Part 1 - Summary Details

CRDC Project Number: CRC45 CCC CRC Project Number: 3.1.29AC

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

Project Commencement Date: July 2002 **Project Completion Date:** June 2005

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Part 3 – Final Report Guide

Background

Vertosols (Vertisols, Usterts) are the most common cotton growing soils in eastern Australia. 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. They have a clayey soil texture and form soil cracks which close when wetting occurs due to swelling of the soil. 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 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 soil quality cotton-based farming systems. As a consequence, 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. 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.

More recently, research from central Queensland has suggested a modification to the cotton/wheat rotation system, whereby the wheat 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. While sowing cotton into standing wheat stubble appears to have 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. Preliminary experiments in a limited number of sites during the 2000-01 cotton season suggested that deep drainage understanding 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 Australian Cotton CRC (and its predecessor the CRC for Sustainable Cotton Production) 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 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 (NO3, 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. The "best" rotation crop sequence for dryland systems were also not identified, although this is related more to the longer time period required rather than to lack of experimentation *per se*. This report focuses on results obtained over the period 2002-2005 from eight experiments (seven irrigated, one dryland) in New South Wales and Queensland on rotation crop management. Where long-term trends are discussed, data collected since 1996 are also included.

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.

Results

<u>1. Salt stress in cotton</u>

Previously it was thought that cotton was highly tolerant to high levels of salinity. It appears, however, that during the seedling stage cotton is quite sensitive. The adjacent figure, based on data collected from 9 fields on 5 farms over the past 3 years indicates the expected yield losses as soil chloride content at sowing increases. The curve suggests that yield losses of the order of 50% would occur when soil chloride levels in the 0-60 cm depth <u>at sowing</u> are of the order of 5.6 t/ha. The corresponding EC_e for this data set is 1.4 dS/m. This figure is very much lower than the 7.7 dS/m which is used in many models of salinity risk for cotton. Occurrence of similar values later in the season does not have any effect on cotton yields. These finding also suggest that cotton in many fields which are currently classified as low

salinity risk may in fact be prone to salt-mediated yield losses. At the same time cotton growers may be underestimating the potential risk involved in growing cotton in these fields without allowing for an adequate leaching fraction (~20%).

Drainage conditions

Drainage under frequently irrigated crops such as cotton and sorghum approached or reached steady state conditions, whereas partially-irrigated or dryland crops such as wheat were best described by assuming transient state conditions. Transient state conditions dominate when high numbers of soil cracks occur to depth. As many users of the chloride mass balance model evaluate deep drainage assuming steady state conditions, these analyses suggest that their estimates of deep drainage in partially-irrigated systems may be an underestimation. However, there were some exceptions, to this general rule. In fields where prior streams exist drainage is best described using transient state assumptions.

Managing retained rotation crop stubble in irrigated cotton systems

a) *Cotton-wheat rotations:*
   Sowing cotton into standing wheat (Fig. 1) or vetch stubble retained on beds and in furrows can reduce erosion and runoff, increase water infiltration, reduce off-field movement of pesticide residues and nutrients, and reduce heliothis moth infestation in young cotton. Disadvantages of standing stubble include blocking of "gas knives" by wheat stubble during injection of anhydrous ammonia as fertiliser, waterlogging during irrigation and inability to incorporate residual herbicides.

   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 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. This management practice was developed during the previous phase of this project (see final report for CRC project 12C) and tested during the 2002-03 to 2004-05 cotton seasons.

   Waterlogging during irrigation events can be avoided by retaining the stubble in the furrows only until the start of the irrigation season. (This is done because the stubble facilitates rainfall harvesting during winter and early spring). 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 attached onto clay particles are deposited in the furrow and do not move off field with runoff.

b) *Cotton-vetch rotations:*
   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 2 applications of spray seed at a rate of 3 L/ha. This process results in a layer of dry, vetch mulch into which cotton seeds can be sown (Fig. 2)

Publications

Journal Articles:

1. Hulugalle, N. R. (2005). Recovering leached N by sowing wheat after irrigated cotton in a Vertisol. J. Sust. Agric. 27, In Press.
2. 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. Sust. Agric. 28, In Press.
3. Hulugalle, N.R., and Weaver, T.B. (2005). Short-term variations in chemical properties of Vertisols as affected by amount, C/N ratio, and nutrient concentration of crop residues. Comm. Soil Sci. Plant Anal. 36, In press.
4. Weaver, T.B., Hulugalle, N.R., and Ghadiri, H. (2005). Comparing deep drainage estimated with transient and steady state assumptions in irrigated Vertisols. Irrigation Sci., In Press.

Conference papers:

1. Weaver, T.B., Hulugalle, N.R., and Ghadiri, H. (2004). Comparing deep drainage estimated with transient and steady state models in irrigated Vertisols. In "Hydrology: Science and Practice for the 21st Century, Vol. II", Proc. British Hydrological Society International Conference, 12-16 July 2004, London, UK, Eds. B. Webb, M. Acreman, C. Maksimovic, H. Smithers and C. Kirby, pp. 168-176. (British Hydrological Society, London, UK).
2. Hulugalle, N.R., Weaver, T.B., Ghadiri, H. and Hicks, A. (2004). Effect of irrigating cotton with treated sewage effluent on soil properties and deep drainage in a Vertisol. In "Conserving Soil and Water for Society: Sharing Solutions", Proc. 13th International Soil Conservation Organisation Conference, 4-9th July, Brisbane, Qld., Australia, Eds. S.R. Raine, A.J.W. Biggs, N.W. Menzies, D.M. Freebairn and P.E. Tolmie, Paper 718, 4 pp. (ASSSI, Warragul, Vic. and IECA, NSW, Australia). [CD-ROM]
3. Weaver, T.B., Hulugalle, N.R., and Ghadiri, H. (2004). Salt, nutrient and pesticide leaching under a sodic Vertisol irrigated with groundwater in north-west New South Wales. In "Conserving Soil and Water for Society: Sharing Solutions", Proc. 13th International Soil Conservation Organisation Conference, 4-9th July, Brisbane, Qld., Australia, Eds. S.R. Raine, A.J.W. Biggs, N.W. Menzies, D.M. Freebairn and P.E. Tolmie, Paper 726, 4 pp. (ASSSI, Warragul, Vic. and IECA, NSW, Australia). [CD-ROM]
4. Weaver, T., Hulugalle, N., and Ghadiri, H. (2004). Deep Drainage under irrigated cotton farming systems in New South Wales estimated with the chloride mass balance method. Proc. 12th Australian Cotton Conference, 10-12 August 2004, Brisbane, Qld., Australia. (Australian Cotton Grower's Research Association, Orange, NSW, Australia). [CD-ROM].
5. Hulugalle, N., Weaver, T., Ghadiri, H., and Hicks, A. (2004). Does irrigation with treated sewage effluent affect soil quality in a grey clay? Proc. 12th Australian Cotton Conference, 10-12 August 2004, Brisbane, Qld., Australia. (Australian Cotton Grower's Research Association, Orange, NSW, Australia). [CD-ROM].
6. Grace, P.R., Rochester, I.., Hulugalle, N., Weier, K., Kiese, R., Butterbach-Bahl, K., Chen, D., and Eckard, R.J. (2004) Full greenhouse gas profiling from irrigated soils in the cotton growing region of Australia. Proc. 2nd Joint Australia and New Zealand Forum on Non-CO_2 Greenhouse Gas Emissions from Agriculture, 20-21 October 2003, Melbourne, Vic., Eds. R. Eckard and W. Slattery, pp. C9. (CRC for Greenhouse Accounting, Canberra).

7. Hulugalle, N.R., and Daniells, I.G. (2005). Permanent beds in Australian cotton production systems. Proc. ACIAR Workshop on Permanent Beds, 1-3 March 2005, Griffith, NSW. (ACIAR, Canberra, Australia). [CD-ROM].

Book Chapters

1. Hulugalle, N.R. (2004). Using poor quality water to irrigate cotton. In "WaterPak –A Guide for Irrigation Management", Eds. H. Dugdale, G. Harris, J. Neilsen, D. Richards, G. Roth and D. Williams, pp. 251-257. (CRDC, Narrabri, NSW, Australia).

Conferences Presentations:

1. Dr. Hulugalle made an oral presentation entitled "Comparing deep drainage estimated with transient and steady state models in irrigated Vertisols" at the International Conference of the British Hydrological Society in held in London from 12-16 July 2004.
2. Mr. Weaver presented 2 poster papers entitled "Effect of irrigating cotton with treated sewage effluent on soil properties and deep drainage in a Vertisol" and "Salt, nutrient and pesticide leaching under a sodic Vertisol irrigated with groundwater in north-west New South Wales" at the 13th Conference of the International Soil Conservation Organisation held in Brisbane from 4th to 9th July.
3. Dr. Hulugalle presented a poster entitled "Effect of irrigating cotton with treated sewage effluent on soil properties of a grey cracking clay" at the Australian Cotton Conference held in Brisbane from 10-12 August 2004.
4. Dr. Hulugalle and Mr. Weaver made presentations at the ACRI Cotton Program's internal review in November 2004.

Seminars, Workshops & Trade Shows:

1. Dr. Hulugalle was team leader for the soil management "hands-on-workshop" held during the Australian Cotton Conference in Brisbane, August 10-12 2004.
2. Dr. Hulugalle presented a paper entitled "Permanent beds in Australian cotton production systems" at the workshop on permanent beds organised by the Australian Centre for International Agriculture Research in Griffith, 1-3 March 2005.
3. Ms. Scott made an oral presentation entitled "Economics: Fertilising cereal and legume crops" and Dr. Hulugalle a field presentation on rotations and stubble management during the CRDC Farming Systems Forum, at Narrabri, 3-4 December 2004. Both presentations were collated in the workshop proceedings.
4. Dr. Hulugalle made a field presentation entitled "Managing irrigated standing stubble systems" during the Lower Namoi Cotton field day.

Grower Magazines and Articles:

1. Hulugalle, N., Finlay, L., Scott, F., and Weaver, T. (2004). Managing irrigated cotton sown into standing stubble. Aust. Cottongrower, 25(5), 58-62.
2. Anonymous (2004). Rotating key to cotton productivity. In the "Land", 23 December 2004.
3. Anonymous (2004). Cotton faces effluent future. In "Innovate Australia", 3(3), 1st July 2004 (http://www.innovateaustralia.com/newsletter/v3_3/grey.htm).

Part 4 – Final Report Executive Summary

The long-term effects of rotation crops and stubble management on carbon sequestration, soil quality and nutrient leaching; and growth, yield and profitability of succeeding cotton was studied in several on-station and on-farm experiments located in New South Wales and SE Queensland. Key management issues considered in the project were tillage systems, rotation crops and stubble management systems, in particular, sowing cotton into standing wheat and vetch stubble, and their effects on soil physical and chemical properties such as carbon, structure, sodicity, salinity; deep drainage; profitability and root growth.

The residual effects of rotation history were evaluated at Merah North and Warren in NSW. Residual effects of the rotation crops sown were present only with respect to sodicity, deep drainage and nutrient and salt leaching at Merah North. At Warra in Queensland where a dryland rotation experiment was terminated in 2005, soil structural properties were affected primarily by tillage system (zero tillage) with rotation crops affecting structure only during a period of relatively higher compaction. Least compaction occurred with double-cropped cotton-wheat. Whilst other soil properties were affected to some degree (statistically significant) by rotation crop, these changes were very small and usually could be considered as negligible as they were unlikely to affect crop growth. The major contributing factor to changes in soil chemical properties was the coarse soil organic matter, the more labile fraction of soil organic matter. However, due to a combination of extended drought leading to poor crop growth and low amounts of crop residues being returned to the soil, the amounts of coarse soil organic matter were very low and usually constituted <8% of total soil organic matter. In most locations, sowing cotton into standing wheat stubble improved soil organic carbon and rainfall harvesting; decreased sediment concentration in runoff, soil ESP and salinity; and improved cotton yields and root growth. Where standing stubble did not result in improved soil properties were instances where either the growth of the wheat crop was poor due to drought or poor management. Sowing vetch as rotation crop improved soil organic C and Ca:Mg ratio, and reduced ESP and soil strength at Goondiwindi. At ACRI less N fertiliser was required when vetch was sown as a rotation crop. Nitrate-N leaching was also lower in the same site. No other soil property was improved by sowing vetch. At ACRI, cotton lint yields were less with cotton-vetch than when wheat was sown as a rotation crop. Poor subsoil structure at the ACRI site may have contributed to this response. Cotton lint yield following vetch was, however, similar to continuous cotton.

Retaining crop stubble *in-situ* can cause several problems such as blocking of "gas knives" during injection of anhydrous ammonia as fertiliser and waterlogging during irrigation. In addition vetch regrowth can suffocate emerging cotton seedlings. These problems can be overcome by management practices such as attaching coulter discs to the front bar of the gas rig to cut through crop stubble, by removing stubble in furrows at the start of the irrigation season and controlling vetch regrowth through a combination of mechanical (slashing, cutting vetch lateral stems with coulter discs) and chemical (paraquat-based herbicides such as "Sprayseed") means.

Australian Government

Cotton Research and Development Corporation

FINAL REPORT

Maintaining profitability and soil quality in cotton farming systems

CRC 45C

July 2002 to June 2005

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NSW DEPARTMENT OF PRIMARY INDUSTRIES

Australian Cotton Cooperative Research Centre

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1. Executive Summary

The effects of rotation crops and stubble management (including the residual effects of past rotation crops) on soil quality, carbon sequestration, deep drainage, nutrient leaching, yield and profitability of succeeding cotton in irrigated and dryland Vertosols was studied in several on-station and on-farm experiments located in New South Wales and SE Queensland from 2002 to 2005. There were eight irrigated experiments (near Warren, Merah North, Boggabri, Narrabri and ACRI[1] in NSW and Goondiwindi in Queensland), and one dryland experiment in Queensland (Warra in the Darling Downs). Key management issues considered were tillage systems, rotation crops and stubble management systems, and in particular, sowing cotton into standing wheat and vetch stubble.

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

- Determine long-term rotation history effects in three of the farming systems experiments established in 1993. The residual effects of rotation history (1993-2000) were evaluated at Merah North and Warren, where a cotton-wheat rotation with minimum tillage was sown in all plots between 2002 and 2005. At Warra in Queensland, the effects of the rotation crops sown between 1993 and 2005 were evaluated.
- Determine the effects of sowing cotton into standing wheat stubble and find solutions to problems such as waterlogging and nutrient leaching.
- Compare cotton-wheat and cotton-vetch rotations in terms of soil quality and long-term cotton production.

Measurements taken in all experiments were: soil physical and chemical properties to a depth of 0.6 m (e.g. soil organic matter, plastic limit, strength with a penetrometer, soil structure, exchangeable Ca, Mg, K and Na, pH, electrical conductivity). Profile water content to 1.2 m, nutrient uptake, crop growth, cotton lint yield and fibre quality were also measured at ACRI, Boggabri, Warren ("Buttabone"site), Wee Waa and Merah North. Economic returns in irrigated sites were evaluated by comparing seasonal and cumulative gross margins. Spatial and temporal deep drainage (with the chloride mass balance model) and nutrient leaching, and profile salinity change with an EM38 meter were measured at ACRI, Narrabri, Wee Waa and Merah North. Investigations were also conducted at ACRI into soil and cotton crop management practices which could overcome problems associated with sowing cotton into standing (retained) rotation crop stubble.

Cropping systems and soil quality

Residual effects of the rotation crops sown were present only with respect to soil structure, sodicity (exchangeable Na), exchangeable K, deep drainage and nutrient and salt leaching at Merah North. Best soil structure occurred in the ex-sorghum plots and worst in the ex-dolichos plots. Exchangeable K and exchangeable Na contents were lowest in the ex-long-fallow cotton. Decreases between 2002 and 2003 in exchangeable Na content in the ex-sorghum, ex-long-fallow and ex-cotton-wheat and ranged from 12 to 26%. Key changes in soil chemical properties in all treatments between 2002 and 2003 were an increase in exchangeable K, and decreases in sodicity, soil organic carbon and the dispersive nature of the soil (due to a general decrease in sodicity). The decreases in sodicity were probably due to changing the source of irrigation water from bore to river water. Deep drainage, nutrient and salt leaching were generally in the order of ex-cotton-wheat > ex-continuous cotton > ex-cotton-dolichos.

At the dryland site in Warra, Queensland, where the experiment was terminated in 2005, soil structural properties were affected primarily by tillage system (changing from conventional to

[1] Australian Cotton Research Institute, Narrabri

zero tillage) with rotation crops affecting structure only during a period of relatively higher compaction. Least compaction occurred with double-cropped cotton-wheat. Whilst other soil properties were affected to some degree (statistically significant) by rotation crop, these changes were very small and usually could be considered as negligible as they were unlikely to affect crop growth. The major contributing factor to changes in soil chemical properties was the coarse soil organic matter, the more labile fraction of soil organic matter. However, due to a combination of extended drought leading to poor crop growth and low amounts of crop residues being returned to the soil, the amounts of coarse soil organic matter were very low and usually constituted <8% of total soil organic matter.

In most locations, sowing cotton into standing wheat stubble improved soil organic carbon, rainfall harvesting and gross margins (during the cotton phase of the rotation), decreased sediment concentration in runoff, soil ESP and salinity; and improved cotton yields and root growth. Where standing stubble did not result in improved soil properties were instances where either the growth of the wheat crop was poor due to drought or poor management. When cotton prices were low cumulative gross margins with either conventionally-tilled continuous cotton or minimum-tilled cotton-wheat were similar. Irrespective of price, gross margins of minimum-tilled continuous cotton were highest.

Sowing vetch as a rotation crop improved soil organic C, exchangeable K, $EC_{1:5}$, $EC_{1:5}$/ESC and Ca:Mg ratio, and reduced ESP and soil strength in sites with good quality soil. At ACRI, where vetch was sown as a rotation crop in a soil of poor quality, less N fertiliser was required and nitrate-N leaching was lower. No other soil property was improved by sowing vetch. At ACRI, cotton lint yields were less and gross margins lower with cotton-vetch than with either cotton-wheat or cotton-wheat-vetch. Cotton lint yield following vetch was, however, similar to continuous cotton. Gross margins of cotton-vetch were always lowest. As cotton price increased, rate of increase in gross margins were highest with the cotton-winter fallow sequence such that it was highest when prices exceeded $450/bale. At lint prices < $450/bale, gross margins of the cotton-wheat (standing stubble)-vetch rotation were highest.

Retaining crop stubble *in-situ* can cause several problems such as blocking of "gas knives" during injection of anhydrous ammonia as fertiliser and waterlogging during irrigation. In addition vetch regrowth can suffocate emerging cotton seedlings. These problems can be overcome by management practices such as attaching coulter discs to the front bar of the gas rig to cut through crop stubble, by removing stubble in furrows at the start of the irrigation season and controlling vetch regrowth through a combination of mechanical methods (slashing, cutting vetch lateral stems with coulter discs) and paraquat-based herbicides such as “Sprayseed”.

Deep drainage, nutrient leaching and salinity

Comparison of estimated deep drainage with pre- and post-season soil chloride concentrations showed that the steady state mass balance model best estimated deep drainage under cotton crops which were irrigated more frequently or wheat crops which had better sub-soil structure. Steady state conditions could therefore be assumed for calculating deep drainage under frequently irrigated crops with a better structured sub-soil. Conversely, if the crops were not frequently irrigated and the sub-soil structure was poor, more accurate estimation of drainage was possible by assuming transient state conditions.

Drainage was generally greater where cotton was sown into standing wheat stubble compared with stubble incorporation. This is due to the higher water infiltration in the former management practice. Management practices which improved subsoil structure such as permanent beds (minimum tillage) or cereal rotation crops also resulted in more drainage than practices which resulted in poorer subsoil structure. Stubble burning can greatly increase deep drainage. This is because the resulting ash releases calcium which is then leached into the sub-soil, decreasing the sodium adsorption ratio of the soil water, thereby improving structure and increasing drainage during the following years.

High sodicity and salinity when combined with a low irrigation rates resulted in a low and hence, insufficient leaching fraction. This resulted in salinization followed by increased sodification. An example of this was the site at "Woodgrain", near Boggabri. The consequences of this were low yields (3-4.5 bales/ha).

Cotton lint yields were, in general, positively related to deep drainage in both sodic and non-sodic soils. This suggests that either salinity or over-irrigation and consequently, waterlogging in the subsoil may have occurred in all sites. Only in sites where a sandy horizon was present in the subsoil was drainage negatively related to lint yield, presumably due to increased water and nutrient stress associated with drainage. With respect to wheat grain yields, in non-sodic soils drainage was negatively related to yields, whereas in sodic soils, yield was positively related to deep drainage.

Values of nutrient and salt leaching observed during 2002-03 and 2003-04 at the ACRI, and "Glenarvon" sites were similar to those observed in previous years. At "Beechworth", however, they were lower than those observed between 2000 and 2002, and were probably due to less chloride accumulation and use of better quality irrigation water.

Early season salinity can have significant detrimental effects on cotton yields, presumably by affecting seedling growth and establishment. Yield losses of the order of 50% can occur when soil chloride levels in the 0-60 cm depth at sowing are of the order of 5.3 t/ha. The corresponding EC_e is 1.5 dS/m. This figure is very much lower than the 7.7 dS/m which is used in many models of salinity risk for cotton. These finding also suggest that cotton in many fields which are currently classified as low salinity risk may in fact be prone to salt-mediated yield losses.

Between 2002 and 2005, training was provided for one PhD student (T.B. Weaver, Griffith University), and two honours students (N. Eulenstein, University of Qld., and N. Luelf, University of Sydney). During the same period, eight journal articles, 15 conference papers and 10 cotton industry and extension publications were published by project research and technical staff.

In summary, cereal crops sown in rotation with dryland cotton improved soil properties more than legumes. Residual effects of past rotation crops were present up to three years after the different treatments were terminated. Sowing cotton into standing wheat stubble can result in improvements to soil physical, chemical and hydrological properties. Management practices which were able to overcome some of the problems associated with sowing cotton into standing wheat stubble such as waterlogging and blocking of gas knives were developed. Sowing cotton into saline soil can result in significant yield losses at salinity levels very much lower than those reported in the literature.

2. Introduction

Vertosols (Vertisols, Usterts) are the most common cotton growing soils in eastern Australia. 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. They have a clayey soil texture and form soil cracks which close when wetting occurs due to swelling of the soil. 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 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 soil quality cotton-based farming systems. As a consequence, 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. 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.

More recently, research from central Queensland has suggested a modification to the cotton-wheat rotation system, whereby the wheat 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.

While sowing cotton into standing wheat stubble appears to have 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. Preliminary experiments in a limited number of sites during the 2000-01 cotton season suggested that deep drainage under 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 Australian Cotton CRC (and its predecessor the CRC for Sustainable Cotton Production) 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 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. The "best" rotation crop sequence for dryland systems were also not identified, although this is related more to the longer time period required rather than to lack of experimentation *per se*.

This report focuses on results obtained over the period 2002-2005 from eight experiments (seven irrigated, one dryland) in New South Wales and Queensland on rotation crop management. Where long-term trends are discussed, data collected since 1996 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.

4. Methodology

4.1 Field Experiments

Evaluating rotation history effects on soil quality profitability, deep drainage and nutrient leaching:

Soil quality (physical and chemical properties, including soil organic carbon) were measured from 2002 to 2005 in two of the trials established in 1993. These were the trials at "Beechworth" in Merah North, NSW, and "Prospect", Warra, Qld. In addition samples were taken during 2004 from the rotation experiment at "Auscott", Warren, which was also established in 1993.

Experimental design at Merah North was a randomised complete block with 3 replications. Individual plots are 400 m x 24 rows. The soil is a grey clay with a very sodic subsoil. The site is subject to periodic salinization and sodification due to irrigation with poor quality bore water. Experimental treatments imposed between 1993 and 2000 were continuous cotton, long-fallow cotton, cotton-unfertilised wheat, cotton-faba bean (1993-98)-cotton-sorghum(1999-2000), cotton-unfertilised dolichos and cotton-dolichos with P and K fertiliser. The individual rotation treatments were discontinued from 2001 due to salinization and the site was monitored for residual effects of the rotations imposed between 1993 and 2000. Between 2002 and 2005, all plots were sown with a cotton (2000)-wheat (2001)-sorghum (2002)-cotton (2002)-wheat (2003)-cotton (2004). Soil was sampled within 2 weeks after picking each year (except 2004). Until 2001 cotton was irrigated with bore water, whereas from 2002 onwards river water, which is of far better quality, was used.

The Warra experiment was a dryland site. The experimental design was a randomised complete block with 3 replications. Individual plots were 110 m x 234 m. The soil is a grey clay. Land preparation until 1996 was with conventional tillage (chisel ploughing to about 20 cm depth followed by 2-4 cultivations with Gyral tyne cultivator). Thereafter (1997-2004) tillage operations at the site consisted solely of pupae-busting to about 7-10 cm after cotton picking with a chisel plough, with weeds being controlled by herbicide applications, and all crops in the rotation sown after zero tillage. Soil was sampled during April of each year from 1996 to 2004. The rotation treatments imposed since 1993 were as follows:

1. Continuous cotton (cotton-summer and winter fallow-cotton), T_1
2. Cotton-sorghum (cotton-winter fallow-sorghum-winter fallow-cotton), T_2
3. Cotton-wheat double cropped (cotton-wheat-summer and winter fallow-cotton), T_3
4. Cotton-chickpea double cropped fb. wheat (cotton-chickpea-summer fallow-wheat-summer and winter fallow-cotton), T_4
5. Cotton-wheat (cotton-winter and summer fallow-wheat-summer and winter fallow-cotton), T_5

The specific crops sown between 2002 and 2005 are given in the following table.

Rotation	2001-02 summer	2002 winter	2002-03 summer	2003 winter	2003-04 summer	2004 winter	2004-05 summer
T_1	Fallow	Fallow	Cotton	Fallow	Fallow	Fallow	Cotton
T_2	Sorghum	Fallow	Cotton	Fallow	Sorghum	Fallow	Cotton
T_3	Fallow	Fallow	Cotton	Wheat	Fallow	Fallow	Cotton
T_4	Cotton	Chickpea	Fallow	Wheat	Fallow	Fallow	Cotton
T_5	Fallow	Fallow	Cotton	Fallow	Fallow	Fallow	Cotton

* wheat not planted due to drought

The experiment at "Auscott-Warren" was conducted between 1993 and 2000, after which a cotton-wheat rotation was sown in all plots. The experimental treatments imposed between 1993 and 1999 were: (1) continuous cotton; (2) long-fallow cotton; (3) cotton-fertilised wheat; (4) cotton-unfertilised wheat; (5) cotton-wheat-fertilised (K+P fertilizer) dolichos (1993-95) fb. (followed by) cotton-faba (1995-99); (6) cotton-field pea; (7) cotton–wheat-unfertilised dolichos (1993-95) fb. cotton-unfertilised dolichos (1995-97) fb. wheat-cotton-cotton (1997-99). The site was sampled to evaluate any long-term residual effects of its rotation history.

Deep drainage and nutrient leaching were monitored in 40-m transects in the continuous cotton, cotton-wheat and cotton-unfertilised dolichos plots at Merah North and in the cotton-N fertilised wheat plots in an experiment at Wee Waa. The Wee Waa experiment was also established in 1993 at "Glenarvon" (CRDC project DAN 83C). The trial had 4 rotation treatments: cotton-N fertilised wheat, cotton-unfertilised wheat, cotton-faba (seed harvested) and cotton-faba (seed incorporated). The individual rotation treatments were discontinued in 1999, and the entire site sown with a cotton-wheat sequence.

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 3 on-farm experiments (one at "Buttabone" near Warren managed by Mr. Rolf Hartge of Twynam Pastoral Company, another at "Federation Farm", near Narrabri and managed by Mr. Greg Coulton, and the last at "Woodgrain" near Boggabri established by Mr. Mark Hickman, upper Namoi cotton IDO in 2001 and managed by Mr. R. Young of South Pacific Pastoral Company). The details of the individual experiments are as follows:

Tillage/rotation experiment at ACRI: 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 has been retained as standing stubble and Round-up Ready cotton (SICALA V2-RR) has been sown. After the cotton-picking was completed in 2002, as evidence of soil compaction was observed in some locations and due to the presence of crooked rows in the minimum-tilled systems, the beds were re-laid in both minimum-tilled treatments after chiselling and discing. The experimental design is a 4RCB in plots 190 m long and 36 rows wide. The soil at this site is a grey clay. Soil quality was evaluated in samples taken during September 2002 and 2004. Soil structure was evaluated with the white paint method and analysed with SOLICON 1.0 during May 2003. This trial was also utilised by the Cotton CRC's water use efficiency group (S. Tennakoon, S. Milroy) to validate and refine their models. The tension lysimeter, funded by CRC/CRDC (CRC 47C), is also located within this experiment. Drs. David Nehl and Ohm Jorar measured black root rot and mycorrhiza in this trial. Heliothis pupae survival and emergence, and parasite numbers were monitored by Mr. Colin Tann in both minimum-tilled treatments. In addition to the main experiment, an individual "drainage plot" (16 rows wide, 190 m long) sown with cotton-wheat (standing stubble) adjacent to the main experiment was established in 2000 to evaluate the spatial variability and dynamics of drainage and nutrient leaching under cotton sown into standing wheat stubble. Mr. Weaver will use these data on drainage and leaching for his PhD thesis. During 2004, drainage was not measured in this plot. It was divided in half, and two treatments were imposed: cotton sown into standing wheat stubble or sown into incorporated wheat stubble. Seasonal carbon dynamics were measured in these plots with soil organic carbon in beds being measured at 2-3 monthly intervals during the 2004-05 cotton season.

Cover crop trial at ACRI 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. The soil at this site is a grey clay. This trial was established in 2001, but re-laid in 2003. Due to funding constraints soil sampling was discontinued in 2004.

Cover crop trial established by Mr. Mark Hickman, Upper Namoi IDO, at "Woodgrain", near Boggabri: Treatments were cotton sown into either (1) standing wheat stubble on beds and in furrows, with stubble in furrows being incorporated during furrow cultivation after cotton emergence; (2) wheat stubble incorporated with a disc-plough, arranged in adjacent plots 232 rows wide and 532 m long. The soil at this site is a grey clay, which is very saline and sodic. This trial was discontinued in 2003 as the property was sold due to poor cotton yields, and cotton is no longer grown on this site. Soil was sampled during December 2001, October 2002 and May 2003.

Gypsum x standing wheat stubble trial at "Federation farm", near Narrabri: Treatments were cotton sown into wheat stubble incorporated plots 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 trial was irrigated with treated sewage effluent which is high in exchangeable Na and has a moderately high EC. Statistical precision was improved by establishing 5 additional sampling plots within each individual treatment plot. Soil was sampled during June 2000 (baseline sampling), September 2001, January 2002, September 2003 and April 2004

Standing stubble trial at "Buttabone", near Warren: The treatments consisted of adjacent fields of different phases of the cotton-wheat rotation; i.e. cotton after cotton or wheat, sown on 2-m beds. Cotton after the wheat phase was sown into standing wheat stubble after the beds were centre-busted with a gas shank to 0.2 m whereas cotton after cotton was sown after the beds were centre-busted and disc-ploughed. Bed renovation occurred in both fields. Soil was sampled only during September 2002 because no wheat was grown in these fields in subsequent years due to the drought

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, nutrient uptake, drainage and leaching and cotton growth were monitored in a long-term experiment which was established in Field D1 at ACRI in 2002. Soil quality was also measured in an on-farm trial established and managed at "McIntyre Downs", near Goondiwindi by Mr. David Turner.

Cotton/wheat/vetch rotations experiment at ACRI: The soil at the experimental site is a grey clay. Land preparation was with minimum tillage ("permanent beds") with most tillage operations being restricted to the bed after cotton picking. In years when cotton was sown, a "Roundup Ready" cotton variety (SICALA V2-RR) was used. The experiment is laid out in 3 RCB, with individual plots being 20 rows wide and 165-m long. Within the more complex rotations, both rotation and cotton phases are sown in the same year to allow evaluation of climatic variability. In winter 2003 vetch was sown in Rotation 1 (see Table below)during May, in winter 2004 in Rotation 4 during April and in Rotation 1 during May, and in winter 2004 in both Rotations 1 and 4 during May. Rotations which did not include a vetch component (Rotations 2 and 3) received 150 kg N/ha during August 2003 and 160 kg N/ha during September 2004 as anhydrous ammonia before sowing cotton. Rotation 1 did not receive any N fertiliser before sowing cotton in 2003. Both cropping systems which included vetch were not fertilised before sowing cotton in 2004, but received 60 kg N/ha as urea in late January 2005. Urea was applied to all wheat crops before sowing at a rate of 60 kg N/ha during 2003, and 80 kg N/ha subsequently. Phosphorus was applied to all treatments as single superphosphate at a rate of 24 kg P/ha during August 2004. Soil quality was evaluated in samples taken during September 2002 (baseline sampling) and 2004. The experiment is expected to run for a period of 12 years. Treatments for 2002-2005 were as follows:

Rotation*	**2002-03 summer**	**2003 winter**	**2003-04 summer**	**2004 winter**	**2004-05 summer**	**2005 winter**
1	Cotton	Vetch$_{GM}$	Cotton	Vetch$_{GM}$	Cotton	Vetch$_{GM}$
2	Cotton	Fallow	Cotton	Fallow	Cotton	Fallow
3a	Cotton	Wheat	Wheat stubble incorporated/ Fallow		Cotton	Wheat
3b	Fallow		Cotton	Wheat	Wheat stubble incorporated/ Fallow	
4a	Cotton	Wheat	Standing wheat stubble/ Fallow	Standing wheat stubble/ Vetch$_{GM}$	Cotton	Wheat
4b	Fallow		Cotton	Wheat	Standing wheat stubble/ Fallow	Standing wheat stubble/ Vetch$_{GM}$

*. The letters a and b denote different phases of the same rotation. Vetch$_{GM}$ = green-manured /stubble mulched vetch

On-farm trial of strip-cropped cotton and corn, with and without vetch, near Goondiwindi: The trial, which consists of paired plots of strip-cropped cotton and corn sown with or without green manured vetch, has been established at "McIntyre Downs", near Goondiwindi by Mr. David Turner. Due to lack of irrigation water vetch was not sown during the 2004 winter. Soil was sampled during September 2003 (shortly after vetch incorporation) and December 2004.

Effect of post-harvest cultivation system on heliothis pupae survival and emergence

At the request of Mr. Colin Tann of CSIRO, *in situ* soil structure was measured with the white paint method in an experiment established at ACRI during the 2002 winter which evaluated the effects of post-harvest cultivation systems on heliothis survival. The experimental treatments, which were arranged in a 3 RCB design, were: pupae busting with an airway cultivator, centre-busting followed by discing, centre-busting followed by go-devilling, stubble eliminator followed by a wheat planter, no-tillage with a wheat planter and an untreated control. Mr. Tann measured pupae and other insect populations by trapping in nets and chambers.

4.2. Sampling & Measurements

4.2.1. Soil quality (physical and chemical properties)

Soil was sampled in all sites from 2002 to 2005. At "Prospect", Warra, four soil pits were dug in each plot with a spade whereas at "Beechworth", Merah North and ACRI, three to four 10-cm diameter soil cores were extracted from each plot with a tractor-mounted soil corer. Four soil clods were taken along their natural cleavage planes from the 0-15 cm, 15-30 cm, 30-45 cm and 45-60 cm depths at Warra and Merah North, and from the 0-10 cm, 10-30 cm, 30-60 cm and 60-120 cm depths at ACRI (average clod volume at field moisture content was 175 cm^3) of each soil pit or core. Bulk soil from these layers was sampled at the same time. In the other sites, soil cores were sampled in parallel transects. At "Woodgrain", Boggabri and "Federation Farm", Narrabri cores were taken from the 0-10 cm, 10-30 cm, 30-60 cm, 60-120 cm and 120-180 cm depths, whereas at "Buttabone", Warren and "McIntyre Downs" Goondiwindi they were sampled from the 0-10 cm and 10-30 cm depths.

Air-dried soil was passed through 2 mm-sieve and the following tests carried out: plastic limit using a drop-cone penetrometer[1]; coarse soil organic matter (particle diameter of 212 µm - 2 mm) with a combination of dispersion (by soaking overnight in a solution of 2:1 10% sodium hexametaphosphate:1M NaOH and gently stirring thereafter with a magnetic stirring rod), flotation and sieving; pH (in 0.01M $CaCl_2$); electrical conductivity (in a 1:5 soil:water suspension); $CaCO_3$ equivalent (by titration with conc. HCl); nitrate-N[2] (with a nitrate electrode pre-calibrated with the Kjehldal method 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 Na/Σexchangeable cations) x100], and the $EC_{1:5}$/ESC ratio[3] (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"[4]. The SOC, coarse soil organic matter and cations in the 0-60 cm depth of the Warra dryland experiment were expressed in kg/m^2, by multiplying their concentration in each depth interval by the bulk density and the depth increment, followed by summing up all the depth intervals.

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[1] 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.

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

[3] 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.

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

Bulk density, ρ_b (g/cm^3) of oven-dry soil clods was determined after coating air-dried clods with 'saran' resin dissolved in ethyl-methyl ketone followed by oven-drying at 110^o C[1]. Bulk density in beds was measured on air-dry soil aggregates (1-10 mm diameter) with the kerosene saturation method[2]. Assuming that residual shrinkage between air-dried and oven-dried water contents was negligible, soil water content measured at the same time was used to convert these values to an oven-dried equivalent. The bulk density in the 0-15 cm was expressed as weighted mean of bulk density evaluated from clods and aggregates in beds. The bulk densities in all depths were used to calculate their oven-dried air-filled porosities, ε_a [=1-(ρ_b/ρ_s) where ρ_s is the density of the solid fraction and is usually taken to be 2.65 g/cm^3] and specific volumes, S_v (=1/ρ_b). Dispersion (after immersion in water of EC = 0.4 dS m^{-1}) was determined with a sediment density-specific gravity meter on air-dried soil aggregates of 1-4 mm diameter[3]. Dispersion was measured every other year, except at Boggabri where dispersion was not measured. 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 also measured with the ASWAT test[4] in samples taken from Warra in 1996 and 2004, and from Goondiwindi in 2004. Soil strength to a depth of 45 cm was measured at regular intervals with a 'Rimik' recording penetrometer. Measurements were made from the top of ridges with three profiles being measured from the four central rows of each plot. Concurrently soil water content was measured in the same locations.

In-situ macroporosity, a measure of soil structure, was evaluated after cotton picking in May 2003 in a single location within each plot in the tillage rotation experiment and in July 2002 in the experiment which evaluated the effects of post-harvest cultivation systems on heliothis pupae emergence. Each location was saturated to exclude the effects of soil cracking and allowed to drain. Ten litres of 1:5 water soluble white acrylic paint:water mixture, followed by a further 20 litres of water, were applied to a 0.10 m deep, 0.20 m wide, 0.50 m long trench dug within beds after excavation of the bed to furrow level and allowed to infiltrate. One week later, 1.5 m deep x 1.5 m (tillage rotation experiment) and 0.3 m x 1.0 m wide (post-harvest cultivation systems experiment) soil pits were dug with a backhoe at right-angles to the trench. After smoothing, a 1 m x 1 m or 1 m x 0.3 m area of the exposed profile face was photographed with a digital camera and the recorded images were downloaded onto a computer. The images were analysed with SOLICON 1.0 to estimate macroporosity at field capacity. SOLICON 1.0 is a software package which is able to capture and process digital images of soil profiles and provide estimates of structural indices such as field porosity and pore star length every 1.5 mm. The results were either fitted to a logarithmic equation of the form $P = a + b(\ln d)$ where P is macroporosity at field capacity and d is depth, and analysed with linear regression analysis (tillage/rotation experiment) or expressed as a percentage of the untreated control (post-harvest cultivation systems experiment).

The tillage/rotation experiment at ACRI suffered from soil physical damage due to a laser-leveller operating in an adjacent field trafficking over this experiment. The resulting physical damage was quantified by measuring soil strength in trafficked and untrafficked areas in wheat stubble incorporated and standing wheat stubble plots with a penetrometer. These

[1] Blake, G.R., and Hartge, K.H. 1986. Bulk density. In: *Methods of Soil Analysis, Part 1: Physical and Mineralogical Methods (ed: A. Klute)*, pp. 363-382. American Society of Agronomy: Madison, WI, USA.
[2] 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.
[3] Entwistle, P.C., Hulugalle, N.R., and Finlay, L.A. 1997. Measuring dispersion with an electronic sediment density meter. In *Proceedings of 2nd National Conference of Australian Soil and Plant Analysis Council, 23-26 November 1997, Launceston, Sparrow LA, Fist AJ (eds.)*, pp. 140-142. ASPAC: Launceston TAS.
[4] McKenzie DC (ed.). 1998. *SOILpak for cotton growers, 3rd edition*. NSW Agriculture: Orange, NSW.

results are included in this report. Similar damage also occurred in the cotton/wheat/vetch rotation experiment at ACRI.

In replicated experiments all data were analysed with analysis of variance appropriate for the specified experimental design. In unreplicated on-farm experiments, where soil was sampled in paired transects, the results were analysed with analysis of variance using either a single factor (treatment) or two-factor (treatment x years) repeated measures design.

4.2.2. Nutrient leaching and drainage

Drainage was measured across a diagonal transect in ex-N fertilised wheat-cotton at Wee Waa; standing wheat stubble/cotton drainage plot at ACRI; all treatments in the tillage/rotation experiment and cotton/wheat/vetch rotations experiment at ACRI; both wheat stubble incorporated and standing stubble plots at Boggabri; gypsum x standing wheat stubble trial at "Federation farm"; and continuous cotton, wheat-cotton and unfertilised dolichos-cotton at Merah North. Nutrient leaching was measured in all sites except Boggabri. 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, and Ca, Mg, K and Na with an atomic absorption spectrophotometer[1]. At each sampling site in the transect soil water content in the 20-120 cm depth interval was measured with a neutron moisture meter (CPN 503-DR Hydroprobe) at the same time that soil water was extracted from the ceramic-cup samplers. 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 costs and benefits 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 KNO_3, and Ca, Mg and Na in terms of their gypsum equivalents[2]. Values of gypsum was assumed to be $70/t (with an additional spreading costs of $10/ha at a rate of 2.5 t/ha), anhydrous ammonia $700/t and potassium nitrate $1.18/kg. Chloride was equated to the increase in yield which could be expected due to Cl being leached out of the soil profile. This was done by deriving a soil Cl-cotton lint yield response curve across all sites (lint yield = $2.5204e^{-0.0587x}$, where x is chloride content in the 0-0.6 m

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

[2] 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. *Adv. GeoEco*l., **37**, In Press.

depth, see section 5.2.3). This curve was then used to estimate the yield of a cotton crop based on the soil chloride at the end of the cropping season. The value of a bale of cotton lint was assumed to be $350. The value of the difference in cotton lint yields between this estimated value (i.e. future yield) and that observed in the present season was taken to be the yield increase which may occur due to the chloride being leached out of the soil profile. The difference between the costs (nutrients lost) and benefits (salts leached) was the estimated value of nutrients and salts leached through in deep drainage. In this report the costs were subtracted from the benefits.

Concurrent with soil sampling, electromagnetic induction surveys were conducted using an EM-38 (Geonics Ltd, Ontario) and a Magellan GPS NAV 5000 PRO™. A linear regression model was used to determine the apparent electrical conductivity, EC_a. The soil electrical conductivity, determined on a 1:5 soil:water suspension, was regressed against the $EM_{0,H}$ readings. The resulting linear regression model used to determine EC_e (mS/m) was: $EC_e = 20.7\exp(0.019EM_{0,H})$, $R^2 = 0.85^{***}$; and that used to determine $EC_{1:5}$ (ms/m) was: $EC_{1:5} = 6.8\exp(0.014\ EM_{0,H})$, $R^2 = 0.74^{***}$.

4.2.3. Determining drainage with the solute 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:

$$DP_z = I(\frac{C_i}{\overline{C_z}}) \qquad (1)$$

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); $\overline{C_z}$ 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:

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

where α and λ were calculated as:

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

$\overline{S}_{(0-z)}$ 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:

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

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.

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 during the 2004-05 season and the results incorporated into the HydroLogic irrigation management decision support software.

Cotton plants sampled in early March and rotation crops sampled in late October were used to evaluate nutrient uptake. N in vetch tissues was measured with a LECO analyser. (Plant nutrient uptake, soil water content and crop agronomy at Warra were evaluated by CRC collaborators and are not presented in this report). After harvest in May, cotton lint fibre characteristics such as micronaire and length were measured with a Spinlab 900 series, and maturity and fineness with a Shirley FMT3.

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. The data collected in the tillage rotation experiment during 2002-03 was used to further refine the water use efficiency model of Dr. S. Tennakoon (CSIRO). During 2004-05 season the HydroLogic irrigation management decision support software was used to plan irrigation in the ACRI experiments.

Cotton root and root carbon turnover in the 0-100 cm depth were measured with a minirhizotron in the sub-surface and subsoil, and with the core-break method in the soil surface layers. 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.

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 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 $350/bale and a seed price of $230/tonne, and costing of operations conducted on each treatment, including weed control costs. The wheat price used was $175 per tonne (based on long term average wheat prices for Prime Hard grade) with the current discount system for low protein and bonuses for low screenings included. 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.

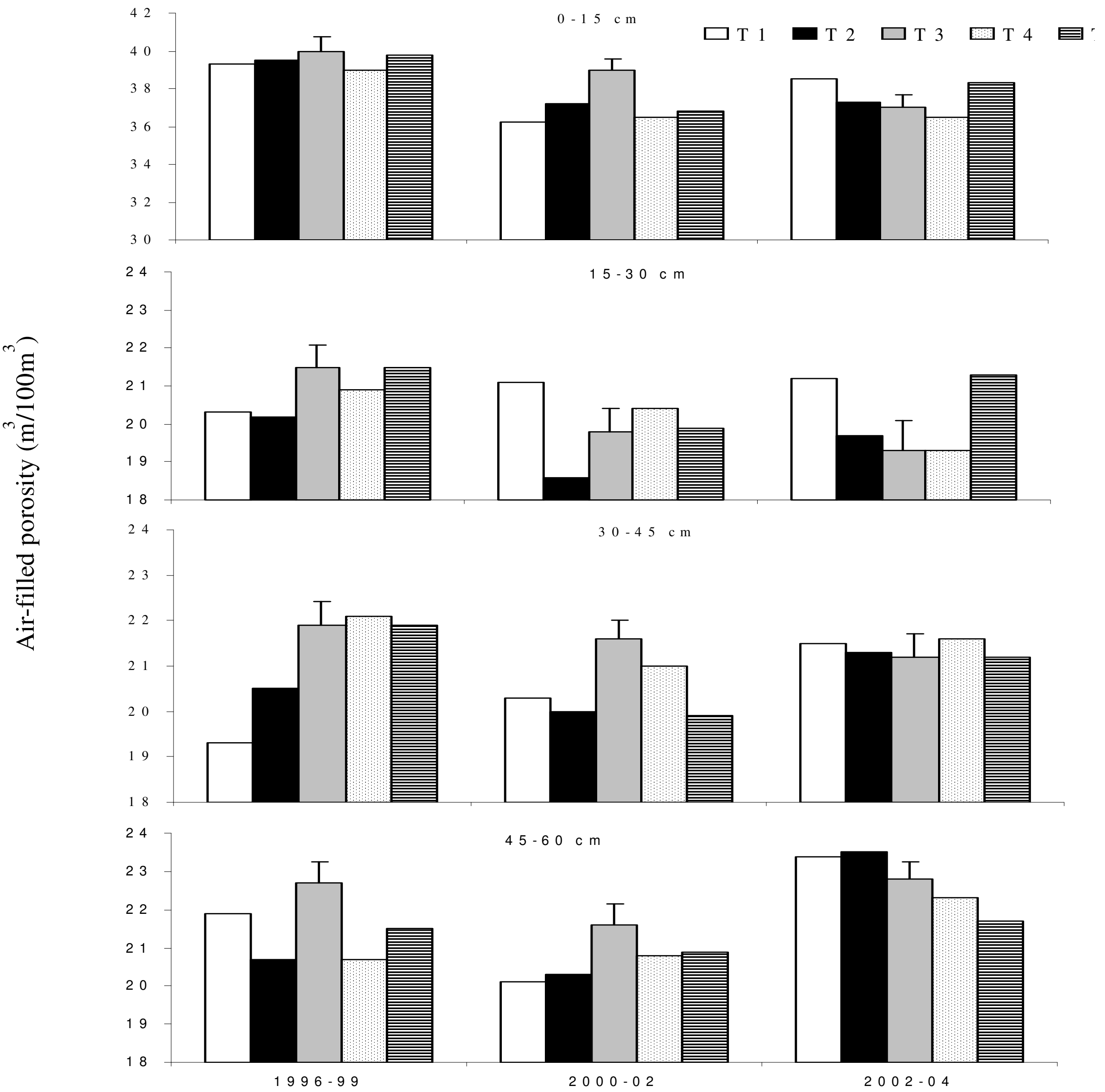

Figure 1. Effect of rotation and time on air-filled porosity of oven-dried soil at "Prospect", Warra. Vertical bars are standard errors of the means.

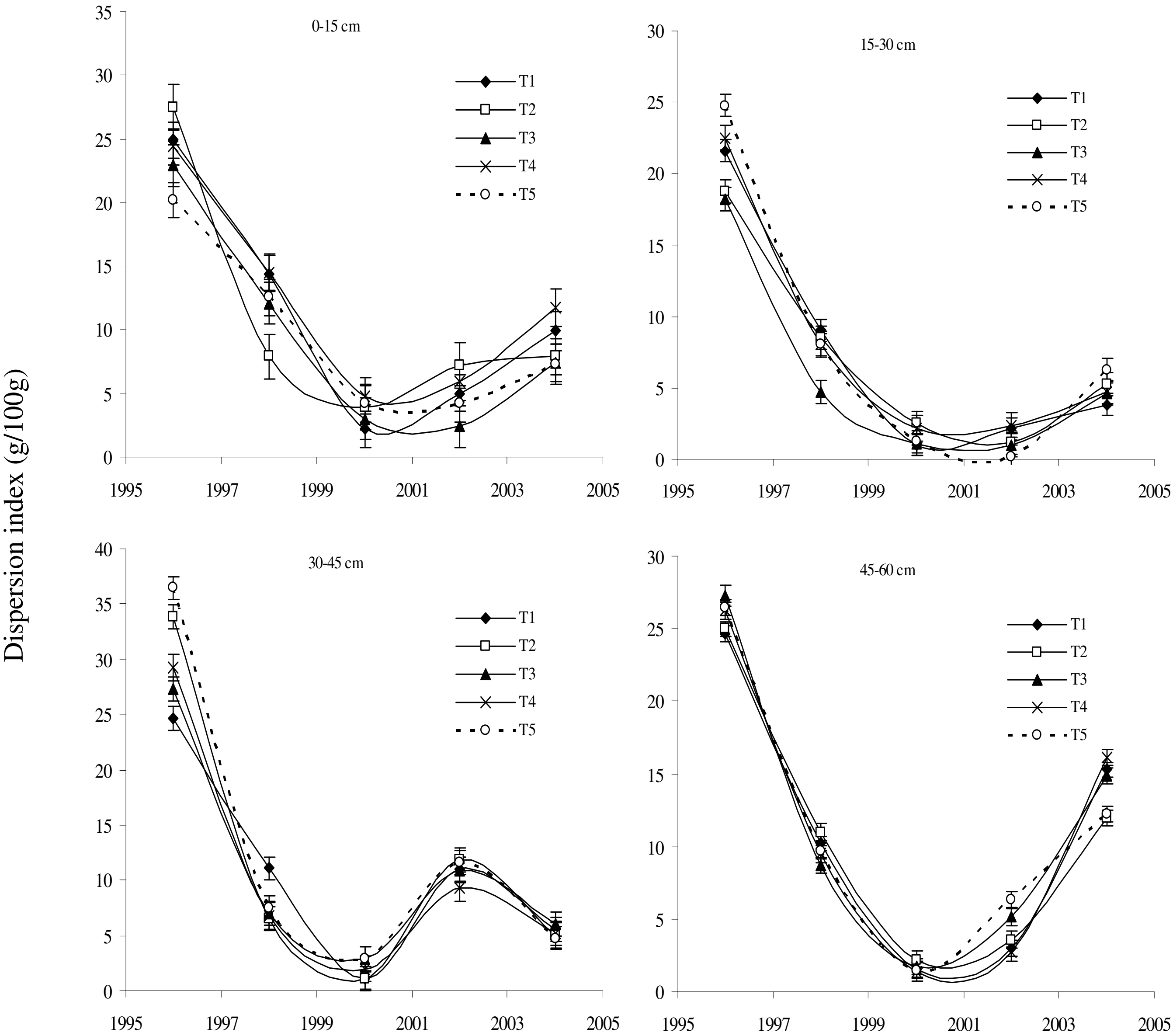

Figure 2. Effect of rotation and time on dispersion index at "Prospect", Warra. Vertical bars are standard errors of the means.

5. Key Results and Discussion

5.1. Cropping systems and soil quality

5.1.1. Long-term effects of crops sown in rotation with dryland cotton on soil physical and chemical properties

There were large fluctuations between years with respect to all the soil properties measured. The major causal factor influencing short-term changes appeared to be summer rainfall. This was particularly evident with respect to soil organic carbon. Rotation crop affected soil properties only with respect to exchangeable K, pH, coarse soil organic matter, $EC_{1:5}$ (an indicator of decomposition), ESP, $EC_{1:5}$/exchangeable Na and soil structure. Soil structure also appeared to be strongly influenced by the shift from the more intrusive conventional tillage to zero tillage, with the tillage system at any one time interacting with crop rotation. Variations in other soil properties were affected primarily by fluctuation in coarse soil organic matter and clay content in each sample. In general the values of the coarse soil organic matter were very low and comprised 3.5% of total soil organic matter (2-13%) and except during 1999, when rainfall was more than adequate, most values were less than 4%. These low values reflect to a large extent the drought conditions which prevailed at this site for much of this experiment, and the low amount of crop residues which were returned to the soil. If zero-tillage had not been practiced the values of coarse soil organic matter may have been very much lower.

Soil structure

Changes in air-filled porosity, ε_a, with time could be grouped into 3 time periods (Fig. 1):

- 1996 to 1999 when the changeover from conventional to zero tillage occurred, with residual effects of the conventional practice being evident up to 1999 with rotation crop affecting values only in the 30-45 cm depth with higher values occurring in treatments where wheat had been sown (Rotations T_1, T_2 and T_3).
- 2000 to 2002 when soil compaction was highest and showed a significant increase ($P < 0.05$) from the preceding time period. An increase in soil compaction has been frequently reported with zero tillage, particularly when controlled traffic systems are not implemented at the same time. During this period the rotation crops had significant effects on ε_a in all depths. Except in the 15-30 cm m depth when ε_a was highest with continuous cotton (Rotation T_1), in all other depths double-cropped cotton-wheat (Rotation T_3) resulted in highest values.
- 2003 to 2004 when soil compaction decreased in comparison with values observed during 2000 to 2002. With decreasing compaction, the rotation crops had a relatively small effect on ε_a with only values in the 45-60 cm depth being affected. This was such that highest values occurred with continuous cotton (Rotation T_1) and cotton-sorghum (Rotation T_2), and lowest with cotton-wheat (Rotation T_5). These observations should be viewed with some caution as 2003-2004 followed a period when the rotation crops were not sown or grew poorly due to an extended and severe drought.

Dispersion was unaffected by rotation crop, but decreased with time (Fig. 2). This was probably due to the fact that the site was managed with zero tillage from 1997 onwards. Increasing aggregate stability is frequently reported to occur with increasing period of zero or minimum tillage. Except in the 30-45 cm m depth, dispersion increased significantly by a small amount between 2002 and 2004. This may be related to the previously mentioned drought when the rotation crops were not sown or grew poorly.

The ASWAT test indicated that structural stability had improved between 1996 and 2004. Mean ASWAT scores for the 0-45 cm depth were 2.0 in 1996 and 0.0 in 2004 ($P < 0.001$, SEM[1] = 0.18). These changes mirror the changes observed in the more traditional laboratory measure of dispersion (Fig. 2).

Soil organic matter

Temporal changes in soil organic carbon, SOC, was not affected by crop rotation. Summer (January-March) rainfall, however, appeared to have a significant effect on soil organic carbon values in the surface 60 cm (Fig. 3). Values of soil organic carbon from 1996 to 2003 were significantly affected by summer rainfall ($r^2 = 0.59$***, n = 120) with peak values usually occurring in years when rainfall exceeded 200 mm. Furthermore these data also suggest that organic carbon will peak at a value of about 20 kg/m^2 when a summer rainfall is of the order of 350 mm. Further increases in rainfall result in decreases in SOC, presumably due to excessive decomposition. The data from 2004 contradicts this trend. Although summer rainfall was of the order of 269 mm, soil organic carbon storage in the 0-60 cm depth averaged 6.4 kg/m^2. This too, may be related to the previously mentioned drought when the

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[1] Standard error of the means

rotation crops were not sown or grew poorly. The uncertainty with this data set is that SOC values for rainfall between 275 and 435 mm is unavailable due to the extreme variability in rainfall at this site. Overall total soil organic matter levels were very low and are 8-12% of that in similar irrigated soils.

Temporal changes in coarse soil organic matter (particle diameter of 212 µm - 2 mm), which consists of the more labile (and dynamic) fraction of soil organic matter, was affected by both year ($P < 0.001$) and crop rotation ($P < 0.05$) (Fig. 4). Mean coarse organic matter values were in the order of Rotation T_2 (0.99 g/100g) > Rotation T_1 (0.71 g/100g), Rotation T_3 (0.70 g/100g), Rotation T_4 (0.76 g/100g) and Rotation T_5 (0.80 g/100g) (SEM = 0.046). The temporal changes in coarse soil organic matter are broadly similar to the SOC changes, although there are some important differences. The peak in coarse soil organic matter during 2002, for instance, is not as marked as that with SOC at the same time. This suggests that the proportion of coarse SOM in overall SOM was relatively low at this time, presumably due to the absence of or low amounts of crop residues being returned to the soil because of the drought. At the same time the sharp increase in total SOC suggests that the proportion of fine SOM (particle diameter <212 µm) in overall SOM was high, and was probably caused by existing coarse SOM decomposing into finer material. The reverse occurred during 1999 when the peak in coarse soil organic matter was far more evident than that in total SOC, and probably indicates the decomposition of crop stubble from the preceding years when good crop growth occurred. Overall, however, as with SOC the fluctuations in coarse soil organic matter were significantly related to summer rainfall ($R^2 = 0.72$***). Coarse soil organic matter was also related to many of the soil properties measured in the 0-60 cm depth (Table 4). R^2 values ranged from 0.33 to 0.44 for exchangeable K, Na and Mg expressed on a gravimetric basis, the sodicity indices ESP and $EC_{1:5}$/ESC, and exchangeable potassium percentage, EKP, but they were very low for physical properties and exchangeable Ca.

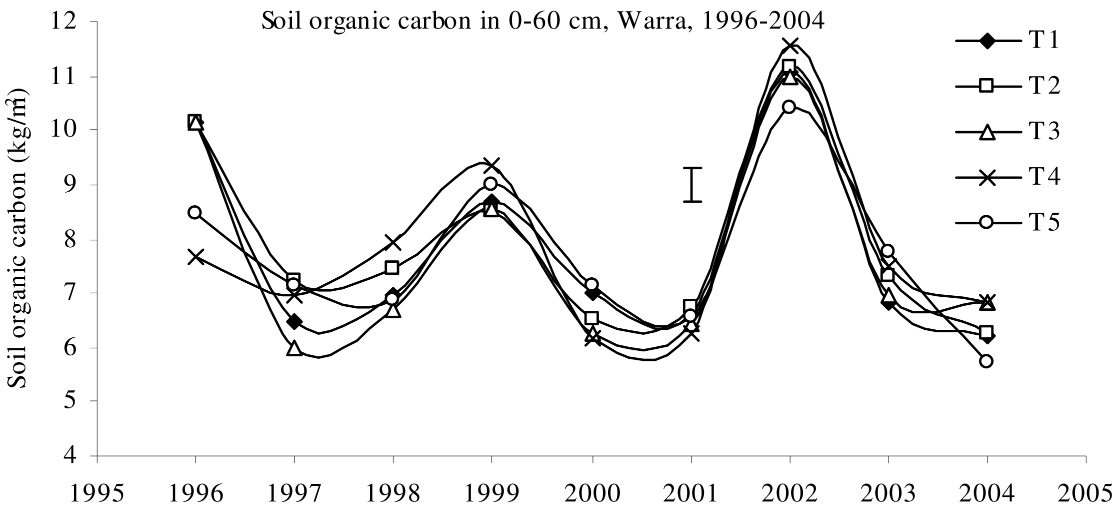

Figure 3. Effect of time and rotation crop on variation of soil organic carbon in the 0-60 cm depth at "Prospect", Warra. Vertical bar is the standard error of the mean.

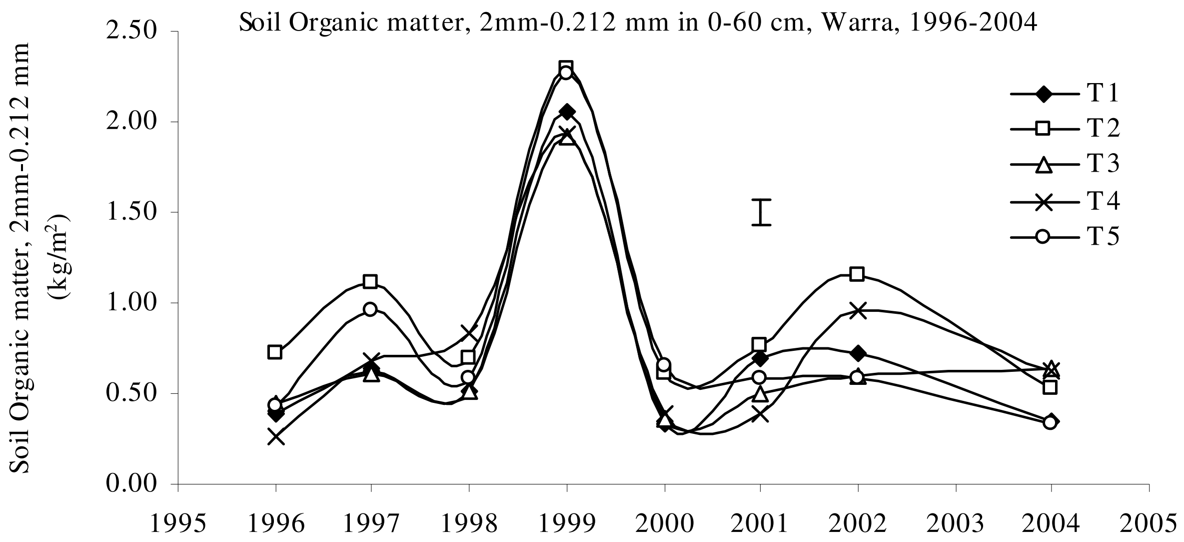

Figure 4. Effect of time and rotation crop on variation of coarse soil organic matter (2mm-212 µm in the 0-60 cm depth at "Prospect", Warra. Vertical bar is the standard error of the mean.

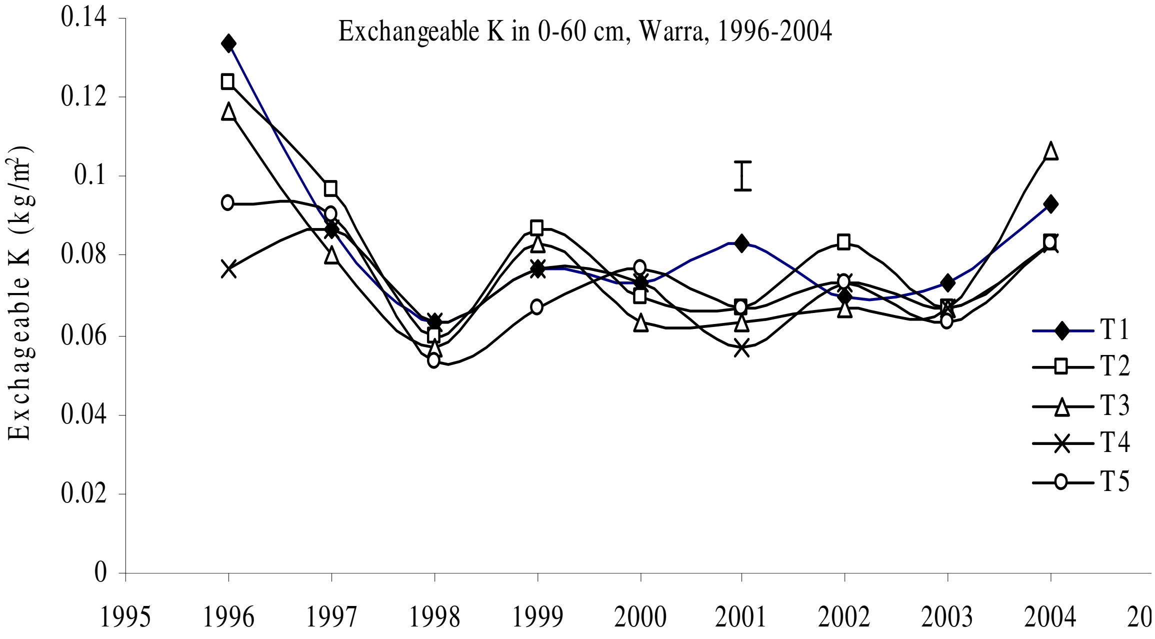

Figure 5. Effect of time and rotation crop on variation of exchangeable K in the 0-60 cm depth at "Prospect", Warra. Vertical bar is the standard error

Exchangeable cations

Crop rotation affected exchangeable K in the 0-60 cm depth only in some years (Fig. 5), although the differences among rotations were extremely small and were unlikely to have affected plant nutrition. In general. the peaks reflect the years when cotton was not sown and troughs when it was. Exchangeable K decreased significantly with time, although between 2003 and 2004 a small increase occurred from 0.07 to 0.09 kg/m^2. Values of exchangeable K were very low and indicate that this is likely to be significant constraint for crop production in this site.

Exchangeable Ca, Mg and Na were not affected at any time by rotation (Table 1). All exchangeable cation values fluctuated significantly with time ($P < 0.001$). The fluctuations in exchangeable Mg, K and Na, expressed on a volumetric basis, were weakly related (R^2 ~0.25**, n = 135) to the changes in coarse soil organic matter, presumably due to an interaction with soil carbonates and decomposing organic matter. R^2 values for linear relationships between coarse organic matter and exchangeable K, Na and Mg were somewhat improved when comparisons were made on a gravimetric basis (Table 4).

Table 1. Variation of exchangeable Ca, Mg and Na in the 0-60 cm depth at "Prospect", Warra, 1996 to 2004

Year	Exchangeable cations (kg/m^2)		
	Ca	Mg	Na
1996	11.9	3.1	0.3
1997	9.8	2.5	0.3
1998	9.0	2.5	0.4
1999	9.5	2.3	0.2
2000	10.4	2.8	0.4
2001	10.0	2.7	0.3
2002	8.6	2.7	0.3
2003	9.5	2.7	0.4
2004	9.2	2.9	0.4
P <	0.001	0.001	0.001
SEM	0.10	0.08	0.02

Sodicity indices

The sodicity indices ESP (exchangeable sodium percentage) and $EC_{1:5}$/ESC changed significantly with time and rotation (Tables 2 and 3), although these changes were relatively small. Further they had negligible effect on dispersion index in the 0-30 cm ($R^2 < 0.04$, P = ns) and were only weakly related to dispersion index in the 30-60 cm depth ($R^2 = 0.16$, $P < 0.001$). Previous analysis (Final Report for CRC project 12C) had suggested that the absence of or a weak relationship between these sodicity indices and dispersion may be due to zero tillage being practiced on this site. ESP and $EC_{1:5}$/ESC in the subsoil (30-60 cm depth), although having only a small or negligible effect on dispersion, may have some effect on plant nutrition, particularly in the context of inhibiting P and K uptake. The variation in both sodicity indices in the entire profile were moderately influenced by the changes in coarse organic matter (Table 4) with lowest ESP and highest $EC_{1:5}$/ESC occurring when coarse organic matter peaked.

Conclusions

Soil structural properties were affected primarily by tillage system (zero tillage) with rotation crops affecting structure only during a period of relatively higher compaction. Least compaction occurred with **double-cropped cotton-wheat** (T_3). While other soil properties were affected to some degree (statistically significant) by rotation crop, these changes were very small and usually could be considered as negligible as they were unlikely to affect crop growth. The major contributing factor to changes in soil chemical properties was the coarse soil organic matter, the more labile fraction of soil organic matter. However, due to a combination of extended drought leading to poor crop growth and low amounts of crop residues being returned to the soil, the amounts of coarse soil organic matter were very low and usually constituted <8% of total SOM. Significant improvement in soil chemical properties can be expected to occur if crops which produce large amounts (>15 t/ha) of dry matter such as forage sorghum were to be sown at regular intervals.

Table 2. Effect of time and rotation on exchangeable sodium percentage at "Prospect", Warra, 1996 to 2004.

Depth (cm)	Year	T1	T2	T3	T4	T5	Mean			
0-15	1996	1.4	0.9	1.5	1.1	1.2	1.2	***AOV***:	P <	SEM
	1997	1.2	0.8	1.4	1.1	0.9	1.1	Rotation (R)	0.05	0.09
	1998	1.9	1.3	1.9	1.1	1.6	1.6	Year (Y)	0.001	0.08
	1999	0.6	0.4	0.6	0.4	0.5	0.5	R x Y	0.01	0.17
	2000	2.1	2.1	2.8	2.1	2.1	2.2			
	2001	1.5	1.4	1.7	1.6	1.9	1.7			
	2002	1.3	1.9	1.3	1.5	1.2	1.3			
	2003	2.1	1.5	2.5	1.5	1.9	2.0			
	2004	2.1	1.4	1.7	1.4	2.2	1.8			
	Mean	1.6	1.4	1.7	1.3	1.5				
15-30	1996	2.4	2.7	2.5	2.3	2.6	2.5	***AOV***:	P <	SEM
	1997	3.6	2.3	3.3	2.2	2.1	3.1	Rotation (R)	ns	0.20
	1998	1.2	3.3	3.3	2.1	3.1	1.2	Year (Y)	0.001	0.18
	1999	3.8	0.9	1.2	1.1	1.3	4.2	R x Y	ns	0.34
	2000	3.4	4.9	4.2	3.5	4.2	3.2			
	2001	3.5	3.9	2.8	2.6	3.2	3.0			
	2002	3.3	2.7	3.2	2.6	2.6	3.1			
	2003	3.1	3.0	3.7	2.6	2.9	3.0			
	2004	2.4	3.0	3.2	2.5	3.1	2.5			
	Mean	3.0	3.0	3.1	2.4	2.8				
30-45	1996	3.4	4.3	4.2	3.9	4.2	4.0	***AOV***:	P <	SEM
	1997	3.8	4.4	5.3	3.6	4.1	4.2	Rotation (R)	ns	0.25
	1998	5.7	5.6	6.6	4.4	5.9	5.6	Year (Y)	0.001	0.23
	1999	1.9	1.6	1.8	1.7	1.9	1.8	R x Y	0.05	0.40
	2000	4.9	7.3	6.3	5.6	5.7	6.0			
	2001	4.3	5.5	4.0	3.9	4.7	4.5			
	2002	5.3	4.8	4.7	4.0	4.0	4.6			
	2003	4.6	5.3	5.3	3.8	3.9	4.6			
	2004	5.0	6.1	5.6	4.5	5.3	5.3			
	Mean	4.3	5.0	4.9	3.9	4.4				
45-60	1996	6.4	6.8	6.1	5.3	6.1	6.1	***AOV***:	P <	SEM
	1997	5.5	7.2	6.4	5.1	6.3	6.1	Rotation (R)	0.05	0.25
	1998	8.0	8.2	8.6	6.5	8.4	7.9	Year (Y)	0.001	0.22
	1999	2.8	2.5	2.9	2.5	3.0	2.7	R x Y	0.05	0.51
	2000	7.7	9.5	8.5	7.4	7.8	8.2			
	2001	5.3	6.9	5.5	5.4	6.2	5.9			
	2002	7.9	5.5	6.1	6.0	5.9	6.3			
	2003	6.5	6.5	7.1	5.3	5.6	6.2			
	2004	6.6	8.1	7.3	6.0	6.5	6.9			
	Mean	6.3	6.8	6.5	5.5	6.2				

Table 3. Effect of time and rotation on $EC_{1:5}$/ESC (exchangeable sodium content) at "Prospect", Warra, 1996 to 2004.

Depth (cm)	Year	T_1	T_2	T_3	T_4	T_5	Mean			
0-15	1996	0.52	0.78	0.63	0.52	0.56	0.60	***AOV***:	P <	SEM
	1997	0.59	0.90	0.52	0.60	0.74	0.67	Rotation (R)	0.05	0.022
	1998	0.40	0.50	0.38	0.45	0.44	0.43	Year (Y)	0.001	0.055
	1999	0.84	1.18	0.96	1.33	0.92	1.04	R x Y	0.01	0.070
	2000	0.59	0.40	0.45	0.57	0.48	0.50			
	2001	0.27	0.22	0.21	0.23	0.19	0.22			
	2002	0.59	0.57	0.69	0.38	0.74	0.60			
	2003	0.26	0.37	0.27	0.42	0.31	0.33			
	2004	0.21	0.28	0.21	0.26	0.22	0.24			
	Mean	0.47	0.58	0.48	0.53	0.51				
15-30	1996	0.23	0.22	0.22	0.18	0.27	0.22	***AOV***:	P <	SEM
	1997	0.26	0.26	0.21	0.28	0.34	0.27	Rotation (R)	ns	0.023
	1998	0.24	0.25	0.24	0.33	0.27	0.27	Year (Y)	0.001	0.019
	1999	0.36	0.53	0.44	0.48	0.39	0.44	R x Y	ns	0.055
	2000	0.32	0.21	0.25	0.30	0.23	0.26			
	2001	0.17	0.12	0.16	0.17	0.15	0.16			
	2002	0.31	0.37	0.37	0.41	0.33	0.36			
	2003	0.28	0.24	0.23	0.25	0.28	0.25			
	2004	0.16	0.14	0.11	0.16	0.17	0.15			
	Mean	0.26	0.26	0.25	0.28	0.27				
30-45	1996	0.21	0.13	0.18	0.15	0.15	0.16	***AOV***:	P <	SEM
	1997	0.18	0.15	0.13	0.17	0.19	0.16	Rotation (R)	ns	0.010
	1998	0.15	0.15	0.13	0.16	0.15	0.15	Year (Y)	0.001	0.008
	1999	0.13	0.15	0.14	0.16	0.13	0.14	R x Y	0.01	0.015
	2000	0.24	0.15	0.17	0.19	0.18	0.19			
	2001	0.16	0.11	0.12	0.15	0.13	0.13			
	2002	0.18	0.22	0.21	0.27	0.25	0.23			
	2003	0.19	0.16	0.15	0.17	0.18	0.17			
	2004	0.11	0.07	0.09	0.10	0.11	0.09			
	Mean	0.17	0.14	0.15	0.17	0.16				
45-60	1996	0.14	0.13	0.10	0.12	0.12	0.12	***AOV***:	P <	SEM
	1997	0.12	0.10	0.10	0.12	0.13	0.11	Rotation (R)	ns	0.007
	1998	0.13	0.11	0.10	0.13	0.11	0.12	Year (Y)	0.001	0.010
	1999	0.10	0.11	0.10	0.12	0.09	0.10	R x Y	0.01	0.016
	2000	0.17	0.12	0.15	0.14	0.14	0.14			
	2001	0.12	0.09	0.10	0.11	0.09	0.10			
	2002	0.16	0.28	0.16	0.16	0.20	0.19			
	2003	0.13	0.13	0.13	0.14	0.13	0.13			
	2004	0.10	0.06	0.07	0.08	0.10	0.08			
	Mean	0.13	0.13	0.11	0.12	0.12				

Table 4. R^2 values for linear relationships between coarse soil organic matter and measured soil properties in the 0-60 cm depth at "Prospect", Warra, 1996 to 2004 (n = 525)

Soil property	R^2	P <
Exchangeable K	0.33	0.001
Exchangeable Na	0.34	0.001
Exchangeable Mg	0.32	0.001
Exchangeable Ca	0.009	0.05
Soil resilience	0.01	0.05
Plastic limit	0.02	0.05
Calcium carbonate equivalent	0.19	0.001
$EC_{1:5}$	0.03	0.001
$EC_{1:5}$/ESC	0.44	0.001
ESP	0.38	0.001
EKP*	0.39	0.001
pH	0.09	0.001

5.1.2. <u>Long-term residual effects of crops sown in rotation with irrigated cotton on soil physical and chemical properties</u>

"Auscott", Warren

Residual effects of the rotation crops sown between 1993 and 1999 in Field 13 at "Auscott", Warren were not evident with respect to the soil physical and chemical properties measured in August 2004. Nevertheless the farm managers indicated that visual effects of the past rotation history were still evident on crop growth patterns. This suggests that the residual effects may be related to biological factors. During the previous phase of the project (see Final report for project CRC 12C) the differences with respect to crop growth were quantified.

Soil chemical properties had, however, improved between 2001 and 2004 (Table 5). Primarily there were large increases (approximately double) in soil organic C and subsoil exchangeable K, and reductions in salinity, sodicity and pH. Overall, there was a significant improvement in soil quality.

Table 5. Changes in soil chemical properties between 2001 and 2004 at "Auscott", Warren.

Soil property	Year	0-15 cm	15-30 cm	30-45 cm	45-60 cm	Mean	AOV
$EC_{1:5}$ (dS/m)	2001	0.30	0.26	0.26	0.29	0.28	P (years) < 0.001
	2004	0.16	0.25	0.23	0.18	0.20	P (years x depths) < 0.01
pH	2001	7.6	7.6	7.6	7.7	7.6	P (years) < 0.001
	2004	7.4	7.3	7.4	7.3	7.4	P (years x depths) < n.s.
Exchangeable Ca	2001	25.2	22.9	17.5	15.5	20.3	P (years) < 0.001
(cmol/kg)	2004	19.4	19.0	18.3	16.9	18.4	P (years x depths) < 0.01
Exchangeable Mg	2001	9.2	10.1	10.8	11.4	10.4	P (years) < 0.001
(cmol/kg)	2004	9.3	9.3	9.6	10.3	9.6	P (years x depths) < 0.01
Exchangeable K	2001	1.2	0.7	0.6	0.6	0.8	P (years) < 0.001
(cmol/kg)	2004	1.3	1.4	1.1	0.8	1.1	P (years x depths) < 0.001
Exchangeable Na	2001	0.5	0.7	1.1	1.8	1.0	P (years) < 0.05
(cmol/kg)	2004	0.6	0.6	0.8	1.7	0.9	P (years x depths) < 0.05
ESP	2001	2.1	2.6	4.3	6.8	4.0	P (years) < 0.001
	2004	2.1	1.9	2.8	5.6	3.1	P (years x depths) < 0.01
Ca:Mg	2001	2.9	2.4	1.8	1.5	2.1	P (years) < 0.001
	2004	2.1	2.0	1.9	1.6	1.9	P (years x depths) < 0.001
Soil organic	2001	0.61	0.42	0.40	0.38	0.45	P (years) < 0.001
carbon (g/100g)	2004	0.86	0.95	0.79	0.67	0.82	P (years x depths) < 0.01

"Beechworth", Merah North

The residual effects of the rotation crops sown between 1993 and 2000 were evident with respect to soil structure in the 15-45 cm depth, shown here as average specific volume of oven-dried soil (Table 6). Highest values occurred in the ex-sorghum plots and lowest in the ex-dolichos plots. Significant differences were absent among the other treatments. Significant residual effects of the rotation treatments were not present in the 0-15 cm depth.

Table 6. Effects of rotation history on soil specific volume (cm^3/100g) in the 0-45 cm depth at "Beechworth", Merah North. Results have been averaged for 2002 and 2003.

Rotation	0-15 cm	15-45 cm
Continuous cotton	61.1	44.7
Cotton-faba (1992-98) fb. cotton-sorghum (1999-2000)	59.8	45.3
Long-fallow cotton	59.9	44.8
Cotton-wheat	58.6	44.8
Cotton -dolichos	60.1	44.7
Cotton-dolichos (+ P and K fertiliser)	59.9	44.4
SEM	0.93	0.19
P <	n.s.	0.05

Table 7. Change in soil chemical properties with depth and year at "Beechworth", Merah North.

Year	Depth	pH (0.01M	$EC_{1:5}$	SOC	Exch. Ca	Exch. Mg	Exch. Na	Exch. K	Ca:Mg	ESP	$EC_{1:5}$/
	(cm)	$CaCl_2$)	(dS/m)	(g/100g)		(cmol/kg)					ESC
2002	0-15	7.1	0.24	1.12	19.9	14.9	2.7	1.0	1.3	6.9	0.10
	15-30	7.2	0.32	1.00	19.0	16.5	4.9	0.7	1.2	11.8	0.07
	30-45	7.2	0.45	0.88	18.3	16.8	6.8	0.6	1.1	15.8	0.07
	45-60	7.3	0.58	0.78	18.4	17.1	7.9	0.6	1.1	17.9	0.07
	SEM	0.01	0.024	0.029	0.13	0.16	0.16	0.02	0.01	0.29	0.005
	P <	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
2003	0-15	7.2	0.28	0.90	21.0	14.8	2.5	1.2	1.4	6.2	0.12
	15-30	7.2	0.27	0.71	21.0	16.7	3.4	0.9	1.3	8.1	0.08
	30-45	7.5	0.29	0.67	20.6	18.4	5.7	0.7	1.1	12.4	0.05
	45-60	7.6	0.32	0.70	20.1	17.8	6.9	0.6	1.2	15.1	0.05
	SEM	0.03	0.022	0.046	0.55	0.41	0.30	0.044	0.02	0.45	0.01
	P <	0.001	n.s.	0.05	n.s.	0.01	0.001	0.001	0.001	0.001	0.001
Between years:											
0-15 cm	SEM	0.03	0.009	0.048	0.33	0.18	0.09	0.04	0.02	0.20	0.003
	P <	0.01	0.05	0.01	0.05	n.s.	n.s.	0.001	0.05	0.05	0.01
15-30 cm	SEM	0.02	0.01	0.04	0.24	0.26	0.13	0.01	0.02	0.28	0.003
	P <	n.s.	0.001	0.001	0.001	n.s.	0.001	0.001	0.001	0.001	0.01
30-45 cm	SEM	0.02	0.011	0.031	0.14	0.16	0.12	0.01	0.01	0.27	0.002
	P <	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.050	0.001	0.001
45-60 cm	SEM	0.01	0.032	0.031	0.20	0.23	0.12	0.10	0.01	0.27	0.004
	P <	0.001	0.001	n.s.	0.001	n.s.	0.001	n.s.	0.01	0.001	0.001

Residual effects of the rotation crops sown at "Beechworth" on soil chemical properties were present only with respect to sodicity and exchangeable K, although there were large differences in all chemical properties between depths and between years for any one depth (Table 7). Lowest exchangeable K was observed in the 15-45 cm depth, and lowest exchangeable Na in the 0-15 cm and 45-60 cm depths of the ex-long-fallow cotton. Decreases between 2002 and 2003 in exchangeable Na in the 45-60 cm depth were also significant ($P < 0.05$) in the ex-sorghum, ex-long-fallow and ex-cotton-wheat and ranged from 12 to 26%. Key changes in soil chemical properties between 2002 and 2003 were an increase in exchangeable K, and decreases in sodicity, soil organic carbon and the dispersive nature of the soil (due to a general decrease in sodicity). The decreases in sodicity were probably due to changing the source of irrigation water from bore to river water.

5.1.3. Effects of sowing irrigated cotton into standing wheat stubble

When cotton is sown into standing wheat stubble on permanent beds (Fig 5), the standing stubble is known to reduce erosion (Fig 6) 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 had not previously been studied. 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 5. Cotton sown into standing wheat stubble at the Australian Cotton Research Institute, near Narrabri, New South Wales

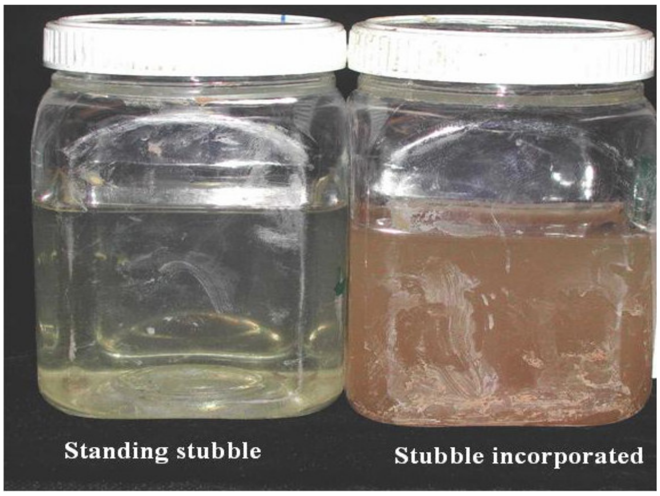

Figure 6. Runoff water from the trial at “Woodgrair near Boggabri, NSW, where cotton was sown either into standing wheat stubble or after wheat stubble was incorporated. Photograph provided by M. Hickman

5.1.3.1 Soil properties

The soil quality benefits in sowing cotton into standing wheat stubble are manyfold. These 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 2004, profile water content was 414 mm with conventionally-tilled/continuous cotton, 411 mm with minimum-tilled continuous cotton and 489 mm with minimum-tilled/cotton-standing wheat stubble ($P < 0.001$, S.E.M. = 4.7). In other words, there was an average difference of 77 mm between the two continuous cotton systems and the cotton-wheat system. 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 are not maintained throughout the cotton season (Fig. 7) due to a combination of varying water extraction by different treatments and clearing stubble from furrows to avoid waterlogging (see section 5.1.5).

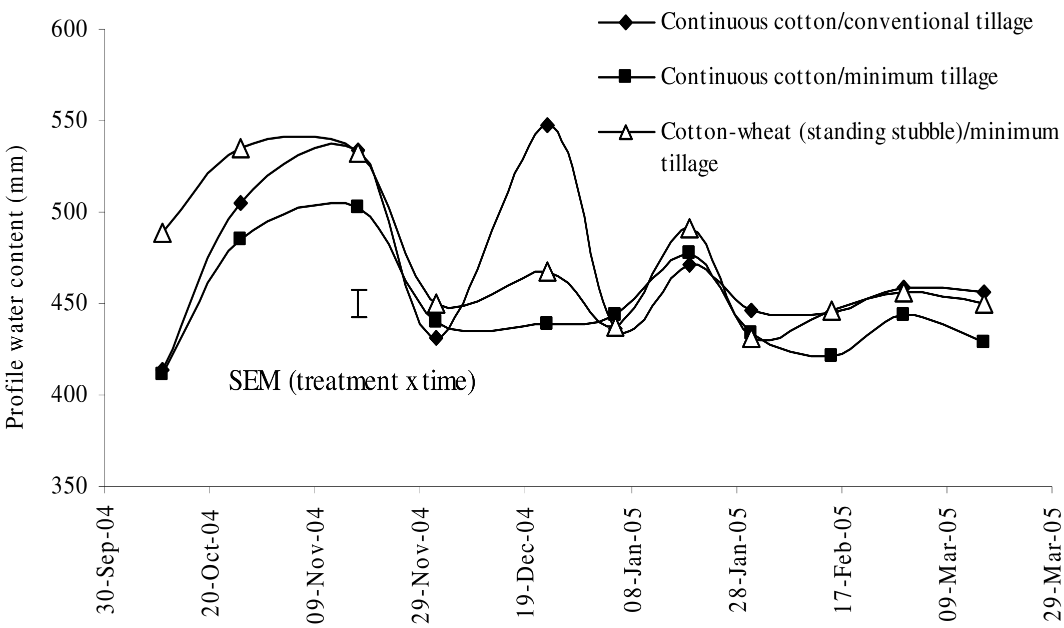

Figure 7. Effect of tillage and cropping system on variation of soil water storage during the 2004-05 cotton season, Field C1, ACRI, Narrabri

- *Soil carbon sequestration:* Sowing cotton into standing wheat stubble resulted in significant increases in soil organic carbon only within the surface 30 cm. Results for deeper soil layers were, therefore excluded from Table 9. In general, soil organic carbon values were higher when cotton was sown into standing wheat stubble. There were two sites where this did not occur; *viz.* at "Buttabone", near Warren and in the cover crop experiment at ACRI. The absence of any response to retaining standing wheat stubble at "Buttabone" may be a reflection of the rainfall received at "Buttabone" (4 mm) during the three months prior to sampling. The virtual absence of rain is likely to have greatly reduced stubble breakdown and conversion to SOC. In the abovementioned experiment at ACRI, wheat growth was poor due to high weed populations and may have confounded the results (Fig. 8).

Figure 8. High populations of dead nettle in wheat plots in Field 4 at ACRI, September 2002.

- *Alleviating salinity and sodicity:* In saline and sodic soils, sowing cotton into standing wheat stubble increases infiltration and hence, drainage. This in turn facilitates leaching of excess salts and exchangeable Na out of the rooting zone. As an example, between 20001 and 2003 at 'Woodgrain", linear regression analysis of time (years) and exchangeable sodium percentage, ESP (sodicity) for pooled data for the 0-120 cm depth resulted in slopes of -3.32 for the standing stubble systems and 3.69 for the stubble incorporated system ($P < 0.001$). In other words, ESP decreased in with standing stubble at a rate of 3.3 percentage units/year whereas with stubble incorporation it increased by 3.7 percentage units/year. This differences is probably dues to differences in drainage and associated salt leaching. Closer analysis of the results indicates that a major part (95%) of the changes occurred between 2001 and 2002 but far less so between 2002 and 2003. This is because there was sufficient water for irrigation and hence, drainage during the 2001-02 season, but not during the 2002-03 season. In addition, only 28 mm of rain fell during the 2002 winter. In soils of low salinity and sodicity such as at ACRI, such changes are far less striking.

- *Soil fertility:* 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 (Table 10). The increases in SOC, however, were usually limited to the surface 30 cm.

Table 9. Effect of sowing cotton into standing stubble on carbon sequestration in the 0-30 cm depth

Site	Cropping system	Soil organic C in the 0-30 cm depth (t/ha)			
		2001	**2002**	**2003**	**2004**
"Buttabone",	Cotton phase of cotton-wheat (standing stubble) rotation		40.2		
Warren	Wheat phase of cotton-wheat (standing stubble) rotation		37.9		
			P = n.s.		
"Woodgrain"	Cotton sown into standing wheat stubble	29.2	34.7	29.8	
Boggabri	Cotton sown into incorporated wheat stubble	37.5	37.8	33.2	
		P (Cropping systems, CS) < 0.05, P (Years) < 0.01, P (CS x years) = n.s.			
ACRI[*1], Narrabri	Bare		36.9	12.8	
(Cover crop	Mustard		42.7	13.3	
experiment of	Vetch		41.0	12.8	
D. Nehl)	Wheat (standing stubble)		37.1	14.1	
			P < 0.05	P = n.s.	
ACRI, Narrabri	Conventional tillage/continuous cotton		34.7		35.8
(Tillage/rotation	Minimum tillage/continuous cotton		39.9		42.0
Experiment)	Minimum tillage/cotton-wheat (standing stubble)		40.5		44.5
			P (CS x years) < 0.05		
ACRI, Narrabri	Continuous cotton				31.2
(Cotton/vetch/	Cotton-vetch				29.5
wheat rotations	Cotton-wheat (stubble incorporated)/cotton phase				33.3
Experiment)	Cotton-wheat (stubble incorporated)/wheat phase				31.8
	Cotton-wheat (standing stubble)-vetch/cotton phase				33.5
	Cotton-wheat (standing stubble)-vetch/wheat phase				31.2
					P = n.s.
"Federation Farm", Narrabri	2.5 t/ha Gypsum in 2000 fb. stubble incorporation in 2003. Between 2000 and 2003 cotton was sown into standing stubble.	28.7	30.4	24.7	25.2
	No-Gypsum fb. standing stubble	29.9	29.4	29.4	25.6
		P = n.s.	P = n.s.	P < 0.05	P = n.s.

[1] 2003 results are limited to the 0-10 cm depth

Table 10. Effect of tillage and cropping system on soil properties, ACRI, September 2004. Cotton stubble was incorporated in all treatments. Results for 2002 and 2004 were pooled. SOC, soil organic carbon; ESP, exchangeable sodium percentage; ESC, exchangeable sodium content.

Depth (cm)	Tillage system	Crop rotation	pH	$EC_{1:5}$ (dS/m)	Exchangeable cations (cmol/kg) Ca	Mg	K	Na	ESP	Ca:Mg	SOC (g/100g)	$EC_{1:5}$ /ESC
0-15	Conventional	Continuous cotton	6.9	0.35	22.5	11.5	1.9	0.8	2.1	2.0	0.89	0.49
	Minimum	Continuous cotton	6.6	0.36	20.3	10.0	1.9	0.5	1.5	2.1	1.03	0.78
	Minimum	Cotton-wheat; wheat stubble retained *in situ* as standing stubble	6.7	0.31	21.2	9.9	1.9	0.4	1.3	2.2	1.13	0.74
	SEM		0.06	0.027	0.72	0.45	0.06	0.04	0.08	0.03	0.027	0.073
	P <		0.05	n.s.	n.s.	n.s.	n.s.	0.01	0.01	0.05	0.01	0.05
15-30	Conventional	Continuous cotton	7.0	0.28	23.9	12.9	1.4	1.4	3.5	1.9	0.66	0.26
	Minimum	Continuous cotton	6.9	0.23	22.1	11.3	1.3	0.9	2.5	2.0	0.75	0.26
	Minimum	Cotton-wheat; wheat stubble retained *in situ* as standing stubble	7.0	0.18	23.5	11.4	1.4	0.9	2.3	2.1	0.72	0.23
	SEM		0.07	0.011	0.81	0.72	0.04	0.23	0.47	0.06	0.047	0.019
	P <		n.s.	0.01	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
30-45	Conventional	Continuous cotton	7.1	0.21	24.5	13.8	1.1	2.0	4.8	1.8	0.55	0.11
	Minimum	Continuous cotton	7.1	0.21	22.5	12.1	1.0	1.5	3.9	1.9	0.64	0.14
	Minimum	Cotton-wheat; wheat stubble retained *in situ* as standing stubble	7.0	0.19	23.7	12.7	1.1	1.3	3.4	1.9	0.67	0.15
	SEM		0.01	0.008	0.51	0.59	0.05	0.18	0.34	0.06	0.036	0.010
	P <		0.05	n.s	n.s	n.s	n.s	0.05	0.05	n.s	n.s	0.05
45-60	Conventional	Continuous cotton	7.1	0.21	23.4	13.7	1.1	2.2	5.4	1.8	0.57	0.10
	Minimum	Continuous cotton	7.0	0.19	21.7	13.3	1.0	1.9	5.0	1.7	0.59	0.11
	Minimum	Cotton-wheat; wheat stubble retained *in situ* as standing stubble	7.0	0.19	23.5	13.3	1.0	1.7	4.1	1.8	0.63	0.12
	SEM		0.03	0.015	0.92	0.74	0.08	0.24	0.47	0.08	0.022	0.012
	P <		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
60-120	Conventional	Continuous cotton	7.1	0.26	20.3	14.8	1.0	3.4	8.6	1.4	0.50	0.08
	Minimum	Continuous cotton	7.1	0.23	19.3	13.8	0.9	2.3	6.3	1.4	0.47	0.10
	Minimum	Cotton-wheat; wheat stubble retained *in situ* as standing stubble	7.1	0.20	20.2	13.6	1.0	2.2	5.8	1.5	0.55	0.10
	SEM		0.03	0.021	0.50	0.64	0.05	0.45	0.97	0.07	0.027	0.010
	P <		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

- *In-situ soil structure*: Soil structure may be improved by sowing cotton into standing wheat stubble. Profile macroporosity in the tillage/rotation experiment at ACRI during May 2003 (Fig. 9) was in the order of minimum-tilled cotton-wheat (standing stubble) > minimum tilled continuous cotton > conventionally tilled continuous cotton. The differences in subsoil structure are probably a long-term cumulative effect of the crop rotations and tillage systems which have been in place rathe than the short-term effects of the standing stubble.

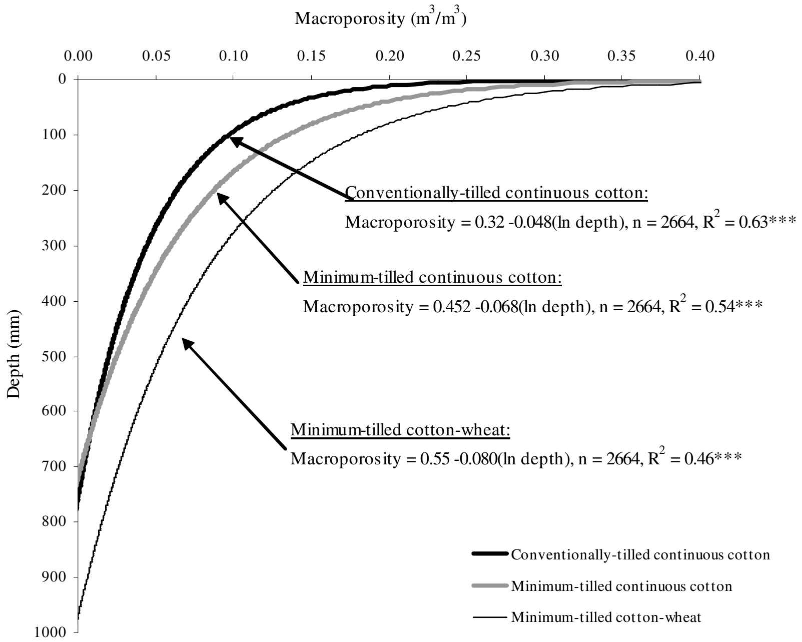

Figure 9. Effect of tillage and cropping system on *in-situ* macroporosity at field capacity in May 2003

- *Root growth and carbon dynamics:* Seasonal soil carbon dynamics was estimated as carbon added to the soil through root initiation and death. Root dynamics were measured with a minirhizotron in the tillage/rotation experiment during the 2002-03 and 2004-05 cotton seasons. Significant differences were absent between cropping systems in 2002-03 but were present during 2004-05. Mean net seasonal carbon in roots at season's end was 1.0 t/ha with conventionally-tilled continuous cotton, 1.1 t/ha with minimum-tilled continuous cotton and 1.7 t/ha with minimum-tilled cotton-wheat during the 2002-03 season (P = n.s.), and 0.3 t/ha with conventionally-tilled continuous cotton, 0.5 t/ha with minimum-tilled

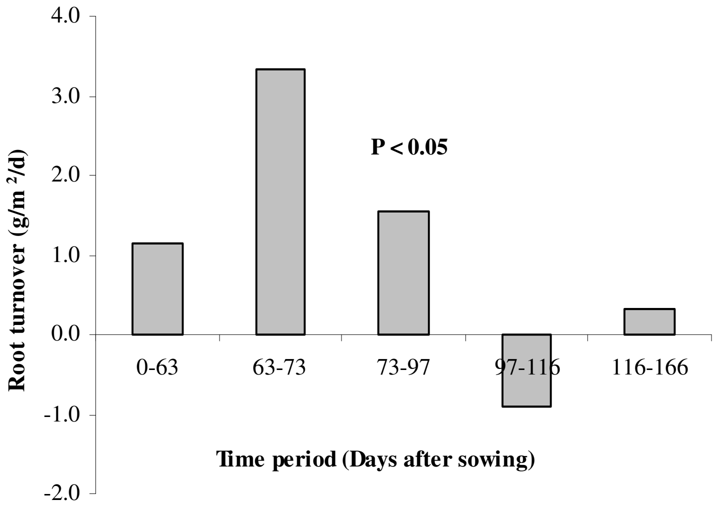

Figure 10. Seasonal variation in root carbon turnover at ACRI, 2002-03

continuous cotton and 0.9 t/ha with minimum-tilled cotton-wheat during the 2004-05 season (P < 0.05). Flooding during 2004-05 may have caused these differences. There were significant (P < 0.001) differences in periods of root initiation, with greatest initiation occurring during between December and January during 2002-03 (Fig. 10) and January and February during 2004-05.

- *Minimising soil physical damage*: Soil physical damage caused by accidental trafficking appears to be minimised by standing wheat stubble. Accidental trafficking in field C1 at ACRI by a laser-leveller operating in an adjacent field increased mean soil strength in the surface 10 cm by 17 times in stubble-incorporated plots and by 12 times in plots where standing wheat stubble was retained *in situ* (Fig 11). Maximum depths of compaction and peak values of penetrometer resistance were also lower in the latter.

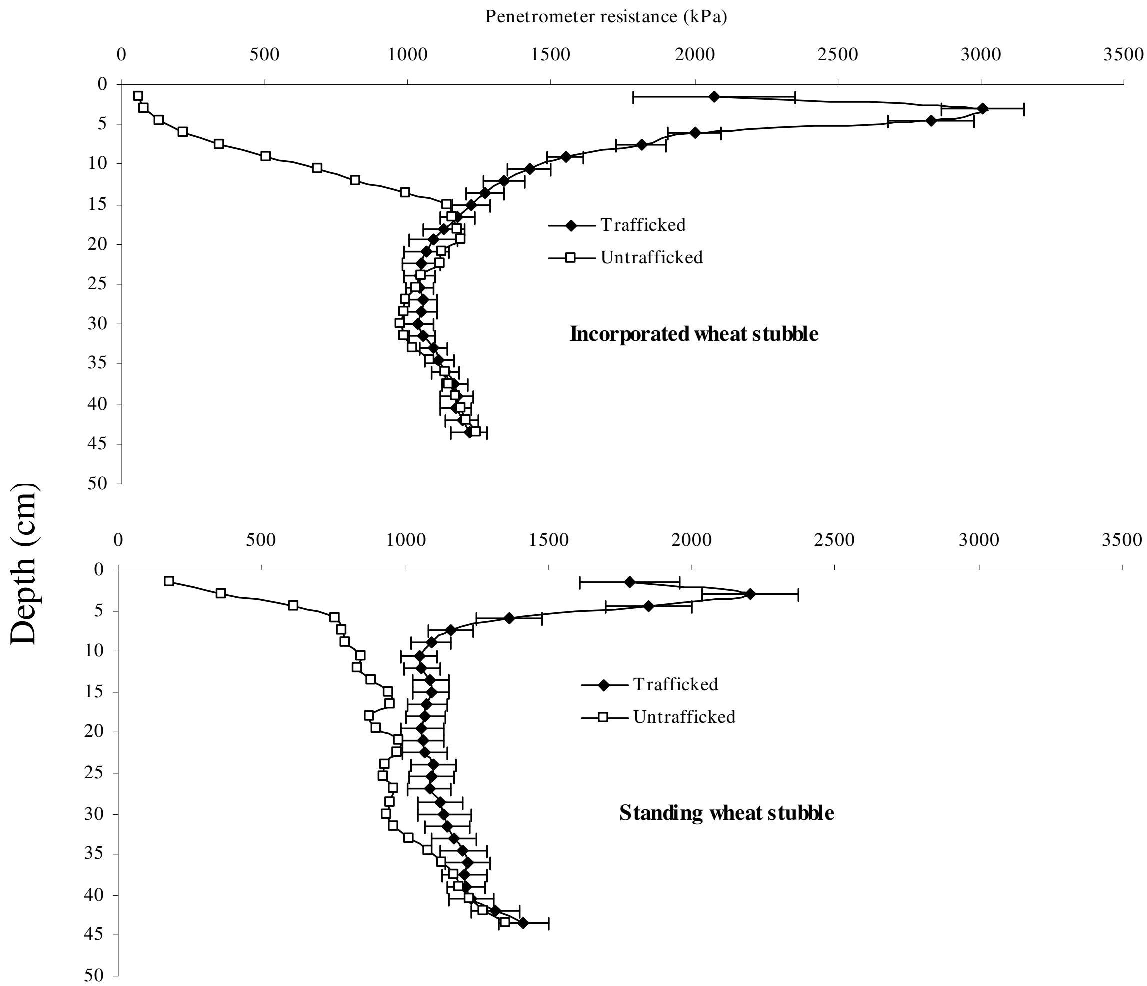

Figure 11. Effect of accidental trafficking with a laser-leveller on soil strength (measured as penetrometer resistance) in plots where wheat stubble was either incorporated or retained a standing stubble, Field C1, ACRI, Narrabri, June 2004. Soil water contents did not differ significantly. Horizontal bars are SEM's.

*5.1.3.2 Cotton lint yield*s

At ACRI, where Roundup-Ready® cotton was sown in all treatments, average lint yields between 2000 and 2005 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 11). In other words, sowing cotton into standing wheat stubble yielded on average 15% more than continuous cotton sown after conventional tillage and 9% 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%. Simulation with HydroLOGIC for the seasonal conditions of 2004-05 resulted in cotton lint yields of 6.1 bales/ha for conventionally-tilled continuous cotton, and 7.1 bales/ha for both minimum-tilled treatments. The simulated yield values were lower than actual yields by an average of 35%. In a second experiment at ACRI, lint yields in paired plots of cotton sown during the 2004-05 season into either standing wheat stubble or after wheat stubble was incorporated were 11.2 ± 2.16 bales/ha and 8.8 ± 1.52 bales/ha, respectively ($P < 0.05$, $t = -2.80$, $n = 5$). Sowing cotton into standing wheat stubble resulted, therefore, in a yield increase of 27%.

Table 11. Effect of tillage system and wheat rotation crop on cotton lint yield (bales/ha), Field C1, ACRI. 1 bale = 227 kg.

Tillage system	Cropping system	2000-01	2002-03	2004-05	Mean
Conventional	Continuous cotton	8.1	6.4	10.0	8.2
Minimum	Continuous cotton	9.5	5.9	10.4	8.6
Minimum	Cotton-wheat[1]	9.8	7.3	11.0	9.4
P <		0.05	0.01	0.05	
SEM		0.30	0.15	0.22	

[1]Wheat yielded 2.0 t/ha during winter 2001and 2.8 t/ha during winter 2003.

Cotton lint yields during the 2002-03 season on permanent beds at "Buttabone", near Warren were 4.5 bales/ha after cotton and 6.9 bales/ha when sown into standing wheat stubble, an increase of 51%. At "Woodgrain", near Boggabri yields were 4.7 bales/ha when cotton was sown in to standing wheat stubble and 3.5 bales/ha when wheat stubble was incorporated. Although yields were low in both fields at Boggabri because of high salinity and sodicity, sowing into stubble increased yield by 34%.

5.1.3.3 Profitability

Gross margins and variable costs

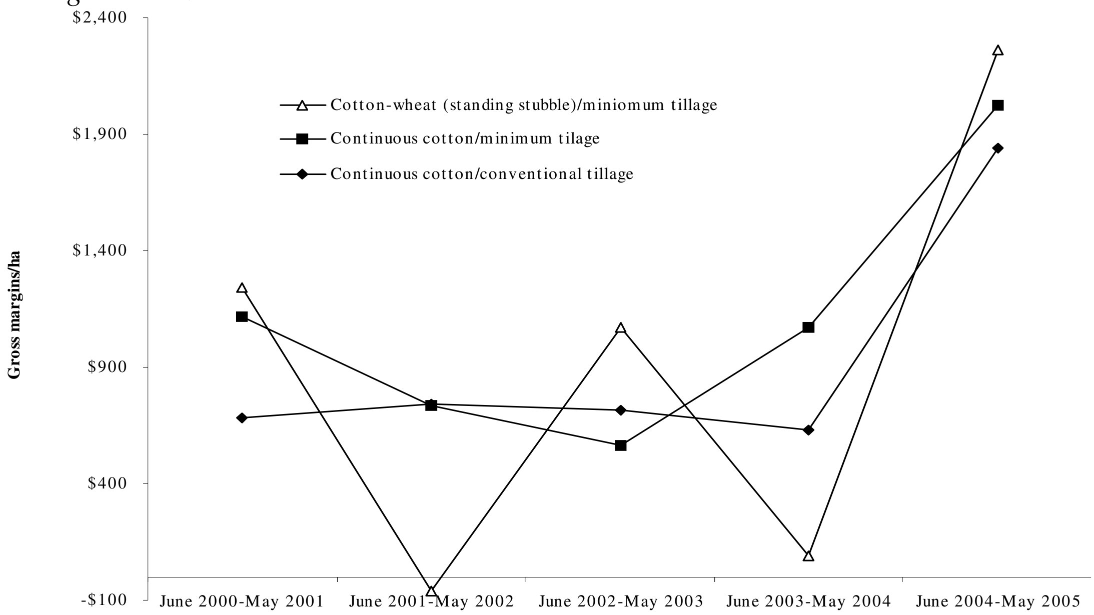

Figure 12. Effect of tillage and cropping system on annual variation of gross margins. 1 bale of cotton lint = $350

Gross margins/ha were highest with minimum-tilled cotton-wheat in years when cotton was sown, but lowest during years when wheat-summer fallow was sown (Fig 12). The cumulative gross margins (Table 12) suggest, however, that the high gross margins during the cotton phase of the rotation were unable to compensate for the low gross margins during the wheat-fallow phase. The very low gross margin values during the latter phase was due to the high cost of chemical weed control associated with controlling regrowth and volunteers of Roundup-Ready® cotton. The absence at ACRI by of suitable attachments for minimum tillage machinery such as centre-busting tines which are widely-used in commercial cotton production systems means that there is an over-dependency on herbicides. These attachments would easily control cotton re-growth by eliminating deep cotton roots during the tillage operation.

Table 12. Effect of tillage and rotation system on cumulative gross margins, income and variable costs from 2000 to 2005, Field C1, ACRI.

Cumulative values	Continuous cotton/ conventional tillage	Continuous cotton/ minimum tillage	Cotton-wheat (standing stubble)/ minimum tillage
Cumulative income ($/ha)	15,013	16,080	12,087
Cumulative variable costs ($/ha)	10,398	10,565	7,475
Cumulative gross margin ($/ha)	4,615	5,515	4,612
Income/ variable costs ratio	1.44	1.52	1.62
Gross margin/ variable costs ratio	0.44	0.52	0.62
Mean cotton yield (bales/ha)[1]	7.41	7.95	9.38
Cumulative gross margins/ML of irrigation water	185	221	210
Cumulative irrigation water applied (ML/ha)	25	25	22

[1] Averaged for all years from 2000 to 2005

Cumulative gross margin was higher with minimum tilled continuous cotton than either of the other two treatments (Table 12). Gross margin values of minimum tilled cotton-wheat and conventionally tilled continuous cotton were similar. However, the gross margin/variable cost ratios indicates that minimum tilled cotton-wheat had the highest return for costs invested. The wheat/cotton rotation also had the highest lint yield per cotton crop.

Gross margins/ML of irrigation water were in the order of minimum tilled continuous cotton > minimum tilled cotton-wheat > conventionally tilled continuous cotton. If irrigation water was the limiting factor and maximum profitability was preferred, then the minimum tilled continuous cotton would have been the preferred option. The annual average returns relative to variable costs (over 5 years) (Fig. 13) show that although minimum tilled cotton-wheat had the lowest gross margin, it also had the lowest costs. At $350/bale of cotton lint, minimum tilled cotton-wheat had almost identical profitability to conventionally tilled continuous cotton, but at lower cost. It seems, therefore, that minimum tillage options offer good alternatives to a conventionally tilled continuous cotton system.

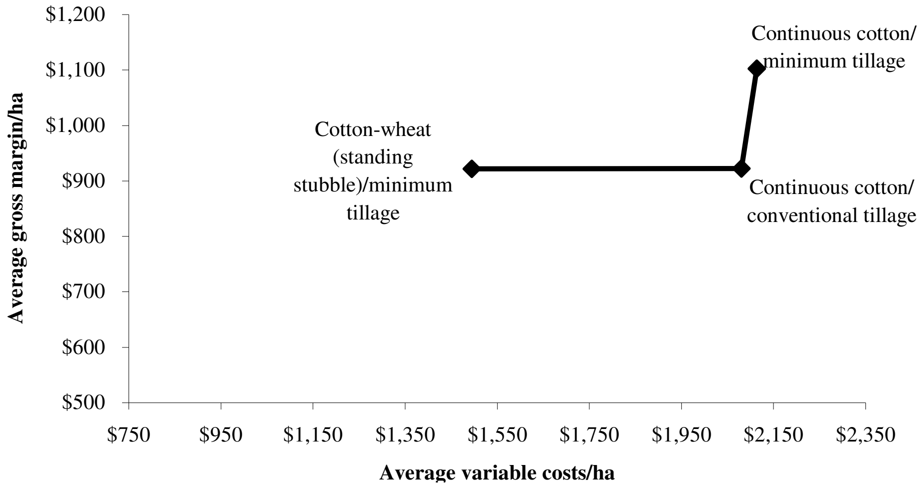

Figure 13. Effect of tillage and rotation system on variation of average annual gross margin returns relative with variable costs

Effect of variable cotton prices

A sensitivity analysis was done to observe the effects of a change in cotton lint price. The cotton seed price was kept at $175 per tonne. Cotton seed is sold into a different market and is not correlated to cotton lint price.

Table 13. Sensitivity table indicating variation of gross margins with varying cotton lint prices (GM/VC, gross margin/variable costs)

Cotton price ($/bale)	Continuous cotton/ conventional tillage		Continuous cotton/ minimum tillage		Cotton-wheat (standing stubble)/ minimum tillage	
	Gross margin/ha	GM/VC ratio	Gross margin/ha	GM/VC ratio	Gross margin/ha	GM/VC ratio
300	2,761	0.27	3,528	0.33	3,204	0.43
350	4,615	0.44	5,515	0.52	4,612	0.62
400	6,467	0.62	7,501	0.71	6,018	0.81
450	8,321	0.80	9,488	0.90	7,426	0.99
500	10,173	0.98	11,474	1.09	8,832	1.18

Irrespective of cotton lint price, the results were the same with cumulative gross margins occurring in the order of minimum tilled continuous cotton > conventionally tilled continuous cotton > minimum tilled cotton-wheat. Highest gross margin to variable costs ratio was with minimum tilled cotton-wheat. When lint prices was $350/bale, minimum tilled cotton-wheat and conventionally tilled continuous cotton had almost identical total gross margins, but the former had better returns to costs. As the cotton lint price fell to $300/bale, conventionally tilled continuous cotton changed from second-most profitable to least profitable.

5.1.4. Comparative effects of cotton-wheat and cotton-vetch rotations

Cotton/wheat/vetch rotation experiment at ACRI

Soil properties and crop agronomy

The cotton/wheat/vetch rotation experiment was established during 2002 in Field D1 at ACRI. This site was characterized by extensive subsoil compaction (Fig. 14), low soil organic carbon (≤ 0.5 g/100g at depths > 30 cm) and subsoil sodicity (ESP at depths > 30 cm was > 8).

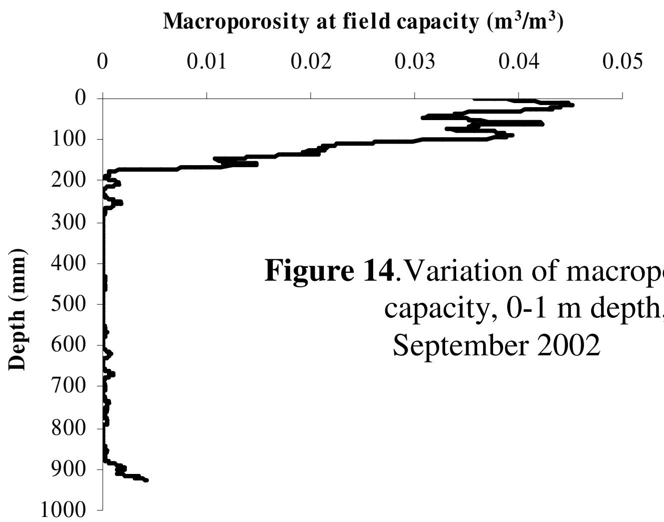

Figure 14. Variation of macroporosity at field capacity, 0-1 m depth, Field D1, ACRI, September 2002

Dry matter production by vetch in the cotton-vetch rotation during the winter of 2003 averaged 4.1 t/ha (N content of 3.9%). After correction for residual soil N, N fixation was estimated to be of the order of 126 kg N/ha. Dry matter production by vetch during winter 2004 was 3.8 t/ha (N content of 3.3%) in the cotton-vetch rotation and 7.9 t/ha (N content of 4.3%) in the cotton-wheat (standing stubble)-vetch rotation ($P < 0.001$, SEM = 0.23). Significant differences did not occur with respect to the N content in dry matter. N fixation by vetch in the cotton-vetch rotation was estimated to be 100 kg N/ha and in the cotton-wheat (standing stubble)-vetch rotation 335 kg N/ha. Mean wheat yields during the winters of 2003 and 2004 were 2.9 t/ha and 4.2 t/ha, respectively.

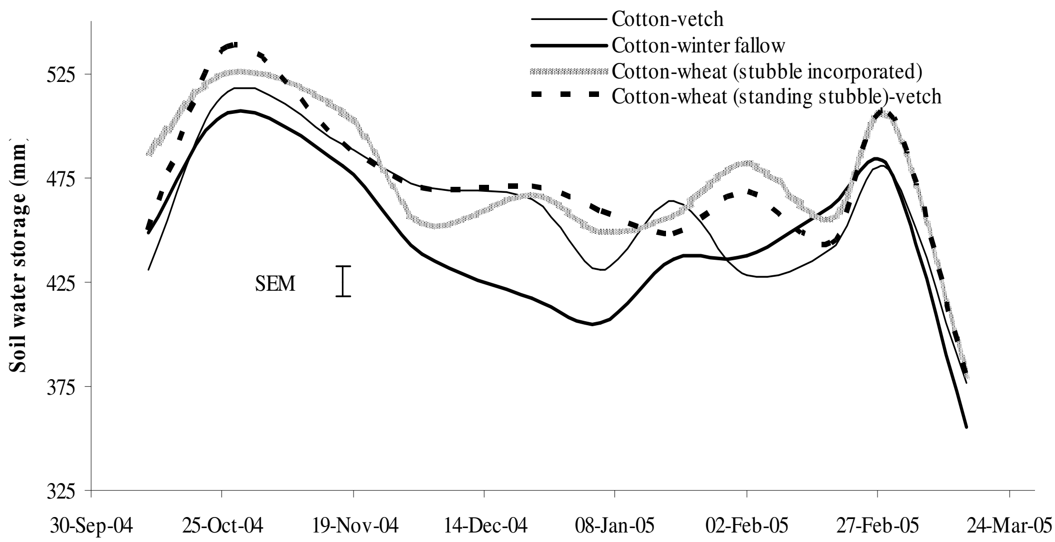

Figure 15. Effect of cropping system on seasonal variation of soil water storage, Field D1, ACRI, 2004-05 season

During the 2004-05 cotton season soil water storage to a depth of 1.2 m between 10 October 2004 and 31 January 2005 was generally higher in cropping systems which included a rotation crop and lowest in the cotton-winter fallow sequence (Fig. 15). These differences were poorly correlated to subsequent cotton lint yield ($R^2 = 0.29$, P = n.s.). Soil water storage in the same depth during February was 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 (Final Report for CRC Project 12C).Yields during the 2004-05 season were significantly correlated to mean soil water storage during February 2005 ($R^2 = 0.52$, $P < 0.001$).

Cotton lint yields were low during the 2003-04 season and may be due to the poor soil quality in this site. Lint yield in the cotton-vetch rotation was lower than that of the cotton-winter fallow sequence (Table 14) and was probably due to a combination of poor soil quality (see earlier comments) and poor emergence of cotton sown into vetch stubble. Cotton crop growth (Fig. 16) and lint yields (Table 14) during the 2004-05 season were higher in cropping systems which included a wheat rotation crop with highest values occurring with cotton-wheat-vetch sequence. As discussed previously, the higher yields with wheat rotation crops may largely be because they improved the numbers of pores which are involved in water storage. Yields in 2004-05 were also higher than those in 2003-04. This may be partly due to higher in-crop rainfall and partly to better overall soil quality. For example, soil organic carbon increased significantly ($P < 0.01$) in all depths. Simulated yields obtained with HydroLOGIC for the seasonal conditions of 2004-05 were identical with actual yields for cotton-vetch, 21% higher for cotton-winter fallow, 5% lower for cotton-wheat and 14% higher for cotton-wheat-vetch.

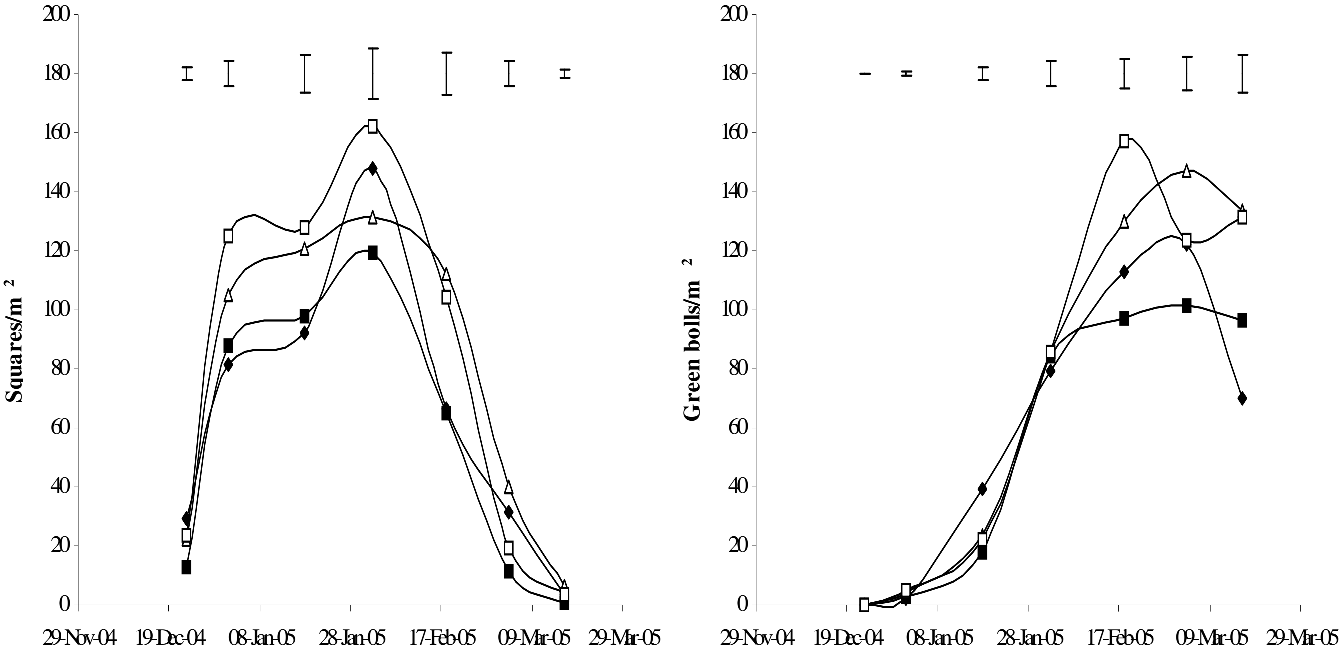

Figure 16. Effect of cropping system on variation of squares and green bolls per unit area during the 2004-05 cotton season. Vertical bars are SEM's. ♦ - Cotton-vetch, ■ - Cotton-winter fallow, Δ - Cotton-wheat (stubble incorporated), □- Cotton-wheat (stubble incorporated)-vetch

Table 14. Effect of cotton/vetch/wheat rotations on cotton lint yield (bales/ha) in Field D1, ACRI, 2002-03 and 2003-04 cotton seasons. Values in parentheses for the 2004-05 season are simulated yield values obtained with HydroLOGIC.

Rotation	Rotation crop stubble management	2003-04	2004-05
Cotton-vetch	Retained *in situ*	4.0	7.9 (7.9)
Cotton-winter fallow	-	6.7	8.1 (9.8)
Cotton-wheat	Incorporated	-	10.1 (9.6)
Cotton-wheat-vetch	Retained *in situ*	-	11.1 (12.7)
SEM		0.11	0.66
P <		0.01	0.05

After completion of a single rotation cycle in the cotton-wheat (stubble incorporated) and cotton-wheat (standing stubble)-vetch sequences, and two cycles of the cotton-vetch and cotton-winter fallow sequences in the cotton-vetch-wheat systems experiment at ACRI, major differences in soil properties were related primarily to differences in nitrate-N concentration (Table 15). Nitrate-N was highest in the surface 10 cm with cotton-winter fallow and cotton-wheat. This was because these rotations, which did not include a vetch component, received 160 kg N/ha as anhydrous ammonia before sowing. (N fertilizer was applied to the other rotations in late January at a rate of 60 kg N/ha in the form of urea). At this stage of the experiment, sowing vetch does not appear to have resulted in nitrate-N accumulation in the soil. The nitrate-N in the wheat stubble incorporated treatment was lower than that in the cotton-winter fallow sequence, and may have been caused by a combination of N volatilization and N leaching. The nitrate-N increased electrolyte concentrations in the soil, and thereby affected $EC_{1:5}$ (R^2= 0.38, P < 0.001, n = 72) and $EC_{1:5}$/ESC (Exchangeable sodium content) (R^2= 0.77, P < 0.001, n = 72). There were also very small differences with respect to exchangeable Ca in the 0-10 cm depth, and exchangeable K and Na, and ESP in the 60-120 cm depth. Carbon sequestration was unaffected by any of the experimental treatments.

Table 15. Soil properties under cotton/vetch/wheat rotations, ACRI, September 2004. Cotton stubble was incorporated but rotation stubble was managed as indicated in table.

Depth (cm)	Rotation	Rotation crop stubble management	pH	$EC_{1:5}$ (dS/m)	Nitrate-N (mg /kg OD soil)	Exchangeable cations (cmol/kg) Ca	Mg	K	Na	ESP	Ca:Mg	SOC (g/100g)	$EC_{1:5}$ /ESC
0-10	Cotton-vetch	Retained *in situ*	6.8	0.20	3.1	23.9	14.1	1.8	0.7	1.8	1.7	1.17	0.27
	Cotton-winter fallow	-	6.8	0.43	155.6	24.6	13.7	1.9	0.6	1.4	1.8	0.95	0.84
	Cotton-wheat/cotton phase	Incorporated	6.9	0.21	32.6	25.3	13.7	1.9	0.6	1.5	1.9	0.95	0.37
	Cotton-wheat/wheat phase	Incorporated	6.9	0.18	3.5	24.6	13.7	1.7	0.6	1.56	1.8	0.96	0.32
	Cotton-wheat-vetch/cotton phase	Retained *in situ*	7.0	0.23	8.3	25.4	14.1	1.8	0.7	1.6	1.8	1.02	0.38
	Cotton-wheat-vetch/wheat phase	Retained *in situ*	6.8	0.17	3.5	24.6	13.7	1.8	0.7	1.8	1.8	1.04	0.24
	SEM		0.07	0.03	24.09	0.28	0.51	0.06	0.07	0.13	0.072	0.104	0.083
	P <		n.s.	0.001	0.01	0.05	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	0.001
10-30	Cotton-vetch	Retained *in situ*	7.0	0.18	2.2	23.9	14.8	1.3	1.7	4.0	1.6	0.46	0.11
	Cotton-winter fallow	-	7.0	0.20	13.9	25.0	14.4	1.3	1.4	3.3	1.8	0.50	0.15
	Cotton-wheat/cotton phase	Incorporated	7.0	0.24	33.1	24.9	14.4	1.4	1.2	2.8	1.8	0.63	0.24
	Cotton-wheat/wheat phase	Incorporated	7.0	0.19	1.9	24.5	14.0	1.3	1.4	3.4	1.8	0.58	0.14
	Cotton-wheat-vetch/cotton phase	Retained *in situ*	7.1	0.19	2.7	25.4	14.8	1.3	1.5	3.4	1.8	0.60	0.13
	Cotton-wheat-vetch/wheat phase	Retained *in situ*	7.0	0.20	2.2	24.3	14.4	1.3	1.4	3.4	1.7	0.52	0.15
	SEM		0.06	0.016	5.36	0.54	0.41	0.05	0.11	0.26	0.07	0.083	0.028
	P <		n.s.	n.s.	0.001	n.s.	ns	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
30-60	Cotton-vetch	Retained *in situ*	7.2	0.27	2.1	20.8	16.6	0.8	3.1	7.6	1.3	0.69	0.08
	Cotton-winter fallow	-	7.1	0.26	2.7	21.5	15.5	0.8	2.6	6.3	1.4	0.74	0.11
	Cotton-wheat/cotton phase	Incorporated	7.2	0.25	9.0	21.8	15.8	0.9	2.3	5.6	1.4	0.65	0.12
	Cotton-wheat/wheat phase	Incorporated	7.1	0.20	1.9	21.0	15.4	0.8	2.5	6.2	1.4	0.66	0.09
	Cotton-wheat-vetch/cotton phase	Retained *in situ*	7.1	0.24	2.4	22.2	15.8	0.9	2.6	6.2	1.4	0.70	0.10
	Cotton-wheat-vetch/wheat phase	Retained *in situ*	7.1	0.23	2.3	20.7	15.1	0.9	2.5	6.5	1.4	0.77	0.10
	SEM		0.02	0.008	0.59	0.73	0.47	0.03	0.16	0.43	0.08	0.041	0.012
	P <		n.s.	0.01	0.01	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
60-120	Cotton-vetch	Retained *in situ*	7.2	0.31	2.0	14.1	16.9	1.0	5.6	14.9	0.8	0.53	0.06
	Cotton-winter fallow	-	7.3	0.28	1.6	15.9	16.6	0.9	4.4	11.5	1.0	0.66	0.08
	Cotton-wheat/cotton phase	Incorporated	7.2	0.30	3.2	16.2	16.9	1.0	4.1	10.3	1.0	0.59	0.09
	Cotton-wheat/wheat phase	Incorporated	7.2	0.24	1.6	14.0	15.5	0.8	4.5	12.3	0.9	0.65	0.06
	Cotton-wheat-vetch/cotton phase	Retained *in situ*	7.2	0.29	1.9	16.2	16.6	1.0	4.2	10.9	1.0	0.62	0.08
	Cotton-wheat-vetch/wheat phase	Retained *in situ*	7.2	0.25	1.4	16.2	16.5	0.9	4.3	11.0	1.0	0.61	0.07
	SEM		0.03	0.015	0.27	0.70	0.48	0.02	0.31	0.93	0.060	0.039	0.010
	P <		n.s.	0.05	0.01	n.s.	n.s.	0.01	0.05	0.05	n.s.	n.s.	n.s.

Profitability

Gross margins and variable costs

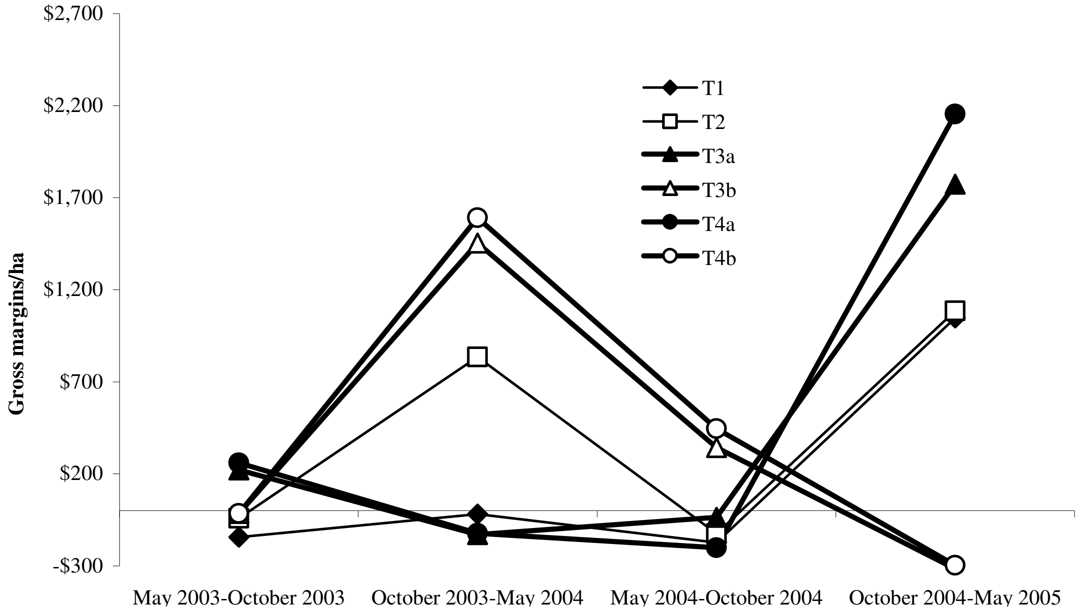

Figure 17. Effect of cropping system on annual variation of gross margins, Field D1, ACRI. T1,Cotton-vetch; T_2, Cotton-winter fallow; T3a, Cotton-wheat (stubble incorporated); T3b, Wheat (stubble incorporated)-cotton; T4a, Cotton-wheat (standing stubble)-vetch; T4b, Wheat (standing stubble)-vetch)-cotton. 1 bale of cotton lint = $350.

Table 16. Effect of rotation and stubble management system on cumulative gross margins, income and variable costs from 2003 to 2005, Field D1, ACRI.

Cumulative values	T1	T2	T3a	T3b	T4a	T4b
Cumulative income ($/ha)	4800	5932	4452	4091	4866	4373
Cumulative variable costs ($/ha)	4088	4176	2624	2625	2777	2648
Cumulative gross margin ($/ha)	712	1756	1828	1466	2089	1725
Income/ variable costs ratio	1.17	1.42	1.70	1.56	1.75	1.65
Gross margin/variable costs ratio	0.17	0.42	0.70	0.56	0.75	0.65
Mean cotton yield, bales/ha[1]	6.0	7.4	10.1	8.4	11.1	8.8
Cumulative gross margins/ML of irrigation water	59	176	261	244	261	288
Cumulative irrigation water applied (ML/ha)	12	10	7	6	8	6

[1] Averaged for all years from 2003 to 2005

The results for the 2002-03 cotton season were excluded from this analysis as this was the first season of the experiment and some residual effects of past experiments may have been present. Both annual and cumulative gross margins/ha were higher wherever a wheat rotation crop was sown, with the cotton-wheat (standing stubble)-vetch rotation tending to produce higher gross margins with time (Fig. 17). Gross margins and yields were lower in both continuous cotton systems, with those in the cotton-vetch rotation being lowest. This is partly due to inhibition of cotton by vetch regrowth and partly to a suspected allelopathic effect. The problems related to vetch regrowth were solved during the 2004-05 season (see section 5.1.5). Overall gross margins were lower than expected due to the high cost of chemical weed control associated with controlling regrowth and volunteers of Roundup-Ready® cotton. The absence at ACRI of suitable attachments for minimum tillage machinery such as centre-busting tines, which are widely-used in commercial cotton production systems means that there is an over-dependency on herbicides. These attachments would easily control cotton re-growth by eliminating deep cotton roots during the tillage operation.

The gross margin/variable cost ratios (Table 16) mirrored the cumulative gross margins with highest values occurring in the cotton-wheat (standing stubble)-vetch rotation (T4) indicating that it resulted in the highest return for costs invested. The gross margin/variable cost ratio with cotton-wheat (stubble incorporated) (T3) was less than that of T4 but more than those of either of the continuous cotton rotations.

Gross margins/ML of irrigation water were in the order of T4b > T4a =T3a > T3b > T1 (Table 16) If irrigation water was the limiting factor and maximum profitability was preferred, then the rotations which included a wheat crop (T4, T3) would have resulted in highest returns, with T4 being the most profitable. The annual average returns relative to variable costs (over 2 years) (Fig. 18) show that T1 (cotton-vetch) is dominated because it is showing a lower rate of return for the level of costs than the other treatments. At $350/bale of cotton lint, the least profitable cropping system was the cotton-vetch rotation. The inclusion of vetch into a continuous cotton system in a soil of poor quality appears, therefore, in the short-term to result in very low financial returns.

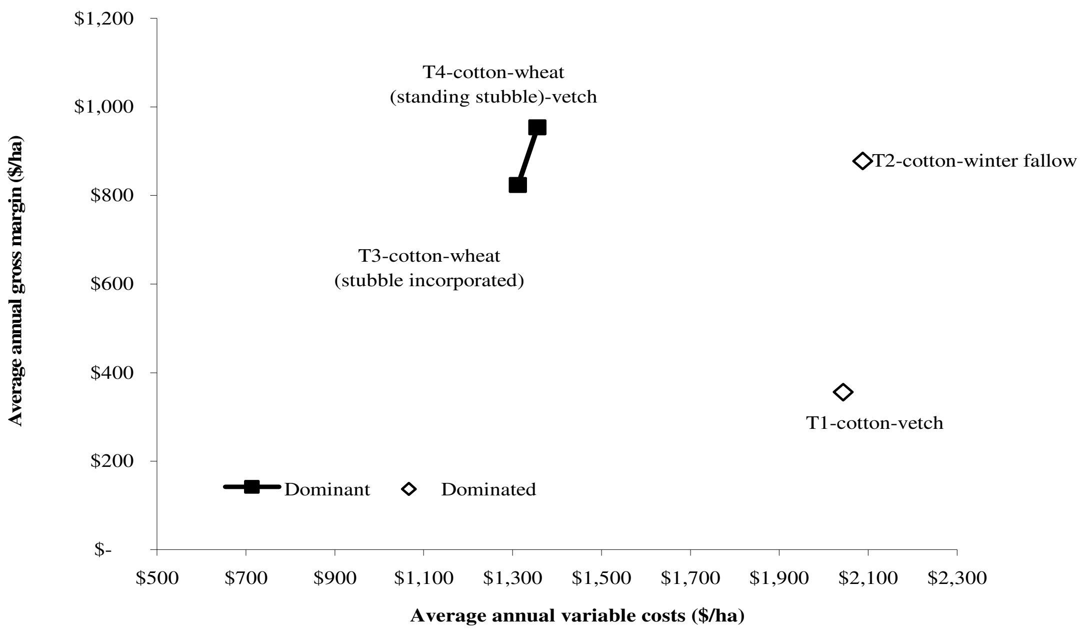

Figure 18. Effect of tillage and rotation system on variation of average annual gross margin returns relative to average variable costs, Field D1, ACRI

Effect of variable cotton prices

A sensitivity analysis was done to observe the effects of a change in cotton lint price. The cotton seed price was kept at $175 per tonne. Cotton seed is sold into a different market and is not correlated to cotton lint price. Further the sensitivity analyses were restricted to treatments T1, T2, T3a and T4a, as these were cropping systems where the full rotation cycles had been completed.

Table 17. Sensitivity table indicating variation of gross margins with varying cotton lint prices (GM/VC, gross margin/variable costs)

Cotton price	T1		T2		T3a		T4a	
($/bale)	Gross margin/ha	GM/VC ratio	Gross margin/ha	GM/VC ratio	Gross margin/ha	GM/VC ratio	Gross margin/ha	GM/VC ratio
300	115	0.03	1016	0.24	1323	0.50	1535	0.55
350	712	0.17	1756	0.42	1828	0.70	2089	0.75
400	1309	0.32	2496	0.60	2334	0.89	2642	0.95
450	1907	0.47	3235	0.77	2839	1.08	3195	1.15
500	2504	0.61	3975	0.95	3345	1.27	3749	1.35

Irrespective of cotton lint price, both gross margins and gross margin/variable cost ratio (GM/VC) were lowest with T1. Profitability of T2 (cotton-winter fallow) was less than either of the rotations which included a wheat crop when cotton lint prices were $350/bale or less. At these lint prices highest gross margin and GM/VC ratio occurred with T4. Highest gross margin to variable costs ratio was with minimum tilled cotton-wheat. When lint prices was $350/bale, minimum tilled cotton-wheat and conventionally tilled continuous cotton had almost identical total gross margins, but the former had better returns to costs. As the cotton lint price fell to $300/bale, conventionally tilled continuous cotton changed from second-most profitable to least profitable.

Table 18. Effect of sowing vetch in strip-cropped cotton + corn on quality of a grey clay at "McIntyre Downs", Goondwindi, 2003 and 2004. SOC, soil organic carbon; ESP, exchangeable sodium percentage; ESC, exchangeable sodium content.

Crop rotation	**Year**	**pH (0.01M $CaCl_2$)**	**$EC_{1:5}$ (dS/m)**	**SOC (g/100g)**	**Exchangeable cations (cmol/kg)**				**ESP**	**Ca:Mg**	**$EC_{1:5}$/ ESC**
					Ca	**Mg**	**K**	**Na**			
Cotton + corn	2003	8.0	0.23	1.08	21.1	8.9	0.9	1.0	3.2	2.4	0.24
	2004	7.3	0.11	0.71	24.3	10.3	0.8	1.2	3.4	2.4	0.09
Cotton + corn-vetch	2003	8.2	0.16	0.72	21.3	10.6	0.6	1.3	3.9	2.0	0.13
	2004	7.0	0.31	0.87	23.9	9.1	0.9	0.9	2.4	2.7	0.36
AOV:											
Rotations		n.s.	n.s.	0.001	n.s	n.s	n.s.	n.s.	n.s.	n.s.	n.s.
Years		0.001	n.s.	0.001	0.001	0.001	n.s.	n.s.	0.05	0.001	n.s.
Rotation x year		0.05	0.01	0.001	n.s.	n.s.	0.01	0.01	0.01	0.001	0.001
SEM:											
Rotations		0.04	0.029	0.011	0.25	0.27	0.04	0.04	0.13	0.06	0.04
Years		0.03	0.029	0.016	0.26	0.12	0.04	0.07	0.18	0.03	0.03
Rotation x year		0.05	0.040	0.022	0.36	0.18	0.06	0.09	0.26	0.04	0.05

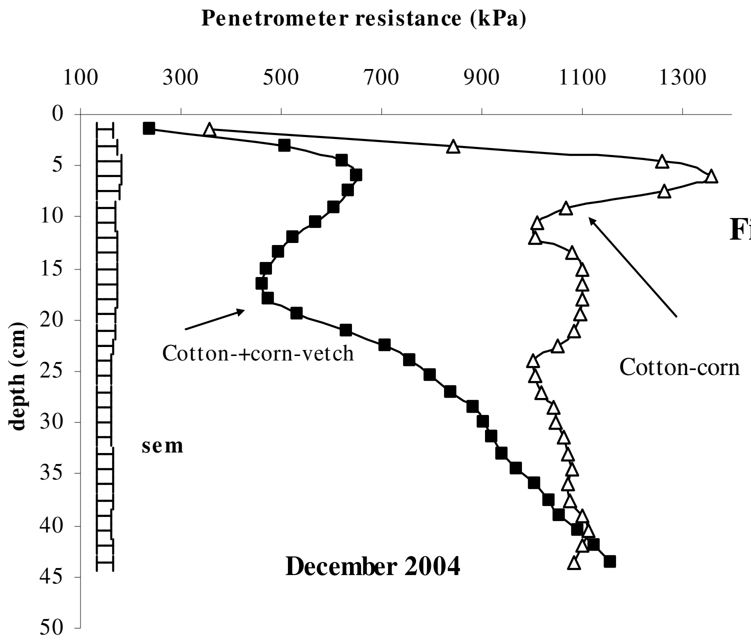

Figure 19. Effect of vetch on penetrometer resistance on cotton-corn rotations, "McIntyre Downs", Goondiwindi, December 2004.

On-farm trial of strip-cropped cotton and corn, with and without vetch, "McIntyre Downs", near Goondiwindi:

Overall of quality of soil at "McIntyre Downs", assessed on samples taken shortly after vetch was incorporated in 2003 was, in general, poorer with the cotton + corn-vetch sequence than with the strip-cropped cotton + corn, and was characterized by lower soil organic carbon (SOC), lower exchangeable K and Na, Ca:Mg and $EC_{1:5}$/ESC (exchangeable sodium content) ratios, and higher ESP (Table 18). Both Ca:Mg and $EC_{1:5}$/ESC ratios are indices of soil structural stability, with low values indicative of a dispersive soil. By 2004, this pattern was reversed with SOC and $EC_{1:5}$ decreasing with the strip-cropped cotton + corn. At the same time, SOC, $EC_{1:5}$, exchangeable K, Ca:Mg and $EC_{1:5}$/ESC ratios increased and exchangeable Na and ESP decreased in the cotton + corn-vetch sequence. Decreases in pH were also greater in the latter. These results are similar to those observed in the 10-30 cm depth of the cotton-vetch sequence in Dr. Nehl's cover crop experiment at ACRI. Data for this experiment was excluded from this report as it was firstly re-laid in 2003, and secondly, due to funding constraints was not sampled in 2004.

These changes may be due to the vetch which was incorporated in 2003 not decomposing until 2004, at which time the beneficial effects on soil quality became evident. Decomposition of vetch residues is likely to 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. Similar changes were also observed in the experiments at ACRI (i.e. rotation experiment of Dr. David Nehl and the cotton/vetch/wheat rotation experiment) which included a vetch crop in the experimental treatments. The increased availability of soluble K may also have caused K to become adsorbed on the clay surfaces and displace exchangeable Na. Consequently, by 2004 exchangeable K increased and exchangeable Na, $EC_{1:5}$/ESC and ESP decreased in the cotton + corn-vetch sequence.

Structural stability, which was measured only during 2004 with the ASWAT test, resulted in an ASWAT score of 0 in both cropping systems, indicating very flocculative soils under both rotations. This is in spite of the strip-cropped cotton + corn having an $EC_{1:5}$/ESC ratio of 0.09, which is more characteristic of a dispersive soil (see Final Report for CRC project 12C). Soil strength was measured as penetrometer resistance during both 2003 and 2004. Results for 2003 were confounded due to significantly higher subsoil water contents under the cotton + corn-vetch sequence. During 2004, however, although water contents were similar throughout the measured profile, soil strength was significantly lower below the cotton + corn-vetch (Fig. 19). This is indicative of a better soil physical condition under this cropping system. It also echoes the previously mentioned better soil quality, particularly the higher $EC_{1:5}$/ESC and Ca:Mg ratios, in this treatment. High values of $EC_{1:5}$/ESC and Ca:Mg ratios are indicative of flocculative soils. These results also imply that the ASWAT test may not be sufficiently sensitive enough to distinguish between treatments in non-sodic soils where differences in structural stability are moderate or small.

In summary, the data collected between 2002 and 2005 from the three experiments described above suggests that sowing vetch can improve properties of a good quality soil. Where soil quality is poor, however, sowing a cereal rotation crop can result in significant yield increases, presumably due to improvements in soil structure.

5.1.5 ***Overcoming some management constraints associated with sowing irrigated cotton into standing crop stubble***

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.

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 (Fig. 20). 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 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. This modification to the gas injection rig, which was developed during 2000-2001 (see Final Report for Project no. CRC 12C) was evaluated during the past three cotton seasons in the experiments at ACRI. We are convinced that it can eliminate the problem related to blocking of “gas knives” during injection of anhydrous ammonia.

Figure 20. Modified anhydrous ammonia rig with coulter discs in front of gas knives

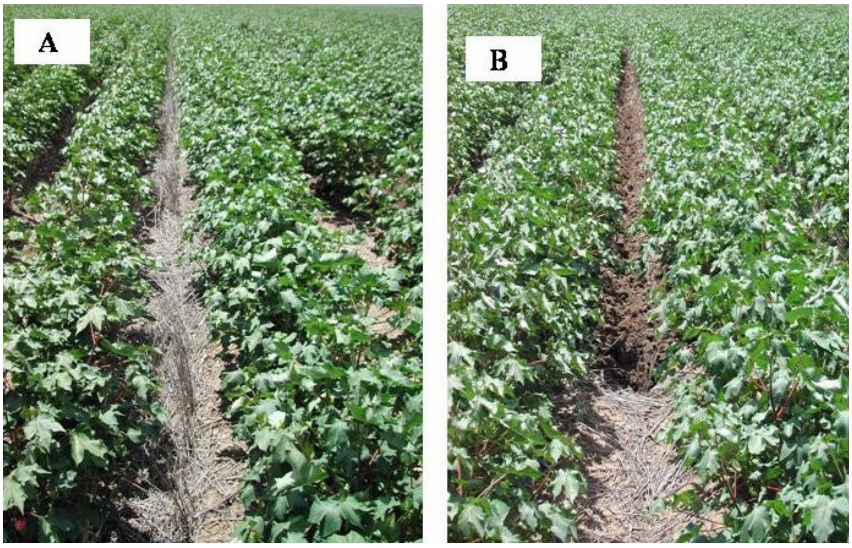

Figure 21. Clearing standing wheat stubble from furrows with sweeps. (A) Uncleared furrow with standing stubble; (B) Cleared furrow with 2-m stubble buffer

Waterlogging during irrigation events can be avoided by retaining the stubble in the furrows only until the start of the irrigation season (Fig. 21A). (This is done because the stubble facilitates rainfall harvesting during winter and early spring). 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 (Fig. 21B). 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 (Fig. 22). Salts, nutrients and pesticides attached onto clay particles are deposited in the furrow and do not move off field with runoff.

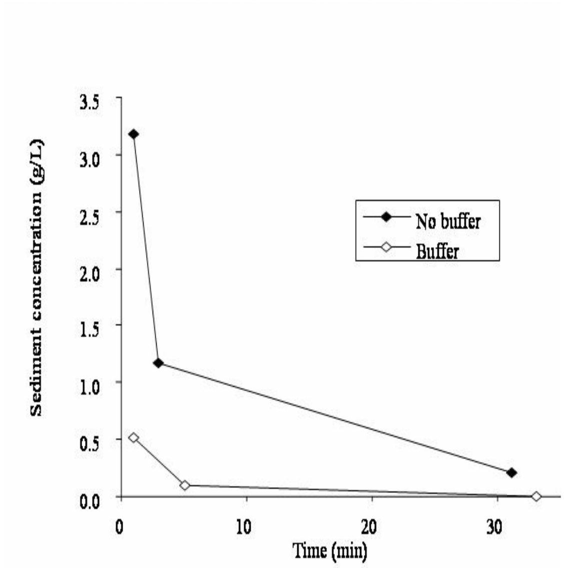

Figure 22. Effect of 2-m vetch buffer on sediment concentration in runoff from 1st irrigation in October 2003 at the Australian Cotton Research Institute, near Narrabri, NSW, Australia

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 2 applications of spray seed at a rate of 3 L/ha (Figs. 23 and 24).

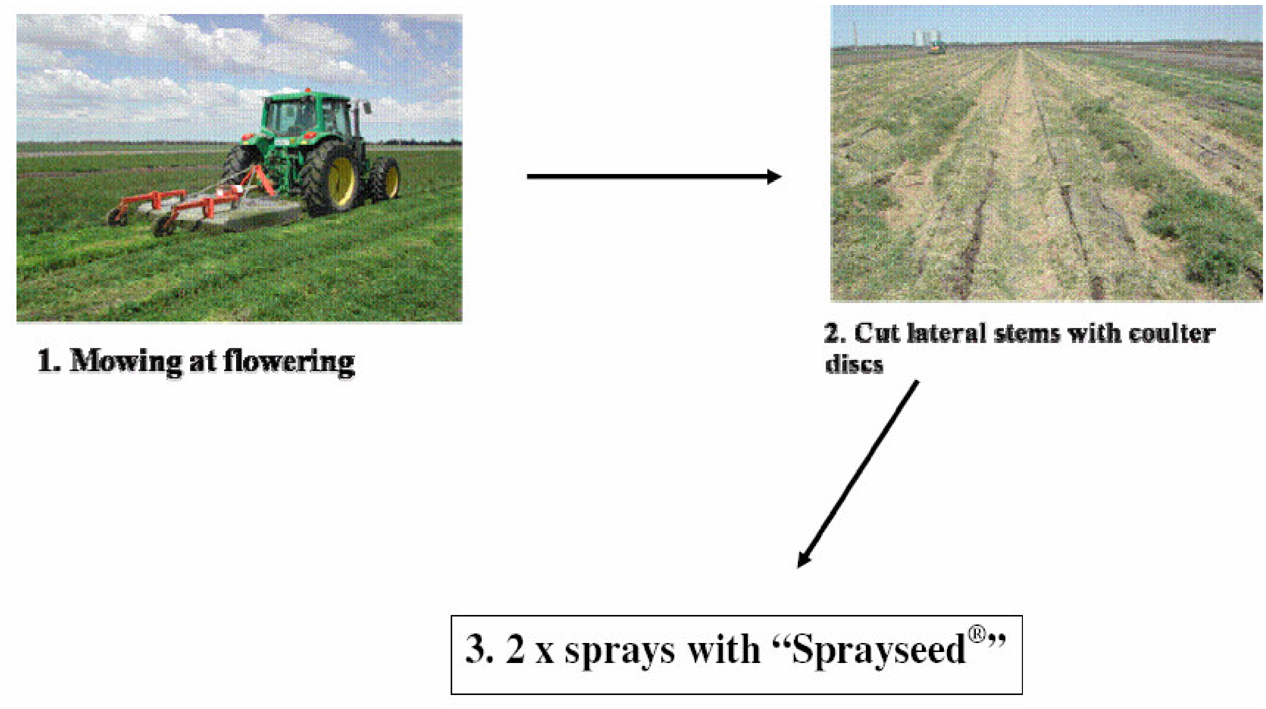

Figure 23. Process of controlling vetch regrowth

Figure 24. Sprayed-out vetch stubble ready to be sown with cotton, October 2004

5.2 *Deep drainage and nutrient leaching*

5.2.1 __Effects of tillage systems, crop rotations and stubble management on deep drainage__

Comparison of estimated deep drainage with pre- and post-season soil chloride concentrations showed that the steady state mass balance model best estimated deep drainage under cotton crops which were irrigated more frequently or wheat crops which had better sub-soil structure. Steady state conditions could therefore be assumed for calculating deep drainage under frequently irrigated crops with a better structured sub-soil. Conversely, if the crops were not frequently irrigated and the sub-soil structure was poor, more accurate estimation of drainage was possible by assuming transient state conditions. Deep drainage out of the 120 cm depth measured in several sites in the Namoi valley is reported in Table 19. The results are summarised as follows:

- Drainage was generally greater where cotton was sown into standing wheat stubble compared with stubble incorporation. This is due to the higher water infiltration in the former management practice.
- Drainage values for the 2004-05 season are likely to have been underestimated as heavy rainfall during December and November 2004 resulted in two flood events in Fields D1 and C1 at ACRI. Due to logistical reasons the amount and quality of water which ran-on could not be measured at these times.
- Drainage was strongly influenced by tillage system and subsoil structure. In other words, management practices which improved subsoil structure such as permanent beds (minimum tillage) or cereal rotation crops resulted in more drainage than in treatments which resulted in poorer subsoil structure. An exception to this was drainage with continuous cotton at Merah North which was similar to the wheat but greater than the dolichos. This was probably due to the fact that the cotton was able to tolerate the saline/sodic conditions in the subsoil at this site, whereas the dolichos was unable to do so. Consequently subsoil structure was poorer at this site as the dolichos roots were unable to penetrate into the subsoil and subject it to a series of wetting/drying cycles. The greater tolerance of both wheat and cotton to the saline/sodic conditions meant that they were able to extend their roots into the subsoil and subject it to a series of wetting/drying cycles and hence, improve subsoil structure. It is noteworthy that even though wheat was sown in all plots from 2001 onwards, the residual effects of the rotation crops sown between 1993 and 2000 were still evident with respect to drainage and leaching.
- High sodicity and salinity when combined with a low irrigation rates resulted in a low and hence, insufficient leaching fraction. This resulted in salinization followed by increased sodification. An example of this the trial site at "Woodgrain". The consequences of this were low yields (3-4.5 bales/ha). Due to these low yields, this farm no longer grows cotton.
- Drainage out of the 1.2 m depth at "Glenarvon", Wee Waa virtually doubled to 159 mm during the 2002-03 cotton season. Prior to this average drainage during the cotton season was of the order of 70 mm. This may be because the stubble produced by the 2001 wheat crop was burned. Our measurements show that stubble burning released calcium (in the form of the ash) which then leached into the sub-soil, decreasing the sodium adsorption ratio of the soil water at the 120 cm depth from 10.8 to 5.3, thereby improving structure and increasing drainage during the following years (mung bean in 2001-02 and cotton in 2002-2003). This effect appears to have been transitionary, as drainage under cotton decreased to 30 mm in 2004-05.
- Gypsum application did not significantly change water drainage at "Federation Farm", Narrabri between September 2001 and January 2002. Between September 2003 and April

2004, however, although gypsum application did not influence water drainage in the 0-1.2 m depth, it did increase drainage out of the 1.8 depth. Drainage in gypsum-treated plots was 187 mm (Ln transformed mean = 5.2289) and in control plots was 137 mm (Ln transformed mean = 4.9219) ($P < 0.05$, standard error. of Ln transformed means = 0.0663). Total water input (rainfall + irrigation) between September 2003 and April 2004 was 1300 mm. The differences in drainage in this depth suggest that gypsum applied in 2000 may have increased drainage during the 2003-04 cotton season by reducing soil (clay tactoid) swelling but not by reducing dispersion, as gypsum increased dispersion index but decreased exchangeable Ca. The effectiveness of gypsum applied in June 2000 on deep drainage during the 2003-04 season but not during the 2001-02 season may be related to the stubble incorporation which took place in gypsum-treated plots in September 2003. Stubble incorporation and associated chemical and physical changes may have solubilised any calcium carbonate deposits which may have formed on gypsum particles, thereby facilitating its dissolution.

5.2.2. Deep drainage and salinity

A stepwise multiple regression was used to determine if a relationship existed between deep drainage and a combination of rotation history, stubble management, water inputs, electromagnetic horizontal ground conductance and possibly electrical conductivity of the irrigation water (EC_w). The following equations describe the relationship that was established including EC_w:

$DD_{(mm)} = 1131.9 - 18.1\mathbf{RN} + 13.9\mathbf{SM} + 0.11\mathbf{I} - 120.7\mathbf{pH} - 109.7\mathbf{EM_H} - 89.2\mathbf{EC_w}$, $n = 66$, $R^2 = 0.64$,

And without EC_w:

$DD_{(mm)} = 850.4 - 18.4\mathbf{RN} + 20.3\mathbf{SM} + 0.12\mathbf{I} - 93.1\mathbf{pH} - 97.8\mathbf{EM_H}$, $n = 66$, $R^2 = 0.62$.

Where,
RN = Rotation History (1 = continuous cotton, 2 = Cotton-Wheat, 3 = Cotton Legume)
SM = Stubble Management (0 = Stubble Incorporation, 1 = Standing Stubble, 2 = Stubble Burnt only, 3 = Stubble Burnt + Incorporated)
I = Water Input Total (Irrigation + Rainfall)
EM_H = Horizontal EM reading (dS/m)
EC_w = Electrical Conductivity (dS/m)

The equations were used to predict deep drainage during 2003-04 in Field 'D1' at the ACRI and were compared to those estimated with chloride mass balance modelling. Although a paired t-test of the deep drainage estimates revealed no significant differences, this was primarily due to the large scatter in the data. Prediction of drainage is likely to be more realistically achieved by including soil factors such as structure and sodicity in the equation, rather than water quality and management practices alone.

5.2.3 Deep drainage and yield

Cotton during 2002-03, 2003-04 and 2004-05

Cotton yields (Y, bales/ha) during 2002-03 at "Glenarvon", Wee Waa and Field C1, ACRI, were significantly and positively related to drainage out of the 60 cm (D_{60}, mm) and 90 cm (D_{90}, mm) depths and weakly related to drainage out of the 120 cm (D_{120}, mm) depth thus:

$Y = 4.56 + 0.046D_{60}$, $R^2 = 0.68^{***}$, $n = 12$;
$Y = 3.25 + 0.075D_{90}$, $R^2 = 0.62^{**}$, $n = 12$;
$Y = 5.63 + 0.036D_{120}$, $R^2 = 0.37^{*}$, $n = 12$;

At "Beechworth", Merah North, cotton yields (Y, bales/ha) during 2002-03 were positively but weakly related to drainage out of the 60 cm (D_{60}, mm) and 90 cm depths (D_{90}, mm) but not the 120 cm depths, implying that cotton had a shallower root system than at either "Glenarvon" or ACRI. Cotton lint yield was related to drainage thus:

$Y = 6.32 + 0.022\ D_{60}$, $R^2 = 0.36^{**}$, n = 18;
$Y = 6.95 + 0.020 D_{90}$, $R^2 = 0.36^{**}$, n = 18;

Cotton yields at "Woodgrain", Boggabri during 2002-03 were weakly but positively related to drainage out of both the 60 cm and 120 cm depths thus:

$\ln Y = 0.92 + 0.057 D_{60}$, $R^2 = 0.35^{**}$, n = 20;
$\ln Y = 1.13 + 0.034 D_{120}$, $R^2 = 0.37^{**}$, n = 20;

where Y is cotton yield in bales/ha, and D_{60} and D_{120} are drainage out of the 60 and 120 cm depths in mm during the 2002-03 cotton season.

Cotton yields at "Federation Farm", Narrabri during 2003-04 were related to deep drainage out of the 180 cm depth in a curvilinear manner thus:

$Y = 7.94 + 0.0179D - 1.78\text{E-}05D^2$, $R^2 = 0.40^{*}$, n = 18;

where Y is cotton yield in bales/ha and D is drainage out of the 180 cm depth in mm during the 2003-04 cotton season. This curve reflects the variability in clay content and sodicity in the field. In locations which had clayey, sodic subsoils, increasing deep drainage increased cotton yields, probably because drainage may have reduced sodicity through leaching exchangeable and soluble Na and Cl, thereby reducing waterlogging and sodium and chloride toxicity. In locations where sandy layers were present in the subsoil, increasing deep drainage decreased cotton yield. This may be due to water stress caused by loss of water and nutrient leaching with drainage.

In summary, during the 2002-03 growing season, cotton lint yields were positively related to deep drainage in both sodic and non-sodic soils. This suggests that either salinity or over-irrigation and consequently, waterlogging in the subsoil may have occurred in all sites where drainage was measured. Only in sites where a sandy horizon was present in the subsoil was drainage negatively related to lint yield, presumably due to increased water and nutrient stress associated with drainage.

Although the negative effect of sodicity and associated waterlogging on cotton growth and yield has been well documented on the past (See SoilPak for cottongrowers, 3rd edition), salinity has long been thought to have a negligible effect on cotton yields. This assumption was questioned during an earlier phase of this research (See Final report for CRC project 12C). Accumulation of further results from several sites during the past three years has clearly indicated that early season salinity can have significant detrimental effects on cotton yields, presumably by affecting seedling growth and establishment. Figure 25, which is based on data collected from 9 fields on 5 farms over the past 3 years shows the expected yield losses as soil chloride content at sowing increases. The curve suggests that yield losses of the order of 50% would occur when soil chloride levels in the 0-60 cm depth at sowing are of the order of 5.3 t/ha. A potential maximum yield of 3 t/ha has been assumed in this estimation. The corresponding EC_e for this data set is 1.5 dS/m. This figure is very much lower than the 7.7 dS/m which is used in many models of salinity risk for cotton. These finding also suggest that cotton in many fields which are currently classified as low salinity risk may in fact be prone to salt-mediated yield losses. At the same time cotton growers may be underestimating the potential risk involved in growing cotton in these fields without allowing for an adequate leaching fraction (~20%).

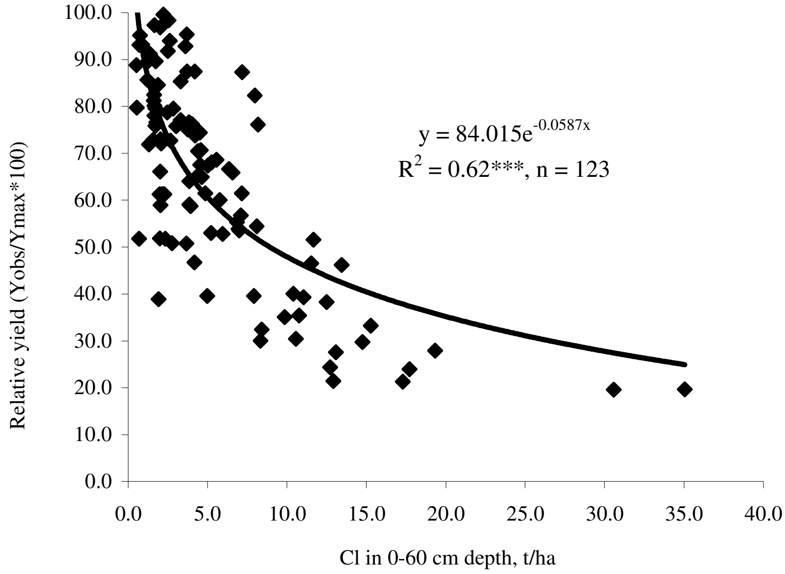

Figure 25. Effect of chloride content in the 0-60 cm depth at sowing on cotton lint yields

Wheat during 2003

Wheat yields in the non-sodic soils at "Glenarvon" and ACRI were negatively related to deep drainage out of the 120 cm depth thus:

$Y = 18.66DD^{-0.59}$, $R^2 = 0.69^{***}$, n = 12,

where Y is wheat grain yield in t/ha and DD is deep drainage out of the 120 cm depth in mm. In the sodic soil at "Beechworth", however, wheat yield in the ex-continuous cotton and ex-cotton-wheat treatments were weakly related to drainage out of the 60 cm depth thus:

$Y = 1.26DD^{0.32}$, $R^2 = 0.33^{*}$, n = 12.

There were marked differences in the response of wheat yield to drainage in the two soil types:

(a) In the non-sodic soils, drainage out of the 120 cm affected yield whereas in the sodic soil yield was affected by drainage out of the 60 cm depth. This suggests that rooting depth was shallower in the latter site.

(b) In the non-sodic soil increasing drainage resulted in decreasing yields, whereas in the sodic soil increasing drainage caused yield to increase by small amounts. The response in the non-sodic soil may reflect water stress caused by loss of water and nutrient leaching with drainage. In the sodic soil drainage may have reduced sodicity by leaching exchangeable Na and soluble Na and Cl, thereby reducing waterlogging and sodium and chloride toxicity, which in turn may have increased wheat yields.

5.2.4 Irrigation water quality

In most locations irrigation water quality was characterised by low values of EC_w and SAR, and low to moderate Cl concentrations during the cotton seasons of 2002-03, 2003-04 and 2004-05 (Tables 20 and 21). An exception to this general pattern was the irrigation water at "Federation Farm", which was high in salts and SAR. This was probably due to it consisting mainly of treated sewage effluent. Moderately high value values of Cl, EC_w and SAR also occurred at "Beechworth" during 2002-03. Overall, irrigation water quality has improved dramatically at this location since 2000-01 (see Final Report for CRC project 12C), and is probably due to the more frequent use of river water. Nitrate-N concentrations in irrigation water at all sites during 2002-03 and at "Federation Farm" during 2003-04 were relatively high, but decreased dramatically by 2004-05. The 2002 drought and heavy rainfall during November and December of 2004 may have contributed to this result.

5.2.4 Nutrient and salt leaching

Values of nutrient and salt leaching observed during 2002-03 and 2003-04 at the ACRI, and "Glenarvon" sites (Table 22) were similar to those observed in previous years. At "Beechworth", however, they were lower than those observed between 2000 and 2002, and were probably due to less chloride accumulation and use of better quality irrigation water. Nonetheless, some accumulation of chloride appears to have occurred during the 2002-03 season. Pre-season chloride content in the 0-0.6 m depth was 4.7 t/ha in the ex-continuous cotton sequence, 3.9 t/ha in the ex-cotton-wheat rotation and 7.3 t/ha in ex-cotton-dolichos rotation. Post-season chloride contents were 6.8 t/ha in the ex-continuous cotton sequence, 4.9 t/ha in the ex-cotton-wheat rotation and 10.3 t/ha in ex-cotton-dolichos rotation. In contrast, during the 2004-05 cotton season significant chloride leaching appears to have occurred in this site. Pre-season chloride content in the 0-0.6 m depth was 10.3 t/ha in the ex-continuous cotton sequence, 9.3 t/ha in the ex-cotton-wheat rotation and 15.2 t/ha in ex-cotton-dolichos rotation. Post-season chloride contents were 9.0 t/ha in the ex-continuous cotton sequence, 7.7 t/ha in the ex-cotton-wheat rotation and 13.6 t/ha in ex-cotton-dolichos rotation. Salt leaching occurred during both 2002-03 and 2004-05 seasons at "Glenarvon", with chloride values in the 0-0.6 m depth decreasing from 2.9 t/ha pre-season to 2.4 t/ha post-season during 2002-03, and 3.1 t/ha pre-season to 1.2 t/ha post-season during 2004-05. The salt leaching at both the above site reflects to a large degree the heavy rainfall received in the Namoi valley during November and December of 2004.

Decreases in chloride content also occurred at ACRI during 2004-05, but were probably confounded (underestimated) because of the flooding and run-on which occurred during November and December 2004, particularly in field C1 which was inundated for approximately a week during December. In addition, water samples could not be collected during these flood events due to logistical reasons and loss of vacuum in the ceramic cup water samplers.

Estimated costs of leaching (Table 23) suggest that as chloride accumulation occurred at "Beechworth" during 2002-03, there was a net cost in all three treatments with ex-cotton dolichos having the highest cost. This also indicates that the residual effects of the rotations sown in this site between 1993 and 2000 were still prevailing. Leaching at "Glenarvon", however, resulted in a net benefit. Although ceramic cup water samplers were not installed in either of these sites during 2004-05, as significant chloride decreases occurred net benefits are likely to have occurred. It is also noticeable that where cotton was sown into standing wheat stubble, a net cost occurred as chloride accumulated in the root zone. This is because salts are not lost in runoff with this management system in the short-term but are infiltrated into the soil. In the long-term, however, these salts are likely to be leached out of the root zone into the subsoil. Furthermore, as cotton yields and profitability were higher with sowing cotton into standing wheat stubble it is unlikely that the accumulated salts were having a negative effect on cotton growth. Gypsum application at "Federation Farm" does not appear to have had any effect on costs.

Table 19. Water inputs and deep drainage in mm (mean ±standard deviation) out of the 1.2 m depth. The leaching fractions are shown in brackets.

Site and Cropping System	2001-02	2002	2002-03	2003	2003-04	2004-05
ACRI			***Standing wheat stubble drainage plot***			
	Wheat-Fallow		**Cotton**	**Wheat**		
Water Input	220		825	331		
Permanent beds/Cotton-wheat (standing stubble)	-1 ± 1 (0)		70 ± 32 (8)	30 ± 11 (9)		
			Tillage/rotation experiment			
			Cotton	**Fallow[1]**	**Cotton**	**Cotton**
Water Input			825			1088
Conventional. tillage/Continuous cotton			24 ± 12 (3)			28 ± 13 (3)
Minimum tillage/Continuous cotton			41 ± 17 (5)			39 ± 11 (4)
Minimum tillage /Cotton-wheat (standing stubble)			67 ± 27 (8)	(Wheat)	(Fallow)	59 ± 17 (5)
			Cotton/vetch/wheat rotation experiment			
					Cotton	**Cotton**
Water Input					858	1154
Minimum tillage /Continuous cotton					27 ± 11 (3)	27 ± 3 (2)
Minimum tillage /Cotton-vetch					33 ± 10 (4)	35 ± 13 (3)
Minimum tillage /Cotton-wheat (stubble incorporated)					-	36 ± 20 (4)
Minimum tillage /Cotton-wheat (standing stubble)-vetch					-	33 ± 12 (3)
"Glenarvon", Wee Waa	**Mung Bean**	**Fallow**	**Cotton**	**Wheat**	**Fallow**	**Cotton**
Water Input	439	81	1025	331	583	770
Wheat Stubble Incorporated	143 ± 25 (28)		159 ± 30 (16)	15 ± 2 (5)	3 ± 2 (0)	30 ± 4 (4)
"Beechworth", Merah North	**Sorghum**	**Fallow**	**Cotton**	**Wheat**	**Fallow**	**Cotton**
Water Input	397	79	1265	331	583	970
Ex-continuous cotton	47 ± 42 (12)	0 ± 3 (0)	50 ± 42 (4)	7 ± 4 (2)	-9 ± 2 (0)	18 ± 8 (2)
Ex-cotton-wheat	40 ± 25 (10)	0 ± 2 (0)	62 ± 66 (5)	17 ± 14 (5)	-2 ± 5 (0)	18 ± 21 (2)
Ex-cotton-dolichos	12 ± 3 (3)	3 ± 1 (4)	19 ± 11 (2)	6 ± 4 (2)	1 ± 6 (0)	8 ± 7 (1)
"Woodgrain", Boggabri			**Cotton**			
Water Input			638			
Standing wheat stubble/ Minimum tillage			11 ± 5 (2)			
Wheat stubble incorporated/ Minimum tillage			4 ± 2 (0.6)			
"Federation Farm", Narrabr[2]	**Cotton**	**Wheat**	**Fallow[3]**	**Fallow**	**Cotton**	**Wheat-Mung bean**
Water Input	286				1300	
2.5 t/ha Gypsum in 2000 fb. stubble incorporation in 2003. Between 2000 and 2003 cotton was sown into standing stubble.	26 (9)				187 (14)	
No-Gypsum fb. standing stubble	25 (9)				137 (11)	

[1] Wheat was sown in the cotton-wheat rotation

[2] Drainage values for "Federation Farm" are those which occurred out of the 180 cm depth and were determined after Ln transformation. Error terms of transformed values are given in the text.

[3] Sorghum was sown in one replicate during the 2002-03 summer

Table 20. Irrigation water quality during the cotton seasons of 2002-03 and 2003-04 at ACRI (Field C1), Merah North (“Beechworth”), Wee Waa (“Glenarvon”) and Narrabri (“Federation Farm”). SAR, sodium adsorption ratio.

Season	Date	Site	Cl	K	Ca	Mg	Na	Nitrate-N	SAR	pH_w	EC_w
			(mg/L)								(dS/m)
2002-03	07-Nov-02	Field C1, ACRI,	248.5	2.1	15.6	14.2	20.9	22.8	0.9	8.5	0.27
	17-Dec-02	Narrabri	245.0	2.9	11.4	12.3	20.5	21.8	1.0	8.3	0.25
	15-Jan-03		198.8	3.1	16.9	14.6	21.5	20.6	0.9	8.2	0.28
	29-Jan-03		166.9	2.1	13.6	10.3	12.8	21.6	0.6	8.2	0.21
	19-Feb-03		216.6	3.5	12.5	15.6	21.5	22.3	1.0	8.2	0.27
		Seasonal sum (kg/ha)	1075.7	13.7	70.0	67.0	97.2	109.2			
	22-Oct-02	"Glenarvon",	276.9	1.8	9.0	9.3	13.7	21.6	0.8	8.2	0.21
	06-Dec-02	Wee Waa	223.7	1.7	11.3	9.0	14.0	21.1	0.7	8.2	0.20
	31-Dec-02		127.8	1.8	13.4	9.8	17.4	20.0	0.9	8.1	0.22
	14-Jan-03		273.4	2.0	22.8	10.8	20.6	17.8	0.9	8.0	0.26
	25-Jan-03		184.6	2.1	15.1	9.9	19.7	20.9	1.0	8.0	0.24
	02-Aug-03		248.5	2.1	13.0	10.6	19.8	22.4	1.0	8.2	0.25
	19-Feb-03		209.5	3.4	21.1	13.3	22.0	20.5	0.9	8.1	0.30
		Seasonal sum (kg/ha)	1544.3	14.9	105.7	72.7	127.2	144.3			
	10-Sep-02	"Beechworth",	259.2	1.8	6.1	8.0	39.0	26.4	2.4	8.8	0.28
	27-Nov-02	Merah North	443.8	1.4	7.5	8.4	41.6	25.8	2.5	8.8	0.27
	12-Feb-02		205.9	1.2	8.9	7.4	35.0	21.6	2.1	8.2	0.25
	19-Dec-02		738.4	1.8	17.8	14.0	99.5	21.1	4.3	8.4	0.62
	03-Jan-03		294.7	1.1	9.8	7.8	34.2	22.0	2.0	8.3	0.28
	13-Jan-03		275.1	1.0	8.9	6.8	29.2	22.5	1.8	8.2	0.23
	22-Jan-03		308.9	1.2	7.0	7.0	34.1	21.5	2.2	8.2	0.26
	1-Feb-03		276.9	1.1	6.0	7.0	33.7	23.2	2.2	8.2	0.23
	13-Feb-03		223.7	1.0	4.6	6.4	36.3	26.1	2.6	8.4	0.24
		Seasonal sum (kg/ha)	3026.4	11.6	76.6	72.8	382.6	210.3			
2003-04	09-Sep-03	“Federation Farm”,	771.5	14.7	24.4	14.6	294.4	28.5	11.7	7.2	1.44
	18-Oct-03	Narrabri	613.0	11.6	18.6	10.0	196.7	22.7	9.2	7.4	0.88
	15-Dec-03		1156.1	11.7	4.5	8.0	353.8	35.0	23.0	8.0	1.35
	30-Dec-03		1156.1	11.7	4.5	8.0	353.8	35.0	23.0	8.0	1.35
	07-Jan-04		1017.1	8.4	3.3	5.4	230.8	32.0	18.2	8.3	0.94
	16-Feb-04		882.8	8.1	3.2	5.1	236.3	28.4	19.0	8.2	0.93
	05-Mar-04		848.5	8.4	3.3	5.4	230.8	32.0	18.2	8.3	0.94
	15-Dec-04		1157.3	11.5	4.5	8.5	371.4	31.2	23.7	7.9	1.32
		Seasonal sum (kg/ha)	5771.8	71.4	64.9	55.39	1834.1	196.7			

Table 21. Irrigation water quality during the cotton seasons of 2003-04 and 2004-05 at ACRI (Fields C1 and D1). SAR, sodium adsorption ratio.

Season	Date	Site	Cl	K	Ca	Mg	Na	Nitrate-N	SAR	pH_w	EC_w
			(mg/L)								(dS/m)
2003-04	22-Oct-03	Field D1, ACRI,	177.5	3.4	12.1	16.7	65.9	18.3	2.9	7.4	0.35
	05-Dec-03	Narrabri	166.9	2.8	21.9	13.7	49.6	21.0	2.0	7.4	0.34
	07-Jan-04		237.9	3.5	21.8	15.9	49.4	1.7	2.0	7.5	0.36
	06-Feb-04		245.0	4.1	24.7	12.5	121.1	4.2	5.0	7.6	0.37
		Seasonal sum (kg/ha)	827.2	13.8	80.5	58.8	286.0	45.2			
2004-05	13-Oct-04	Field C1, ACRI,	317.5	4.0	18.3	19.9	57.0	6.0	2.2	8.0	0.40
	14-Jan-05	Narrabri	190.7	2.5	18.0	14.5	20.8	3.7	0.9	8.2	0.20
	01-Feb-05		257.9	2.6	19.7	9.8	37.2	8.4	1.7	8.1	0.30
	16-Feb-05		219.6	4.8	24.9	14.6	24.6	4.3	1.0	8.0	0.30
	25-Feb-05		233.7	3.8	28.8	14.4	40.1	5.3	1.5	8.1	0.30
	11-Mar-05		212.5	4.8	28.1	15.9	48.1	3.5	1.8	8.0	0.30
		Seasonal sum (kg/ha)	1432.0	22.5	137.8	89.1	227.8	31.3			
	06-Jan-05	"Glenarvon",	208.9	4.4	32.9	16.4	50.0	8.2	1.8	8.0	0.30
	18-Feb-05	Wee Waa	172.0	6.5	28.7	13.7	48.0	3.8	1.8	8.0	0.30
	07-Mar-05		219.6	4.2	29.1	14.4	8.4	5.0	0.3	8.0	0.30
		Seasonal sum (kg/ha)	600.6	15.1	90.7	44.5	106.4	17.0			
	26-Dec-05	"Beechworth",	212.5	3.3	29.2	16.3	36.3	9.2	1.3	8.0	0.20
	08-Jan-05	Merah North	271.4	1.7	14.8	8.7	65.5	15.0	3.3	7.9	0.30
	18-Jan-05		219.6	3.8	21.5	14.0	30.5	4.7	1.3	8.0	0.20
	15-Feb-05		261.3	1.6	14.3	8.9	70.9	12.0	3.6	7.9	0.40
	03-Mar-05		304.5	2.5	18.4	14.2	84.8	7.4	3.6	8.2	0.40
		Seasonal sum (kg/ha)	1269.3	12.9	98.2	62.1	288.0	48.3			
	15-Oct-04	Field D1, ACRI,	307.8	2.9	15.1	14.0	83.8	5.0	3.7	8.0	0.30
	12-Jan-05	Narrabri	264.7	3.3	97.3	70.5	36.6	3.0	0.7	7.4	0.40
	28-Jan-05		333.5	4.2	28.5	14.6	46.1	3.5	1.8	7.8	0.30
	14-Feb-05		320.7	3.9	17.2	15.5	45.7	3.5	1.9	8.0	0.30
	28-Feb-05		168.2	4.5	19.4	16.9	26.5	2.7	1.1	8.1	0.20
	18-Mar-05		294.7	3.7	22.4	14.3	39.1	2.5	1.6	7.9	0.40
		Seasonal sum (kg/ha)	1689.5	22.5	199.9	145.8	277.8	20.1			

Table 22. Nutrient movement in kg/ha (mean ±standard deviation) out of the 120 cm depth at selected sites in the Namoi valley during the cotton growing seasons of 2001-02, 2002-03, 2003-04 and 2004-05.

Site	Cropping system	Season	NO_3-N	Cl	Ca	Mg	K	Na
ACRI								
Standing wheat stubble drainage plot	Minimum tillage/Cotton-wheat (standing stubble)	2002-03	36 ± 19	804 ± 268	19 ± 10	28 ± 13	2 ± 1	105 ± 32
Tillage/rotation experiment	Conventional. tillage/Continuous cotton	2004-05	15 ± 11	193 ± 54	47 ± 1	23 ± 0	2 ± 1	168 ± 23
	Minimum tillage/Continuous cotton*		149	141	93	37	4	129
	Minimum tillage/Cotton-wheat (standing stubble)		43 ± 23	136 ± 49	24 ± 16	40 ± 18	4 ± 3	174 ± 44
Cotton/vetch/wheat rotation experiment	Minimum tillage/Continuous cotton	2003-04	4 ± 3	305 ± 167	2 ± 1	3 ± 1	0.3 ± 0.1	39 ± 28
	Minimum tillage/Cotton-vetch[1]		10	Insufficient sample	1	2	0.2	25
	Minimum tillage/Continuous cotton	2004-05	40 ± 23	155 ± 23	25 ± 15	21 ± 4	3 ± 0	206 ± 38
	Minimum tillage/Cotton-vetch		46 ± 16	277 ± 275	26 ± 16	28 ± 29	4 ± 3	307 ± 253
	Minimum tillage/Cotton-wheat (stubble incorporated)		110 ± 107	139 ± 52	16 ± 1	28 ± 16	3 ± 1	162 ± 14
	Minimum tillage/Cotton-wheat (standing stubble)-vetch		18 ± 3	165 ± 18	11 ± 2	17 ± 3	2 ± 0	186 ± 7
"Glenarvon", Wee Waa	Cotton sown into incorporated wheat stubble	2002-03	67 ± 19	1893 ± 890	45 ± 20	81 ± 37	5 ± 2	299 ± 204
"Beechworth", Merah North								
Ex-continuous cotton	Cotton sown into incorporated wheat stubble	2002-03	36[1]	2083 ± 1356	26 ± 21	33 ± 22	2 ± 2	305 ± 251
Ex-cotton-wheat			Insufficient sample	3601 ± 941	75 ± 19	69 ± 34	3 ± 2	464 ± 271
Ex-cotton-dolichos			No samples obtained					
"Federation Farm", Narrabri								
2.5 t/ha Gypsum in 2000	Cotton sown into standing wheat stubble/ Minimum tillage	2001-02	6 ± 8	8 ± 9	8 ±14	10 ± 14	1 ± 2	38 ± 48
No-Gypsum			3 ± 3	5 ± 4	2 ± 3	5 ± 6	0 ± 1	20 ± 16

[1]Sufficient samples were obtained only from a single site. Hence, no error terms were estimated.

Table 23. Values ($/ha) of nutrients and salts leached out of the 120 cm depth at selected sites in the Namoi valley during the cotton growing seasons of 2002-03, 2003-04 and 2004-05. Leaching of K, nitrate-N and Ca was defined as a cost, and leaching Cl, Na and Mg as a benefit.

Site	Cropping system	Season	NO_3-N	Cl[1]	Ca	Mg	K	Na	Benefits-costs
ACRI									
Standing wheat stubble drainage plot	Minimum tillage/Cotton-wheat (standing stubble)	2002-03	30.73	-79.72	6.03	8.89	6.11	16.67	-97.03
Tillage/rotation experiment	Conventional. tillage/Continuous cotton	2004-05	12.80	398.63	14.93	7.30	6.11	26.68	402.86
	Minimum tillage/Continuous cotton*		127.20	242.83	29.54	11.75	12.22	20.48	114.29
	Minimum tillage/Cotton-wheat (standing stubble)		36.71	-48.45	7.62	12.70	12.22	27.63	-56.49
Cotton/vetch/wheat rotation experiment	Minimum tillage/Continuous cotton	2003-04	3.41	41.69	0.64	0.95	0.92	6.19	43.87
	Minimum tillage/Cotton-vetch		8.54	202.98	0.32	0.64	0.61	3.97	198.11
	Minimum tillage/Continuous cotton	2004-05	39.27	578.47	8.26	8.89	12.22	48.75	576.37
	Minimum tillage/Cotton-vetch		34.15	679.05	7.94	6.67	9.17	32.71	685.18
	Minimum tillage/Cotton-wheat (stubble incorporated)		93.90	483.89	5.08	8.89	9.17	25.73	410.36
	Minimum tillage/Cotton-wheat (standing stubble)-vetch		15.37	1058.10	3.49	5.40	6.11	29.54	1068.07
"Glenarvon", Wee Waa	Cotton sown into incorporated wheat stubble	2002-03	57.20	97.74	14.29	25.73	15.28	47.48	84.18
"Beechworth", Merah North									
Ex-continuous cotton	Cotton sown into incorporated wheat stubble	2002-03	30.73	-342.03	8.26	10.48	6.17	48.43	-328.21
Ex-cotton-wheat			30.73	-176.21	23.82	21.91	9.17	73.68	-144.34
Ex-cotton-dolichos			0.00	-408.78	0.00	0.00	0.00	0.00	-408.78
"Federation Farm", Narrabri									
2.5 t/ha Gypsum in 2000	Cotton sown into standing wheat stubble/ Minimum tillage	2001-02	5.12	-220.21	2.54	3.18	6.11	6.03	-224.78
No-Gypsum			2.56	-211.53	0.64	1.59	0.61	3.18	-210.17

[1] Negative values indicate an expected future yield loss whereas positive values a yield increase.

5.3 Post-harvest cultivation and heliothis pupae emergence

In the tillage-rotation experiment, pupae emergence from both minimum-tilled treatments was negligible, even though post-harvest pupae numbers ranged between 2 and 7/m^2. This may be due to the post-harvest cultivation which included root cutting followed by go-devilling (1-2 times) under relatively dry conditions which resulted in significant disturbance of the bed.

In the post-harvest cultivation experiment conducted by Mr. Tann, the results indicated that soil disturbance, for the most part, was inversely related to pupae emergence (Fig. 26). (The curve in Fig. 26 excludes results of pupae emergence with the aer-way cultivator).The exception was the aer-way cultivator, where disturbance did not differ significantly from either the untreated control or the no-tilled wheat but resulted in a very low rate of pupae emergence. This may be because pupae-busting with the aer-way cultivator under dry condition results in an increase in the number of micropores (very fine cracks), which are not detected by the method used in this study.

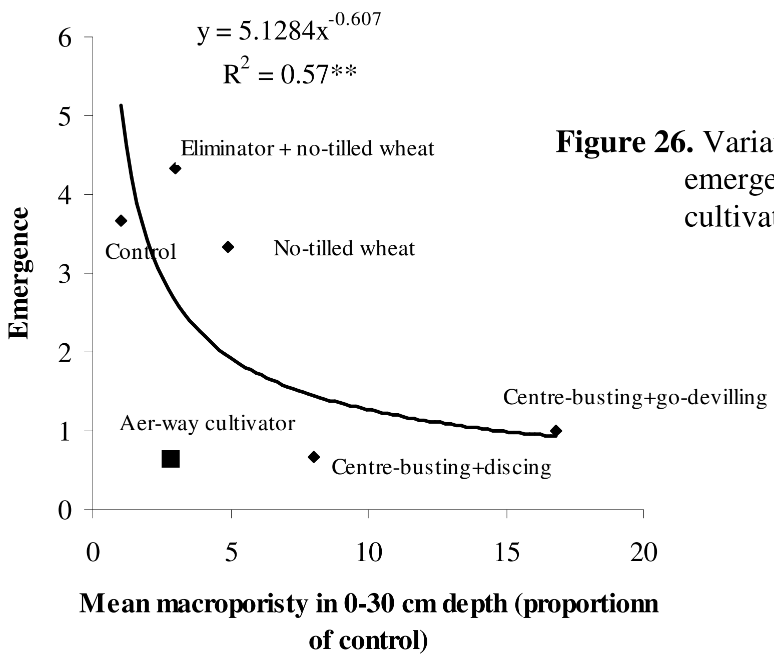

Figure 26. Variation of heliothis pupae emergence with post-harvest cultivation system

6. Conclusions and recommendations

- Residual effects of the rotation crops sown were present at Merah North up to 3 years after the different rotation systems were replaced by a single cropping system (cotton-wheat) in all plots. The soil properties which were affected were structure, deep drainage and nutrient and salt leaching, and to a lesser extent, sodicity and exchangeable K.
- Cereal crops sown in rotation with dryland cotton improved soil properties more than legumes. Sowing double-cropped cotton-wheat minimised soil compaction whereas cotton-sorghum improved soil organic matter contents. These results reflect the low K status and extended periods of drought which the Warra experimental site and the Darling Downs in general, was subjected to. Both drought and low K discriminate against pulse crops such as chickpea.
- In general, sowing cotton into standing wheat stubble improved soil quality, rainfall harvesting, cotton yields, root growth and gross margins (during the cotton phase of the rotation).

- Sowing vetch as a rotation crop improved soil quality further in sites with good quality soil, but not where soil quality was poor (at least not in the short-term). However, when vetch was sown as a rotation crop, less mineral N fertiliser was required and nitrate-N leaching was lower. In sites of poor or moderate soil quality, vetch did not improve either cotton yield or gross margins.
- Retaining crop stubble *in-situ* can cause several problems such as blocking of "gas knives" during injection of anhydrous ammonia as fertiliser and waterlogging during irrigation. In addition vetch regrowth can suffocate emerging cotton seedlings. These problems can be overcome by management practices such as attaching coulter discs to the front bar of the gas rig to cut through crop stubble, by removing stubble in furrows at the start of the irrigation season and controlling vetch regrowth through a combination of mechanical methods (slashing, cutting vetch lateral stems with coulter discs) and herbicides (paraquat-based herbicides such as “Sprayseed”).
- The steady state mass balance model best estimated deep drainage under under frequently irrigated crops with a better structured sub-soil. Conversely, if the crops were not frequently irrigated and the sub-soil structure was poor, more accurate estimation of drainage was possible by assuming transient state conditions.
- Drainage was generally increased by management practices which increased water infiltration (sowing cotton into standing wheat stubble), and improved structural stability and porosity (stubble burning, permanent beds/minimum tillage and cereal rotation crops). Conversely, drainage was poor in highly sodic soils. Cotton lint yields were, in general, positively related to deep drainage.
- Early season salinity significantly reduces cotton yields, presumably by affecting seedling growth and establishment. Yield losses of the order of 50% occur when soil chloride levels in the 0-60 cm depth at sowing are of the order of 5.3 t/ha. The corresponding EC_e is 1.5 dS/m. This figure is very much lower than the 7.7 dS/m which is used in many models of salinity risk for cotton. These finding also suggest that cotton in many fields which are currently classified as low salinity risk may in fact be prone to salt-mediated yield losses.

Suggested areas of future research

- Identify wheat and other rotation crop varieties which can rapidly recover nutrients leached below the cotton root zone. Varieties which are able to rapidly extend their root systems into the subsoil would be best.
- 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.
- Identify causal factors for deep drainage in a wide range of soil types and environments where cotton is grown. Research should include measurements from non-cotton production systems (irrigated and dryland) in cotton regions.
- Devise whole-farm approaches to managing poor quality irrigation water. "Poor quality" includes water which is saline, saline-sodic, alkaline, or contains high amounts of nutrients such as nitrates and phosphates or toxic elements.
- Identify other rotation crops (e.g. corn) and/or combinations of crops which can return large amounts of good quality crop residues to the soil within a single rotation cycle, thereby increasing soil organic matter levels relatively quickly.

Suggested/planned extension activities

- At the request of the cotton extension staff, a soils workshop was organised in May 2003 to address their perceived technical deficiencies in soil management (see section 10 for complete details). Many of these extension staff have since departed from the cotton industry's extension services. Regular workshops based on the model of the May 2003 workshop 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 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" 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 Australian Cotton CRC could provide significant assistance in this area by identifying and contacting the relevant publications.

7. New methods and techniques

- Precision of drainage estimates was improved by comparing pre- and post-season chloride profiles to determine whether chloride movement had occurred under steady-state or transient-state conditions. After determining which state condition had prevailed, either the steady-state or transient-state equations were applied to estimate drainage using the chloride mass balance model. This methodology was presented as an oral presentation at an international conference and published in its proceedings (*Weaver, T.B., Hulugalle, N.R., and Ghadiri, H. 2004. Comparing deep drainage estimated with transient and steady state models in irrigated Vertisols. In "Hydrology: Science and Practice for the 21st Century, Vol. II", Proc. British Hydrological Society International Conference, 12-16 July 2004, London, UK, Eds. B. Webb, M. Acreman, C. Maksimovic, H. Smithers and C. Kirby, pp. 168-176. British Hydrological Society, London, UK*). An expanded version of the same paper was published as a research paper in "Irrigation Science" (*Weaver, T.B., Hulugalle, N.R., and Ghadiri, H. 2005. Comparing deep drainage estimated with transient and steady state assumptions in irrigated Vertisols. Irrigation Sci., 23,183-191. DOI 10.1007/s00271-005-0106-5*).
- A management practice was developed to avoid waterlogging in cotton sown into standing wheat stubble during irrigation events. This involved retaining stubble in the furrows only until the start of the irrigation season, when 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 and increase the water flow through the field. The retained 2-m strip slows water flow just enough to settle out dispersed clay and silt. Salts, nutrients and pesticides attached onto clay particles are

deposited in the furrow and do not move off field with runoff. An article describing the modification was published in the "Australian Cottongrower" (*Hulugalle, N., Finlay, L., Scott, F., and Weaver, T. 2004. Managing irrigated cotton sown into standing stubble. Aust. Cottongrower, 25(5), 58-62*). In addition field presentations were given during the field tour of the CRDC Farming Systems Forum in December 2004 (*Hulugalle, N.R. 2004. Field Tour. In "Crop Nutrition", Proc. Farming Systems Forum, 3-4 December 2004, Narrabri, NSW. Australian Cotton CRC/CRDC, Narrabri, NSW)* and the Lower Namoi cotton field day (*Hulugalle, N.R. 2005. Managing irrigated standing stubble systems. In "Lower Namoi 2005 Field Day Book", p. 25, Eds. R. Baker and D. Gibbs. NSW DPI/CRDC/Australian Cotton CRC, Narrabri, NSW*).

- 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"). Either herbicides or mechanical methods alone, as reported in the literature, were unable to control vetch regrowth. Field presentations were given during the field tour of the CRDC Farming Systems Forum in December 2004 (*Hulugalle, N.R. 2004. Field Tour. In "Crop Nutrition", Proc. Farming Systems Forum, 3-4 December 2004, Narrabri, NSW. Australian Cotton CRC/CRDC, Narrabri, NSW)* and the Lower Namoi cotton field day (*Hulugalle, N.R. 2005. Managing irrigated standing stubble systems. In "Lower Namoi 2005 Field Day Book", p. 25, Eds. R. Baker and D. Gibbs. NSW DPI/CRDC/Australian Cotton CRC, Narrabri, NSW*).

8. Problems encountered

- Due to the drought of 2002-2003, two experiments at, "Buttabone" near Warren, and "Woodgrain", near Boggabri, were discontinued due to lack of irrigation water. Due to the combined effects of drought and salinity, cotton production at "Woodgrain" was unprofitable and it no longer grows cotton.
- Equipment failure, particularly the neutron probe used for measuring soil water, was a major issue during 2004-05. Consequently, some over-expenditure of project funds occurred.
- Control and volunteer and regrowth "Roundup Ready" cotton was 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 escalated significantly.

9. Impact on Cotton Industry

Several issues which are of significance to the Australian Cotton Industry were identified by this project. These are briefly summarised as follows:

- "Best-bet" rotations" were identified for dryland cotton in potassium deficient soils. Similar to irrigated systems, soil structure was best with a cotton-double cropped wheat sequence whereas soil fertility was best with a cotton-sorghum rotation.
- The residual effects of the rotation crops, particularly with respect to soil structure and deep drainage, were present for up to 3 years in an irrigated saline-sodic soil after the rotation treatments ceased. This supports observations reported in the Final Report for CRC project 12C. The residual effects on soil fertility were, however, relatively short-lived or very small. These results imply that whereas soil structural amelioration by rotation crops can be maintained for extended periods with good soil management practices (e.g. minimum tillage), more frequent sowing of rotation crops are required to maintain soil chemical fertility.

- Overall soil quality, water availability and cotton yields can be improved by sowing cotton into standing crop stubble. The problems reported by cotton growers[1] can be overcome by appropriate management practices.
- Leguminous rotation crops such as vetch while having significant benefits in good quality soil, were less effective in poor or moderate quality soil in the short-term ($\leq$ 3 years). The preliminary results from this project suggest that a combination of cereal and leguminous rotations crops may be of most benefit to soil quality, and consequently, sustainability of cotton soils. The former would be able to ameliorate soil structural degradation whereas the latter would benefit soil fertility more.
- Sowing vetch as rotation crop minimised the amounts of mineral fertiliser required for a cotton crop in addition to minimising nitrogen losses through leaching and volatilisation. Substantial environmental benefits can, therefore, be realised by sowing vetch in rotation with cotton.
- Cotton growth and yield can be significantly reduced by salinity. This confirms the observations reported in the Final Report for CRC project 12C. Additional data collected from more sites indicated that 50% yield reduction takes place when Cl content in the 0-60 cm depth at sowing was of the order of 5.3 t/ha. Previously, cotton was thought to be highly salt-tolerant.
- Management practices which can increase or decrease deep drainage were identified. This means that cotton growers can modify their deep drainage to either increase salt leaching or reduce water losses by applying suitable agronomic management practices.

10. Training

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

Table 19. Postgraduate and honours research conducted within CRC Project 45C

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
N. Eulenstein	B.Agr.Sci. (Hons.)	University of Queensland, St. Lucia, Qld.	2003-04	Comparative effects of continuous cotton and cotton/vetch cropping systems on deep drainage and nutrient leaching
N. Luelf	B.Agr.Sci. (Hons.)	University of Sydney, Sydney, NSW	2004-05	The effect of different rotational systems on cotton root production, turnover, and soil microbial activity in a grey Vertosol.

The project hosted five work experience students from years 10 and 11 at Narrabri High School, Narrabri and St. Mary's College, Gunnedah. They were:

- Brad Cantrill, Narrabri High School
- Tim Reddan, Narrabri High School
- Mark Roberts, Narrabri High School
- Sam Mensah, St. Mary's College
- Courtney Croft, Hurlstone Agricultural High School, Glenfield, Sydney.

[1] Henggeler, S., Shaw, G., and McLellan, P. 2000. Farming systems using cereal stubble – A summary of current trial results and industry practices. In "*Proceedings of 10th Australian Cotton Conference, 16-18 August 2000, Brisbane, Qld*", pp. 233-239. ACGRA, Orange, NSW

Dr. Hulugalle functioned as resource person for a soil training workshop for Cotton Industry Development Officers (IDO's) and extension staff held on 19 May 2003. Prior to the workshop individual extension staff were requested to prepare draft extension reviews/presentations of subject areas which were of interest to them. During the workshop an extension plan was developed with the cotton IDO's. Specific tasks were allocated to individual extension officers and researchers. As an outcome, several articles were subsequently published. Details are summarised in the following Table (Table 20):

Table 20. Authors and publications arising from the soils workshop held on 19 May 2003 for Cotton extension staff

Author(s)	Year	Publication
Weaver, T., Hulugalle, N., and Ghaderi, H.	2003	Salt and nutrient leaching under irrigated cotton. Aust. Cottongrower, 24(4), 24-26.
Smith, R.	2004	Soil testing: How does the McIntyre valley stack up? In "Crop Nutrition", Proc. Farming Systems Forum, 3-4 December 2004, Narrabri, NSW. (Australian Cotton CRC/CRDC, Narrabri, NSW).
O'Halloran, J.	2004	Guidelines for on-farm trials. In "Crop Nutrition", Proc. Farming Systems Forum, 3-4 December 2004, Narrabri, NSW. (Australian Cotton CRC/CRDC, Narrabri, NSW).
Smith, R., and Rourke, K.	2003	Nutrition and salinity management in cotton. Aust. Cottongrower, 24(4), 19.
Christiansen, I.	2003	What are the critters doing to your soil? CRC Information Update. Unpublished.
Hulugalle, N.	2004	Using poor quality water to irrigate cotton. In "WaterPak –A Guide for Irrigation Management", Eds. H. Dugdale, G. Harris, J. Neilsen, D. Richards, G. Roth and D. Williams, pp. 251-257. (CRDC, Narrabri, NSW, Australia).

11. 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.

Dr. Hulugalle was team leader for the hands-on workshop on "Managing problem soils" which was held for cotton growers during the ACGRA Cotton Conference in the Gold Coast during August 2004. The workshop consisted of an introduction (1 min), identifying soil degradation (5 min), demonstrations and posters (6 min), a Question and Answer session (15 min) and final summing-up (1 min). An outline of the workshop is given below:

1. Welcome and overview of workshop
2. Visual effects of soil degradation in the field on cotton crop growth (with reference to item 3)
3. Identifying soil problems and some solutions. Demonstrations were as follows:
    a. Soil profile photographs and stereoscopic views of soil clods from degraded and ameliorated (gypsum, rotations, rational tillage) sites; to be reviewed by participants at their leisure

b. Timed, continuous ppt presentation on setting up and using white paint method to evaluate soil structure in a paddock; inc. images of sodic and non-sodic soils, rotation and continuous cotton

c. ASWAT test with water of varying quality and managing dispersion with amendments. This demonstration consisted of sedimentation cylinders with a sodic grey clay to which amendments such as gypsum, lime + sulpher, humates, gin trash compost, PAM and rock dust had been added.

4. Question and answer session with growers on issues such as farming systems experiments, increasing soil organic matter, managing standing stubble in irrigated grey clays, irrigation with poor quality water, deep drainage, managing salinity and sodicity (inc. practical experience of Shane Bodiam in Macquarie valley, other tillage and rotation options), sensitivity of cotton to salinity, pupae busting and soil compaction. The specific issues discussed depended on the questions put by the growers

5. Summing up

Specific details of published articles and oral presentations (1 July 2002 to 30 June 2005, including those "in press") are given below. The web addresses for those items which have been published on-line are also provided.

Technical journals

1. **Hulugalle, N.R., Rohde, K.W., Yule, D.F**. (2002). Cropping systems and bed width effects on runoff, erosion and soil properties in a rainfed Vertisol. Land Degrad. Develop. 13, 363-374. (DOI 10.1002/ldr.510). (http://www3.interscience.wiley.com/cgi-bin/abstract/96516912/ABSTRACT).

2. **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. (DOI 10.1071/SR02058). (http://www.publish.csiro.au/paper/SR02058.htm).

3. **Hulugalle, N.R., Nehl, D.B., and Weaver, T.B**. (2004). Soil properties, and cotton growth, yield and fibre quality in three cotton-based cropping systems. Soil Till. Res., 75, 131-141. (DOI still.2003.07.003). (http://dx.doi.org/10.1016/j.still.2003.07.003).

4. **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. Adv. GeoEcol., 37, In Press.

5. **Hulugalle, N. R.** (2005). Recovering leached N by sowing wheat after irrigated cotton in a Vertisol. J. Sust. Agric. 27(2), In Press.

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1. **Hulugalle, N.R., Weaver, T.B., and Ghadiri, H.** (2002). Value of salt and nutrient leaching under irrigated cotton. Proc. 11th Australian Cotton Conference, 13-15 August 2002, Brisbane, Qld., Australia, pp. 571-574. (Australian Cotton Grower's Research Association, Orange, NSW, Australia). (http://cotton.pi.csiro.au/Publicat/conf/coconf02/watrmang/078/078.htm).

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3. **Weaver, T.B., Hulugalle, N.R. and Ghadiri, H.** (2002). Measuring deep drainage and nutrient leaching under irrigated cotton. Proc. 11th Australian Cotton Conference, 13-15 August 2002, Brisbane, Qld., Australia, pp. 549-554. (Australian Cotton Grower's Research Association, Orange, NSW, Australia). (http://cotton.pi.csiro.au/Publicat/conf/coconf02/watrmang/076/076.htm).

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6. **Hulugalle, N.R., N'Kem, J.N., and Lobry de Bruyn, L.A**. (2002). Invertebrate populations and N cycling during the wheat phase of wheat-cotton rotations in a Vertosol. In "Future Soils: Managing Soil Resources to Ensure Access to Markets for Future Generations", Proc. National Conference of Australian Soil Science Society Inc., 2-6 December 2002, Perth, WA, pp. 225-226. (ASSSI, Perth, WA).

7. **Hulugalle, N.R., Weaver, T.B., Scott, F. and Hickman, M**. (2003). Soil organic carbon and profitability of irrigated cotton sown into standing wheat stubble. Proc. 16th Triennial Conference of the International Soil Tillage Research Organisation, Ed. W. Hoogmoed, 13-18 July 2003, Brisbane, Qld., pp. 566-571. (ISTRO, Brisbane, Qld.). [CD-ROM].

8. **Hulugalle, N.R**. (2004). Recovering leached N by sowing wheat after irrigated cotton in north-western New South Wales. Proc. Irrigation 2004, Irrigation Australia 2004 Conference, 11-14 May 2004, Adelaide, SA. (IAA, Adelaide, SA, Australia). [CD-ROM] (http://www.irrigation.org.au/2004Proceedings/index.html).

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Raine, A.J.W. Biggs, N.W. Menzies, D.M. Freebairn and P.E. Tolmie, Paper 718, 4 pp. (ASSSI, Warragul, Vic. and IECA, NSW, Australia). [CD-ROM]. (http://tucson.ars.ag.gov/isco/isco13/ISCO%20Proceedings.pdf).

11. **Weaver, T.B., Hulugalle, N.R., and Ghadiri, H**. (2004). Salt, nutrient and pesticide leaching under a sodic Vertisol irrigated with groundwater in north-west New South Wales. In "Conserving Soil and Water for Society: Sharing Solutions", Proc. 13th International Soil Conservation Organisation Conference, 4-9th July, Brisbane, Qld., Australia, Eds. S.R. Raine, A.J.W. Biggs, N.W. Menzies, D.M. Freebairn and P.E. Tolmie, Paper 726, 4 pp. (ASSSI, Warragul, Vic. and IECA, NSW, Australia). [CD-ROM]. (http://tucson.ars.ag.gov/isco/isco13/ISCO%20Proceedings.pdf).

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14. **Grace, P.R., Rochester, I.., Hulugalle, N., Weier, K., Kiese, R., Butterbach-Bahl, K., Chen, D., and Eckard, R.J.** (2004) Full greenhouse gas profiling from irrigated soils in the cotton growing region of Australia. Proc. 2nd Joint Australia and New Zealand Forum on Non-CO_2 Greenhouse Gas Emissions from Agriculture, 20-21 October 2003, Melbourne, Vic., Eds. R. Eckard and W. Slattery, pp. C9. (CRC for Greenhouse Accounting, Canberra). (http://www.greenhouse.crc.org.au/crc/products/nonco2forum.pdf).

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Cotton industry magazines and extension publications

1. **Hulugalle, N., Weaver, T., Hicks, A., and Campbell, L.** (2003). Irrigating cotton with treated sewage. Aust. Cottongrower, 24(3), 41-42. (http://www.greenmountpress.com.au/cottongrower/issues/243jjcot03/243sewage.htm).

2. **Weaver, T., Hulugalle, N., and Ghadiri, H.** (2003). Salt and nutrient leaching under irrigated cotton. Aust. Cottongrower, 24(4), 24-26. (http://www.greenmountpress.com.au/cottongrower/issues/244ascot03/244asleaching.htm).

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5. **McKenzie, D.C., Shaw, A.J., Rochester, I.J., Hulugalle, N.R., and Wright, P.R.** (2003). Soil and nutrient management for irrigated cotton. AGDEX 151/510, no. P5.3.6, 40 pp. (NSW Agriculture, Orange, NSW, Australia). (http://www.agric.nsw.gov.au/reader/fibres/soil-nutrient-irrigated-cotton).

6. **Hulugalle, N.R.** (2004). Using poor quality water to irrigate cotton. In "WaterPak –A Guide for Irrigation Management", Eds. H. Dugdale, G. Harris, J. Neilsen, D. Richards,

G. Roth and D. Williams, pp. 251-257. (CRDC, Narrabri, NSW, Australia). (http://cotton.pi.csiro.au/Assets/PDFFiles/WATERpak/WP5_4.pdf).

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8. **Hulugalle, N.R**. (2004). Managing clay soil with cropping systems. Proceedings Annual Meeting of Cotton Consultants Australia Inc., 18-19 May 2004, Narrabri, NSW.

9. **Hulugalle, N.R.** (2004). Field Tour. In "Crop Nutrition", Proc. Farming Systems Forum, 3-4 December 2004, Narrabri, NSW. (Australian Cotton CRC/CRDC, Narrabri, NSW).

10. **Scott, F.** Economics: Fertilising cereal and legume crops. In "Crop Nutrition", Proc. Farming Systems Forum, 3-4 December 2004, Narrabri, NSW. (Australian Cotton CRC/CRDC, Narrabri, NSW).

11. **Hulugalle, N.R.** (2005). Managing irrigated standing stubble systems. In "Lower Namoi 2005 Field Day Book", p. 25, (Eds. R. Baker and D. Gibbs). (NSW DPI/CRDC/Australian Cotton CRC, Narrabri, NSW).

Presentations

1. **Hulugalle, N.R.** Cotton farming systems and their effects on soil quality. Presentation to Cotton Industry Development Officers Annual Workshop, 20 November 2002, Dalby, Qld.

2. **Hulugalle, N.R.** Presentation to Lower Namoi Valley Cotton Consultants meeting at Wee Waa on 12 September 2002 on long-term experiments and soil management

3. **Scott, F.** Presentation on 14 November 2002 at Tamworth to NSW Agriculture's trainee district agronomists on economics in cotton-based rotation systems.

4. **Hulugalle, N.R.** Presentation on rotations, soil management and crop nutrition to South Burnett Cotton growers on 6 May 2003.

5. **Hulugalle, N.R.** Presentation to Sydney University final year crop science students on field instrumentation for cotton systems on 2 April 2003.

6. **Hulugalle, N.R.** Presentation entitled "Long-term experiments in cotton-based farming systems" at Annual meeting of Cotton Consultants Australia Inc. in Narrabri on 18 May 2004.

7. **Hulugalle, N.R.** Three poster papers presented at ACGRA Cotton conference, 13-15 August 2002, Brisbane Qld. Paper titles were: "Root Growth of Rotation Crops", "Measuring deep drainage and nutrient leaching under irrigated cotton", and "Value of salt and nutrient leaching under irrigated cotton".

8. **Hulugalle N.R.** Poster paper entitled "Deep drainage and leaching in Australian Vertisols under irrigated cotton" presented at International Symposium on Sustainable Use and Management of Soils in Arid and Semi-Arid Regions, Cartagena, Spain, 22-26 September 2002.

9. **Hulugalle, N.R.** Poster paper entitled "Invertebrate populations and N cycling during the wheat phase of wheat-cotton rotations in a Vertosol" presented at National Conference of Australian Soil Science Society Inc., 2-6 December 2002, Perth, WA.

10. **Hulugalle, N.R** Oral presentation by Dr. Hulugalle at the 16th Triennial Conference of the International Soil Tillage Research Organisation, 13-18 July 2003, Brisbane, Qld.

11. **Weaver, T.B.** Oral presentation entitled "Deep Drainage under irrigated cotton farming systems in New South Wales" at Northern Murray Darling Basin Water Balance

workshop, 19 – 20 November 2003, Narrabri, NSW

12. **Hulugalle, N.R.** Poster paper at Irrigation 2004, Irrigation Australia 2004 Conference, 11-14 May 2004, Adelaide, SA.
13. **Hulugalle, N.R** Internal seminar at ACRI on 4 June 2004 entitled "Measuring root growth in Vertisols".
14. **Hulugalle, N.R**. Presentation on minimum tillage systems for pupae busting at field day organised by Annie Johnston, IDO, on 19June 2003.
15. **Hulugalle, N.R**. Oral presentation entitled "Comparing deep drainage estimated with transient and steady state models in irrigated Vertisols" at the International Conference of the British Hydrological Society in held in London from 12-16 July 2004.
16. **Weaver, T.B.** Two posters entitled "Effect of irrigating cotton with treated sewage effluent on soil properties and deep drainage in a Vertisol" and "Salt, nutrient and pesticide leaching under a sodic Vertisol irrigated with groundwater in north-west New South Wales" at the 13th Conference of the International Soil Conservation Organisation held in Brisbane from 4th to 9th July.
17. **Hulugalle, N.R**. Poster presentation entitled "Effect of irrigating cotton with treated sewage effluent on soil properties of a grey cracking clay" at the Australian Cotton Conference held on the Gold Coast from 10-12 August 2004.
18. **Hulugalle, N.R**., and **Weaver, T.B**. Oral presentations at the ACRI Cotton Program's internal review in November 2004.
19. **Hulugalle, N.R**. Oral presentation entitled "Permanent beds in Australian cotton production systems" at the workshop on permanent beds organised by the Australian Centre for International Agriculture Research in Griffith, 1-3 March 2005.
20. **Scott, F.** Oral presentation entitled "Economics: Fertilising cereal and legume crops" at the CRDC Farming Systems Forum, at Narrabri, 3-4 December 2004.
21. **Hulugalle, N.R**. Oral presentation entitled "Managing irrigated standing stubble systems" during the 2005 Lower Namoi Cotton field day.
22. In addition to the above, annual presentations were given at the Australian CRC's annual reviews, Lower Namoi cotton growers' 2005 cotton field day, during 2003 to the ACRI's Centre of Excellence board of management, during 2004 to the NSW Minister of Agriculture, the Hon. Ian McDonald, during 2005 to NSW DPI's Chief Scientist Dr. Stephen Keneally, and between 2002 and 2005 to groups of visiting scientists, industry personnel and farmer groups from India, Israel, Brazil and China.

Final Reports

1. **Eulenstein, N.J., and Hulugalle, N.R.** (2004). "Final report to Australian Cotton Co-operative Research Centre on Summer Student Scholarship 2003-04 (Nutrient and salt leaching under cotton-vetch and continuous cotton rotations in a poorly structured Vertisol)", 4 pp.
2. **Luelf, N.** (2005). "Final report to Australian Cotton Co-operative Research Centre on Summer Student Scholarship 2004-05 (The effect of different rotational systems on cotton root production, turnover, and soil microbial activity in a grey Vertosol)", 12 pp.

Theses

1. **Gleeson, J.E**. (2002). The effect of tillage on the soil furrow characteristics, crop growth and water use of cotton in an irrigated Vertisol. B. Sc. (Agric.) Thesis, University of Sydney, Sydney, NSW.
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.
3. **Roberts, P**. (2002). The use of a minirhizotron to observe the effect on root growth caused by minimum and maximum tillage treatments. B. Sc. (Agric.) Thesis, University of Sydney, Sydney, NSW.
4. **Eulenstein, N.** (2004). Comparative effects of continuous cotton and cotton/vetch cropping systems on deep drainage and nutrient leaching. B. Agric. Sci. (Hons.) Thesis, University of Queensland, St. Lucia, Qld.

Popular media

1. Dr. Hulugalle was interviewed by ABC's Landline with respect to managing soil and water quality at Federation Farm. Interview was broadcast on 28 July 2002. (http://www.abc.net.au/landline/stories/s613043.htm).
2. Articles in the local and regional newspapers included:
   a) "Injecting straight into wheat stubble" in "Agriculture Today" by Brett Fifield`
   b) "Repairing soil" in "Agriculture Today" by Tom Braz
   c) "Grey water a real option for cotton crop" in "Agriculture Today" by Annette Cross.
   d) "Grey water could be the answer – Treated sewerage water saviour for irrigators?" in the "Narrabri Courier".
   e) "Cotton industry focus in greenhouse gas project" in the "Cotton Magazine", Narrabri.
3. Media release by Annette Cross, NSW DPI's media officer entitled "Grey water has uses". (http://cotton.pi.csiro.au/Assets/PDFFiles/MediaRel/mr300803.PDF).
4. Anonymous. Rotating key to cotton productivity. In the "Land", 23 December 2004. (http://theland.farmonline.com.au/news_daily.asp?ag_id=23932).
5. Anonymous. Cotton faces effluent future. In "Innovate Australia", 3(3), 1st July 2004 (http://www.innovateaustralia.com/newsletter/v3_3/grey.htm).

12. Links to Other Projects

1. DAN153C – Managing black root rot of cotton
2. DAN 144C – Industry development officer – Gunnedah
3. DAN 177C – Diseases of Cotton VIII
4. CRC 52C – Nutritional constraints to efficient cotton production
5. CRC 32C – Purchase of minirhizotron for the study of root dynamics in cotton-based farming systems
6. DAN 166 C – Operational costs for cotton experiments III
7. CRC 47C - Quantifying deep drainage using lysimetry
8. GCRC 4C - Reducing losses of nitrogen from cotton rotation systems
9. CSP 164 - Delivering science to agribusiness: Smart approaches to cotton irrigation management
10. CRC 5.1.5 - Coordination and promotion of innovative farming systems
11. CRC3.1.5.AC – Sustainable weed management systems for cotton
12. ACCRC Summer scholarship 2003/04 – N. Eulenstein
13. ACCRC Summer scholarship 2004/05 – N. Luelf
14. CRC 4.1.07 (H9) - Honours scholarship 2002/03 (J. Gleeson)

13. Addressing CRDC's outputs

Economic

The project's primary objective was to identify cropping systems which maintain and improve soil quality (i.e. sustainability of soil resources) and profitability through a combination of rotation crops, minimum tillage and stubble retention. Compared with other rotation systems, a minimum-tilled cotton-wheat rotation where cotton is sown into standing wheat stubble is more profitable while at the same time it has the potential to improve soil quality (e.g. soil structure, N recycling, sodicity, salinity, soil organic C) and water conservation. Better water conservation can result in more water becoming available for irrigation, and hence higher yields and profits. Use of minimum tillage and stubble retention also results in less need for capital investment in heavy tillage and stubble management machinery, and consequently, in lower fixed costs. Nutrient and salt leaching with deep drainage can have significant economic costs and benefits, and were summarised in depth in an earlier section of this report.

Environmental

In addition to the abovementioned general improvements in soil quality due to rotation, stubble retention and minimum tillage, the project's findings also identified several other environmental benefits. Some of these are summarised as follows:

- Measurements made in the experiments at ACRI by this project and that led by Dr. Peter Grace (*GCRC 4C - Reducing losses of nitrogen from cotton rotation systems*) showed that minimum tillage and stubble mulching resulted in some improvement in carbon sequestration and reduced nitrous oxide emissions. Both of these processes can reduce rates of greenhouse gas emissions.
- Stubble mulching of leguminous crop residues resulted in negligible leaching of nitrate-N out of the cotton root zone. It can be surmised, therefore, that potentially there will be negligible nitrate-N intrusions into groundwater.
- Several management practices which could improve in-field water conservation while concurrently optimising drainage were identified. This could result in better use of available water and reduce excessive water movement into groundwater supplies.
- Sowing cotton into retained stubble was found to reduce sediment loads in runoff water. It is, therefore, a management practice which can significantly improve quality of reticulated and dam water. The same management practice, because of higher infiltration and drainage, was also able to reduce sodicity and salinity in saline/sodic soils.

Social

The project has addressed social issues by providing training for honours and post-graduate students. Mr. T. Weaver, the technical officer employed by the project, is enrolled for a PhD degree to be based on the research on leaching and drainage conducted in the context of this project. During this project two honours students from the Universities of Queensland and Sydney University conducted research on root growth, nutrient leaching and drainage. Details of their projects were summarised under "Training". In addition between 2002 and 2005, the project hosted 5 work experience students from years 10 and 11 at Narrabri High School, Narrabri, St. Mary's College, Gunnedah, and Hurlstone Agricultural High School, Glenfield.

The experimental site at "Federation Farm" is irrigated with treated sewage effluent generated within Narrabri town. The farm was established by the Narrabri Shire Council to demonstrate the viability of using treated sewage effluent as source of irrigation water for cotton production. The income generated from the farm is re-distributed to the local schools within Narrabri town. Hence, this research has very visible public profile within and without the Shire and has been featured in media releases, regional and national publications. The results from this site will be used by the Council to identify problems and advantages related to the long-term use of treated sewage effluent for irrigation. Nitrate and salt leaching and its potential consequences on ground water quality have implications for the CRDC's "social" output.

14. Acknowledgements

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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	2002-03	2003-04	2004-05
	($)		
A. STAFFING			
Salaries	62528	61164	60626
Other	7547	7277	6937
Payroll tax	4730	5626	5598
Workers Compensation	1625	2906	2907
Superannuation	6168	8710	8480
TOTAL	**82598**	**85683**	**84548**
B. TRAVEL			
Sustenance	4052	3514	4190
TOTAL	**4052**	**3514**	**4190**
C. OPERATING			
Vehicle expenses	7182	8500	8500
ACGRA conference registration	400		
Construction of soil water samplers	5000	0	0
Economic analyses/software upgrade	500	500	300
Soil & water analyses, glassware, consumables	23,786	15,860	15,237
Laboratory maintenance/repairs/QA	3773	4000	1500
Repairs/servicing of neutron probe, corer, penetrometer	0	0	0
Field items (bags, seed envelopes, tags etc.)	0	1740	0
Library services support	1509	1205	941
Non-cotton related crop management (seeds, chemicals etc.)	1200	1998	1783
TOTAL	**43,350**	**33,803**	**28,262**
D. CAPITAL	0	0	0
GRAND TOTAL	**130,000**	**123,000**	**117,000**

TOTAL FUNDS (2002-2005): $370,000