - Yield data" at Australian Cotton CRC's Final conference, 7-9 August 2005.
4. Presentation by Miss A. Devereux entitled "Effects of corn rotation on cotton - Yield data" at Moree Cotton Trade Show, 30-31 May 2007.
5. Internal seminar given by Miss A. Devereux on 4 May 2007 at the University of Queensland, St. Lucia, Qld.

13.5 Final Reports

1. **Terry, J. (2007)**. "Final report to Cotton Catchment Communities Co-operative Research Centre on Summer Student Scholarship 2006-07 (Cotton yield and soil carbon under continuous cotton, cotton-corn and cotton-wheat rotations)", 10 pp.

13.6 Theses

1. **Terry, J. (2007)**. Cotton yield and soil carbon under continuous cotton, cotton-corn, cotton-vetch-corn and cotton-wheat rotations, 104 pp. B. Sc. (Agric.) Thesis, University of Sydney, Sydney, NSW.

13.7 Popular media

1. Crosse, A. (2006). Hidden benefits of sowing cotton into stubble. A media release by NSW DPI, January 2006. As a consequence of this media release, Dr. Hulugalle was interviewed and his comments reported by several radio stations (2TM, ABC, Southern Cross Netwrok News, 2WEB, 2 VM), regional newspapers (Northern Daily Leader, Narrabri Courier, Queensland Country Life), and Blogs.
2. Article entitled "Benefits of sowing cotton into stubble" published in the February 2006 issue of "Agriculture Today".

3. Dr. Hulugalle was interviewed by Prime TV on new soils laboratory and future activities, 23 June 2006.
4. Media releases by Cotton CRC on entitled "Wheat confirmed as best cotton rotation crop", 13 November 2006. As a consequence of this, Dr. Hulugalle was interviewed by 2VM, a Moree radio station, and "Australian Grain". Print articles also appeared in NSW and Queensland regional newspapers.
5. Dr. Hulugalle was interviewed by NBN TV on current and future soil management research activities, 14 February 2007. The interview was broadcast on the evening news bulletin of 20 February 2007.
6. Media release by Cotton CRC on profitability of rotation systems, 1 March 2007. As a consequence of this, Dr. Hulugalle was interviewed by 2VM, and print articles also appeared in NSW and Queensland regional newspapers.

14. Acknowledgements

The technical assistance of Mr. L. Finlay is gratefully appreciated. D. Turner, W. Bidstrup, G. Coulton, H. Gaynor, J. Ramsay and their staff are thanked for provision of land to conduct the trials, management expertise and continuing support and interest. Mr. B. McCorkell is thanked for biometrical support. Messrs A. Meppem (Manager, ACRI) and D. Magann (Farm Supervisor, ACRI) for support with respect to on-station experiments, and laboratory and office facilities.

15. 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.

16. Appendix 1: Budget

Item	**2005-06**	**2006-07**	**2997-08**
	($)		
A. STAFFING			
Total Salaries	63,792	66,344	68,997
Other (leave loading/Rec. leave)	3,866	4,021	4,182
Payroll tax	4,465	4,644	4,830
Workers Compensation	1,734	1,803	1,875
Superannuation	5,741	5,971	6,210
TOTAL	**79,598**	**82,783**	**86,094**
B. TRAVEL			
Sustenance	4,500	5,500	5000
TOTAL			**5000**
Soil analyses	17,500	17,000	15,600
Laboratory/office maintenance	6,000	8,000	2,741
Field sampling (inc. Vehicle costs)	9,430	10.810	10,275
Maintenance of field equipment	3,000	6,000	0
Research levy	2,017	2,355	8,079
Economic analyses	3,500	3,500	3,325
Computer & software leasing, licences, freight	6,100	6,500	3,100
Farm operations	3,500	4,000	27,768
ACGRA Cotton Conference registration	0	500	
TOTAL	**51,047**	**58,665**	**70,888**
D. CAPITAL	0	0	0
GRAND TOTAL	**135,145**	**146,948**	**161,982**

TOTAL FUNDS (2005-2008): $444,075