## *Part 1 - Summary Details*

# REPORTS

*Please use your TAB key to complete part 1 & 2.*

**CRDC Project Number:** **CRC 12C**

|  |  |  |
|---|---|---|
| **January Report:** | ☐ | Due 29-Jan-01 |
| **August Report:** | ☐ | Due 03-Aug-01 |
| **Final Report:** | ☒ | Due within 3 months of project completion |

**Project Title:** Long term effects of cotton rotations on the sustainability of cotton soils II

**Project Commencement Date:** 1/7/1999 **Project Completion Date:** 30/6/2002

**Research Program:** Soils

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COTTON RESEARCH AND DEVELOPMENT CORPORATION

# FINAL REPORT

## Long-Term Effects of Cotton Rotations on the Sustainability of Cotton Soils II

### CRC 12C

July 1999 to June 2002

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ISBN 0 7347 1397 5

NSW Agriculture

Australian Cotton
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## 1. Executive Summary

The effects of rotation crops and their management on soil properties of Vertosols, cotton yield and profitability were monitored from 1993 to 2001 in 3 irrigated field trials in NSW (Warren in the Macquarie valley, and Merah North and Wee Waa in the lower Namoi valley), and 2 dryland trials in Queensland (Warra in the Darling Downs and Emerald in the Central Highlands). The dryland trials were monitored only from 1996 onwards. The rotations sown at each site were as follows:

***Warren:*** (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). Since 1999, all treatments in this site were sown to a cotton-wheat rotation to evaluate the residual effects of the rotation crops sown between 1993 and 1999.

***Merah North:*** (1) continuous cotton; (2) long-fallow cotton; (3) unfertilised dolichos-faba-cotton (1993-94) fb. cotton-unfertilised wheat (1994-2001); (4) cotton-unfertilised dolichos; (5) cotton-fertilised (K+P fertilizer) dolichos; (6) cotton-faba (1993-99) fb. vetch (winter 1999) and cotton-sorghum (2000-01). Due to excessive salinity, this trial was discontinued from 2001. Wheat was sown during winter 2001 in all plots, and sorghum in summer 2001-02.

***Wee Waa:*** (1) cotton-N fertilised wheat; (2) cotton-unfertilised wheat; (3) cotton-grain legume (chickpea in 1993, faba bean thereafter) where legume grain was harvested; (4) cotton-grain legume (chickpea in 1993, faba bean thereafter) where legume grain was incorporated during land preparation. Since 1999, all plots were sown to a wheat-cotton rotation to evaluate the residual effects of the rotation crops sown between 1993 and 1999.

***Warra:*** (1) long-fallow cotton; (2) cotton-sorghum; (3) cotton-double-cropped wheat; (4) cotton-chickpea; (5) cotton-wheat.

***Emerald***: (1) early cotton sown between August and October; (2) wheat (sown in May and sprayed out)-early cotton; (3) wheat (allowed to mature, harvested)-late cotton sown between October and December; (4) sorghum-cotton. In addition to rotations, this trial also compared 1- and 2-m beds, and controlled traffic farming was practiced over the whole site. Since 1999, plots were sown with wheat to measure the residual effects of the bed widths and rotation crops sown between 1993 and 1999.

Minimum tillage was used at Warren, Warra and Emerald, and reduced tillage at Wee Waa and Merah North. In all sites rotation crop stubble was incorporated. In the 3 former sites, minimum tillage resulted in dispersion being reduced to extremely low values. When the Emerald site was deep-ripped in 2000 after the last cotton crop, dispersion increased tenfold.

Additional observations were also made in a long-term (16 years to date) trial at the Australian Cotton Research Institute (ACRI). The treatments are continuous cotton/intensive tillage; continuous cotton/minimum tillage; and cotton-wheat/minimum tillage. Since 1999 the wheat stubble was not incorporated but retained as standing stubble, into which the cotton was sown.

Between 1999 and 2002, this project has provided training for 1 PhD student (T.B. Weaver), and 4 honours students (K. Jackson and N. Waters, University of Qld., and P. Roberts and J. Gleeson, University of Sydney).

Measurements taken in all trials 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. Economic returns in irrigated sites were evaluated by comparing seasonal and cumulative gross margins. Commencing from the 2000-01 cotton season spatial and temporal deep drainage (with the chloride mass balance model) and nutrient leaching were measured at

ACRI (cotton sown into standing wheat stubble), Wee Waa (wheat-cotton) and 3 rotations (continuous cotton, wheat-cotton and dolichos-cotton) at Merah North.

***Rotation crops:***

Under present cotton management practices, cereal crops such as wheat sown in rotation with cotton will give the best outcome. This is because when compared with leguminous rotation crops:

1. They are easier to manage (e.g. weed control, herbicide options, time of sowing, reduction in labour and associated costs etc.) and are more profitable. One co-operator (J. Kahl) also noted that a dependable marketing structure exists for wheat whereas this did not exist for legumes.
2. Soil structural amelioration which occurs with wheat is more stable. Because of better subsoil structure, when salinity and sodicity problems arise (due to saline irrigation water) the salt can be leached out quickly. Furthermore the residual effects of the rotation history at Warren, Emerald and Wee Waa are still measurable, even though since 1999 all plots at Warren and Wee Waa have been sown to a cotton-wheat rotation. In plots where wheat-cotton rotations were sown between 1993 and 1999 subsoil structure is better than where grain legumes such as faba bean were sown.
3. They are not alternate hosts for black root rot of cotton, whereas most grain legumes such as faba and field pea are. Although wheat will not eliminate black root rot in cotton, its rate of increase can be retarded.
4. They can recycle nutrients, such as nitrogen, which have been leached out of the cotton root zone. Between 36-138 kg N/ha (depending on the season, N management and location) held in a wheat crop at harvest comes from N leached out of cotton root zone. In terms of percentages, N leached out of the cotton root zone can account for between 8 and 60% of N taken up by a wheat crop sown after cotton.
5. Subsoil root densities of wheat are greater than those of tap-rooted legumes. This allows wheat to: (1) dry out the soil more during a wetting-drying cycle, and thereby improve soil structure more; and (2) extract more nutrients from deep in the subsoil.
6. Fertilising a wheat crop (with N) increases wheat yields, protein content of the grain, gross margins and the ability of that wheat crop to scavenge leached nutrients from depth. This is because the additional N increases subsoil root density in the wheat.

The grain legumes can, however, "fix" substantial amounts of N. Rotation crop did not affect soil organic carbon in any of the sites. However, the decline in soil organic carbon observed in the early years of the project have either been arrested or reversed. The tillage/rotation experiment at ACRI shows that with present soil management practices, it is tillage system, crop rotation and stubble management, not crop rotation alone, which can substantially increase soil organic matter; e.g. sowing cotton into standing wheat stubble can greatly improve soil organic matter levels. In all sites soil K and K uptake have decreased since commencement of measurements, with very low soil K values now occurring in the dryland sites. Premature senescence at Warra and yield losses due to falling K/Na ratios at Merah North are some of the consequence.

Highest gross margins (over the period of the study) were with continuous cotton. This was because there were more cotton crops with continuous cotton than with the cotton-rotation crop combinations. Average yield, however, was lowest with continuous cotton and continued to fall. In the irrigated sites, gross margins/ha were in the order of continuous cotton > cotton-fertilised wheat > cotton-unfertilised wheat > long-fallow cotton ≥ cotton-legumes. At Warren and Wee Waa, gross margins/ML of irrigation water supplied, were in the order of long-fallow cotton > cotton-unfertilised wheat ≥ cotton-fertilised wheat ≥ cotton-legumes >> continuous cotton, and at Merah North, they were in the order of cotton-wheat > continuous cotton > long-fallow cotton > cotton-dolichos > cotton-faba.

### *Deep drainage, nutrient leaching and salinity*

During the 2000-01 cotton season, deep drainage at Merah North was 98 mm with continuous cotton, 76 mm with cotton-wheat and 19 mm with cotton-dolichos; 118 mm with cotton-wheat at Wee Waa; and 151 mm with cotton-wheat where cotton was sown into standing wheat stubble at ACRI. Differences in stubble management, subsoil structure, texture, rainfall distribution and sodicity caused these differences. Under present cotton irrigation management practices, the major pathway for deep drainage appears to be matrix flow, whereas during the rotation season when the soil is allowed to dry out and deep cracks form, preferential ("by-pass") flow through soil cracks can predominate.

Benefit-cost analyses showed that in all cases because deep drainage was involved in salt leaching, a net benefit occurred. This was in spite of the fact that some nutrients like N and K were leached out of the cotton root zone. In general a minimum deep drainage of about 5-7% of total water inflow (rainfall and irrigation) is needed to maintain soil salinity at a level where cotton yields are not significantly reduced, although total leaching fraction is of the order of 20%. Applying the model "WaterMod" showed that drainage events usually occurred early and late in the growing season when frequent rainfall was present, and in mid-season when irrigation was followed by heavy rainfall. These were periods when water availability was far in excess of cotton's water requirements. However, during the peak irrigation periods (late December-early February), when water demand by the cotton crop was high, irrigation alone resulted in few drainage events and deep drainage was very low. These observations were confirmed during the 2001-2002 season when limited early-season rainfall resulted in deep drainage being virtually absent.

Because of higher drainage with continuous cotton and cotton-wheat systems, most of the salt which had accumulated in previous seasons, and came in with irrigation water in 2000-01 season was leached out of the root zone when water quality improved after the November 2000 floods. This did not occur with the cotton-dolichos as drainage was low, and large amounts of salt remained in the soil profile at the end of the 2000-01 season. (N.B. Chloride in irrigation water during the 2000-01 cotton season was about 1.5 t/ha at Wee Waa and ACRI, and 6.5 t/ha at Merah North. Nitrate-N in irrigation water was 119 kg/ha at Wee Waa, 35 kg/ha at ACRI and 214 kg/ha Merah North).

Nutrient and salt leaching were significant in all sites. For example, nitrate-N leached out of the root zone during the 2000-01 cotton season was 129 kg/ha/season with cotton-wheat, 174 kg/ha/season with continuous cotton and 23 kg/ha/season with cotton-dolichos at Merah North; 130 kg/ha/season with cotton-wheat at Wee Waa; and 200 kg/ha/season with cotton sown into standing wheat stubble at ACRI.

Yield variation in transects across the field at Wee Waa and ACRI were due mainly to nitrate-N leaching and waterlogging (ACRI only), whereas salinity was the main cause at Merah North. Yield losses due to salinity averaged 46% (average yield of 4.3 ba/ha) in 2000-01 at Merah North, whereas average yields in 1998-99 were 7.9 bales/ha. Excluding the two treatments that had 7.5 t/ha of gypsum added in 2000-01 (long-fallow cotton and sorghum-cotton), the average gross margin/ha at Merah North was $341/ha. Reduction in profitability due to salt was, therefore, high at Merah North.

In summary, this project identified wheat as the "best" rotation crop to follow cotton due to a combination of bio-physical and economic reasons. Contrary to the widely held assumption that deep drainage, and nutrient and salt leaching were negligible in Vertosols, we have measured significant amounts of water, salts and nutrients moving out of the cotton root zone. Nutrient, particularly potassium, decline and salinization of irrigation water were identified as potential problem areas for the sustainability of cotton production systems in eastern Australia.

## 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 cracking by drying of 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 and biology, and economic profitability of such cropping systems. Furthermore, many cottongrowers have shown an interest in utilising rotation crops and their management as a tool in land preparation for cotton. A survey conducted by Mr. J. Cooper of NSW Agriculture in 1992 (CRDC Project DAN 76C) showed that although wheat was the preferred rotation crop, many cotton growers were interested in (1) legumes and (2) rotation crop management strategies, and their effects on soil properties, cost effectiveness, cotton agronomy, and pest and disease incidence during the following cotton crop. This report focuses on results obtained over the period 1999-2002 from three irrigated and two dryland on-farm experiments in New South Wales and Queensland on rotation crop management which commenced in 1993. However, where long-term trends are discussed, data collected since 1993 are also included. In two of the irrigated sites and one dryland site, the different rotation treatments were terminated, and all plots were sown to either cotton-wheat in the irrigated sites or wheat in the dryland site to evaluate the long-term residual effects of the previously sown rotation crops.

## 3. Aims and Objectives

Determine the long-term effects of rotation crops and their management on soil quality changes, nutrient uptake and cycling, growth and yield of succeeding cotton, and profitability on Vertosols used for irrigated and dryland cotton production in New South Wales and Queensland.

## 4. Methodology

### *4.1 Field Experiments*

The effects of rotation crops and their management on soil properties of Vertosols, cotton yield and profitability were monitored from 1993 to 2001 in 3 irrigated field experiments in NSW (Warren in the Macquarie valley, and Merah North and Wee Waa in the lower Namoi valley), and 2 dryland experiments in Queensland (Warra in the Darling Downs and Emerald in the Central Highlands). The dryland trials were monitored only from 1996 onwards. This report presents results for the period 1999-2002. The rotations sown at each site were as follows:

***Warren:*** (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). Since 1999, all treatments in this site were sown to a cotton-wheat rotation to evaluate the residual effects of the rotation crops sown between 1993 and 1999.

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***Wee Waa:*** (1) cotton-N fertilised wheat; (2) cotton-unfertilised wheat; (3) cotton-grain legume (chickpea in 1993, faba bean thereafter) where legume grain was harvested; (4) cotton-grain legume (chickpea in 1993, faba bean thereafter) where legume grain was incorporated during land preparation. Since 1999, all treatments in this site were sown to an N fertilised (140 kg/ha) wheat-cotton rotation to evaluate the residual effects of the rotation crops sown between 1993 and 1999.

***Warra:*** (1) long-fallow cotton; (2) cotton-sorghum; (3) cotton-double-cropped wheat; (4) cotton-chickpea; (5) cotton-wheat.

***Emerald***: (1) early cotton sown between August and October; (2) wheat (sown in May and sprayed out)-early cotton; (3) wheat (allowed to mature, harvested)-late cotton sown between October and December; (4) sorghum-cotton. In addition to rotations, this trial also compared 1- and 2-m beds, and controlled traffic farming was practiced over the whole site. Since 1999, all treatments in this site were sown with wheat to measure the residual effects of the bed widths and rotation crops sown between 1993 and 1999.

Minimum tillage was used at Warren, Warra and Emerald, and reduced tillage at Wee Waa and Merah North. In all sites rotation crop stubble was incorporated.

Additional observations were also made on nutrient leaching and deep drainage, root growth (with a minirhizotron), crop water use and agronomy, soil quality in trafficked and untrafficked furrows and organic carbon and nutrient dynamics in beds in a long-term (16 years to date) experiment at the Australian Cotton Research Institute (ACRI). The treatments are continuous cotton/intensive tillage; continuous cotton/minimum tillage; and wheat-cotton/minimum tillage. Since 1999 the wheat stubble was not incorporated but retained as standing stubble, into which the cotton was sown. Cotton was not sown in this site during the 1999-2000 cotton season.

### *4.2. Sampling & Measurements*

#### *4.2.1. Soil quality (physical and chemical properties)*

Soil was sampled in all sites from 1999 to 2002. At Warren and Warra, four soil pits were dug in each plot with a spade whereas at Wee Waa, Merah North and Emerald, four 10-cm diameter soil cores were extracted with a tractor-mounted soil corer. Two or three soil clods were taken along their natural cleavage planes from the 0-15 cm, 15-30 cm, 30-45 cm and 45-60 cm layers (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.

Air-dried soil was passed through 2 mm-sieve and the following tests carried out: plastic limit using a drop-cone penetrometer; 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 (with a nitrate electrode after extraction with 0.02M $K_2SO_4$); 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); and dispersion. These data were used to derive two sodicity indices: the "traditional'" exchangeable sodium percentage, ESP (= (exchangeable Na/Σexchangeable cations) x100), and the $EC_{1:5}$/exchangeable Na ratio. Soil resilience, a measure of the self-mulching ability of the soil, was determined by puddling and oven-drying at 40 °C for 72 h, air-dried soil which had been previously passed through a sieve with aperture diameters of 2 mm. The size distribution of the aggregates formed was expressed as the geometric mean diameter of the soil aggregates. Total soil organic carbon was determined by the wet oxidation method of Walkley and Black on soil which had been passed through a 0.5 mm-sieve. The results were multiplied by 1.72 to determine total organic matter. Fine soil organic matter (particle diameter < 212 µm) was calculated as the difference between total soil organic matter and coarse soil organic matter. Bulk density of dry soil clods was determined after coating the clods with 'saran' resin dissolved in ethyl-methyl ketone. Bulk density in beds was measured on air-dry soil aggregates (1-10 mm diameter) with the kerosene saturation method. The bulk density in the 0-15 cm was expressed as weighted mean of bulk density evaluated from clods and aggregates in beds. 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. Dispersion was measured every other year, except at Emerald when an additional measurement was made in 2001 to quantify the effects of deep ripping. Dispersion index (in g/100g) was expressed as:

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

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. Soil water content at Wee Waa in the 20-120 cm depth interval was measured at regular intervals with a neutron moisture meter which had been calibrated *in situ*. Surface soil water content was measured gravimetrically at the same time.

Short-term soil organic C dynamics in the bed (0 to 10-cm depth) was monitored in the long-term rotation/tillage experiment (16 years to date) at ACRI from January 2000 to July 2001. Sampling interval ranged from 4 weeks until March 2001, with a final sample being taken in July 2001 after land preparation had been completed for the following cotton crop.

Additional data on this topic was collected in: (a) a laboratory experiment on nutrient addition to soil by decomposition of rotation crop stubble. The crop stubble used in this experiment were cotton, green wheat, mature wheat, soybean and faba (inc. grain), and the soils were from Merah North and Wee Waa.; (b) surface soil (0-10 cm) from a field experiment on legume rotations conducted by I. Rochester of CSIRO in field F6W at ACRI; (c) the soil sampled for organic C dynamics described in the preceding paragraph. The soil chemical analyses conducted in this experiment were described in an earlier section.

### *4.2.2. Nutrient leaching and drainage*

Nutrient leaching and drainage was measured during the 2000-01 cotton season across a diagonal transect in ex-unfertilised wheat-cotton at Wee Waa, standing wheat stubble/cotton at ACRI and continuous cotton, wheat-cotton and unfertilised dolichos-cotton at Merah North. The aim of these measurements was to evaluate whether significant amounts of nutrients were being leached out of the root zone, and if so, their quantities.

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, EC (salinity), chloride by titration, nitrate-N with a nitrate electrode, and Ca, Mg, K and Na with an atomic absorption spectrophotometer. 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 (October 2000) and after (April-May 2001) the cotton season and after (December 2001) 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, EC, chloride 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, except for chloride which is described in detail in the following section (see "Determining drainage with the solute mass balance model").

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 and regressed against the $EM_{0,H}$ readings. The resulting linear regression model used to determine $EC_a$ (mS/m) was: $EC_a = 0.5083 \times EM_{0,H} - 14.199$ $r = 0.53^*$. A linear regression and stepwise multiple regression was also conducted on the drainage estimates from the solute mass balance model using $EM_{0,H}$ values from the EM38, exchangeable sodium percentage (ESP) and clay content as variables. We believe that this method (and the resulting equations) could provide growers and consultants with a methodology for quick evaluation of deep drainage under field conditions.

### *4.2.3. Determining drainage with the solute mass balance model*

A steady state model (equation 1) was used to determine the drainage rates at each of the experimental sites – with chloride as a tracer. Equations 2 and 3 were used to calculate $C_z$ and $S_{(0-z)}$ respectively for the soils sampled at each experimental site to a depth of 1.2 metres. The soil was separated into 0.3 metre increments. The chloride concentration of the soil was determined using a blotting paper tension table. The saturated paste extract was obtained by centrifuging 35 grams of paste at 7000 rpm for 10 minutes and decanting the supernatant. The supernatant was titrated through a Buchler chloridimeter.

The infiltration rate (I) in equation 1 was calculated for each site using a combination of rainfall, irrigations, evapotranspiration ($Et_o$) and profile water content - obtained from neutron probe data. When an irrigation occurred between sampling dates or rainfall was greater than $Et_o$, infiltration was calculated by adding the change in profile water content and the $Et_o$. When the $Et_o$ was greater than rainfall and no irrigation, the rainfall total between the sampling dates was used as the total infiltration for that time period. If there was no irrigation and no rainfall the infiltration was zero.

The $C_i$ in equation 1 accounted for dilution of chloride in water when rainfall occurred between sampling dates. If there was no rainfall during two sampling dates there was no dilution of the chloride concentration.

$$L = \frac{[(IC_i) - z(\bar{S}_{(0-z)t1} - \bar{S}_{(0-z)t2})]}{C_z} \text{ --------------------------------Equation 1}$$

where I = Infiltration of water from irrigation and rainfall (mm)
$C_i$ = Concentration of chloride in irrigation (meq $l^{-1}$)
z = depth increment (m)
$C_z$ = mean chloride concentration of drainage water (meq $l^{-1}$)

$$C_z = \frac{C_{SP}\theta_{SP}}{\theta_g} \text{ ---------------------------------------------------------Equation 2}$$

$$S_{(0-z)} = 0.814 C_{SP}\theta_{SP}\rho_s \text{ -----------------------------------------Equation 3}$$

where $C_{SP}$ = chloride concentration of saturated paste extract (μmol $cm^{-3}$)
$\theta_{SP}$ = water content of saturated paste (g $g^{-1}$)
$\rho_S$ = soil bulk density (g $cm^{-3}$)
$\theta g$ = *saturated moisture content at which drainage occurs (g $g^{-1}$)

0.814 = factor accounting for anion exclusion in the saturated paste
(*The saturated moisture content was estimated as 93% of the total porosity, and the total porosity was calculated from the bulk density.)

### *4.2.4. Crop agronomy and nutrient uptake*

Plant samples were taken at regular intervals at Wee Waa and Warren during the cotton growing season to evaluate dry matter production, leaf area index and boll production. Cotton plants sampled in early March and rotation crops sampled in late October were used to evaluate nutrient uptake. N in plant tissues was measured with a near-infra red protein analyzer which had been pre-calibrated with the Kjeldahl method for tissue N. Plant uptake of S, Mo, Zn, B, Mn, Cu, Mg, Ca, K and Na were evaluated by determining nutrient concentration in plant dry matter with an inductively coupled plasma-atomic emission spectrometer after microwave digestion with concentrated nitric acid. (Plant nutrient uptake at Warra and Emerald; soil water content at Merah North, Warra and Emerald; and plant agronomy at Warra, Emerald and Merah North 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 at Wee Waa and the long-term tillage rotation experiment at ACRI. The data collected in the latter site is being used to further refine the water use efficiency model of Dr. S. Tennakoon (CSIRO).

### *4.2.5. Profitability*

Financial returns and profitability for each rotation were evaluated for the Wee Waa, Warren and Merah North sites 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 margins were calculated using the input operations and yield results for each treatment. The commodity and individual input prices used were the same for each season (e.g. $495/tonne for cotton lint). This was to prevent fluctuations in commodity prices and input prices concealing rotation effects on the gross margins. Gross margins were also described according to the amount of variable costs invested in each rotation. Cotton price sensitivity testing is reported, using prices of $400 and $600 per bale.

## 5. Key Results and Discussion

### *5.1. Soil Quality*

### *5.1.1 Soil structure*

Soil structural indices measured in this project were: soil structural form (volume-based indices) such as air-filled porosity, specific volume and density; and structural stability such as dispersion index.

As in previous years, treatments where winter cereal crops such as wheat had been sown before cotton tended to have better subsoil structure than when legumes were sown. This was a common trend in both dryland and irrigated sites. Data from Merah North (Fig. 1) and Warra (Fig. 2) are shown as examples. Both data sets relate to the times of sampling before cotton was sown in all plots. In saline-sodic soils like Merah North, subsoil structure with long-fallow cotton was similar to that after wheat. This may be due to reduced tillage and traffic load under a lower cropping intensity reducing structural damage, rather than structural amelioration. In dryland sites such as Warra, surface soil structure was, in general, poorest with long-fallow cotton, and was best with double-cropped wheat-cotton. In general, surface structure with cotton-rotation crop sequences (R2, R3, R4, R5) were better than with long-fallow cotton (R1). Details of the cropping sequence sown in this trial between May 1998 and April 2001 are summarised in Table 1. In the subsoil a broadly similar response pattern, namely cotton-rotation crop sequences resulted in better soil structure, occurred. However, other factors also appeared to influence subsoil structure. These were seasonal rainfall and distribution, and whether a crop, any crop, had been sown during the season before soil sampling occurred. For example, the absence of a crop in chickpea-cotton (R4) and wheat-cotton (R5) during summer 2000-01 resulted in deterioration in air-filled porosity between April 2000 and April 2001. In contrast, soil structure was maintained or improved with long-fallow cotton (R1), sorghum-cotton (R2) and double cropped wheat-cotton (R3), all of which were sown with cotton during 2000-01 (Fig 2). Both cropping and frequent rainfall facilitate wetting/drying cycles, which in turn contributes to soil structural improvement.

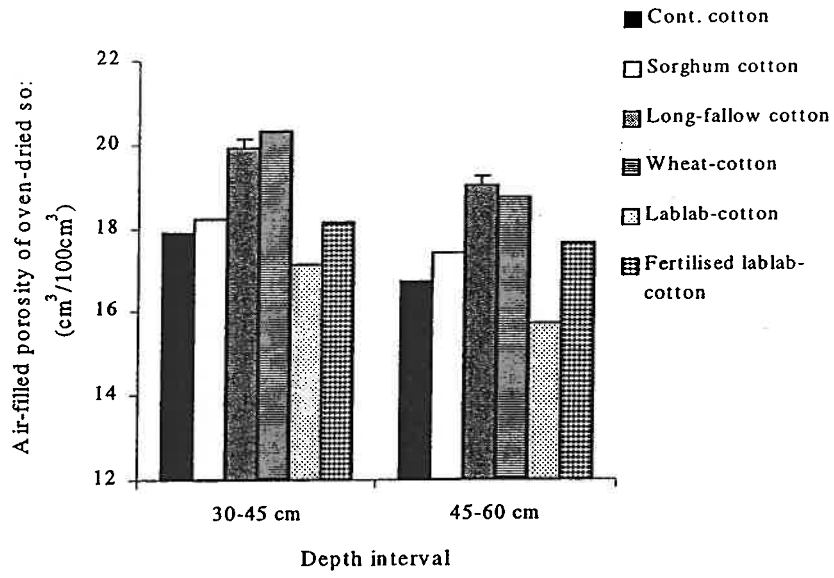

**Figure 1.** Effect of rotation on soil structure in the 30-45 cm and 45-60 cm depths measured as air-filled porosity of overn-dried soil, at "Beechworth", Merah North, in May 2000. Vertical bars are standard errors of the mea for each depth interval

In sites where the individual rotation treatments had been terminated in 1999 and uniform cropping systems sown over the entire site; i.e. minimum-tilled irrigated cotton-wheat at Warren, laser-levelling in 1999, followed by intensively-tilled irrigated wheat-cotton at Wee Waa, and deep-ripping to 45 cm followed by dryland wheat at Emerald, residual effects of the previous rotations were evident. At Emerald, in the 0-15 cm depth both ex-wheat-based rotation systems, and in the 15-30 cm depth the ex-wheat-based systems and the early sown cotton had the best structure (Fig. 3). In other words rotation systems which produced the most ground cover resulted in better structure than those which did not. These results may be due to higher erosion in low ground cover systems, and hence, exposure of more compacted subsoil. At Wee Waa soil structure in the 0-30 cm depth was not significantly affected ($P = 0.05$) by rotation history, whereas in the 30-60 cm depth the ex-fertilised wheat-cotton sequence had the best structure ($P = 0.05$). At Warren, significant differences between ex-rotation systems were absent. However, soil structure in the 15-30 cm ($P = 0.05$), 30-45 cm ($P = 0.01$) and 45-60 cm ($P = 0.001$) depths was poorest in the ex-legume rotations (field pea-cotton and faba-cotton), with generally better structure occurring with rotations which had included wheat at some stage.

The results from Emerald, Wee Waa and Warren show that, in general, soil structural improvements brought about by wheat (and other non-legumes) are more stable than those resulting from leguminous crops (Figs. 3-5). This may be related to more frequent and intense wetting/drying cycles under wheat (which stabilises soil aggregates) and the higher C:N ratio of the non-legumes. A higher C:N ratio results in less decomposable subsoil organic matter and root material, which in turn can maintain an active microbial population for longer periods than the easily decomposable organic matter derived from legumes. This suggests that microbial stabilisation of soil structure may have occurred in these rotations.

Similar stabilisation of soil aggregates due to organic matter-microbial associations and wetting/drying cycles under different rotations was reviewed in a paper presented by Professor A. Smucker of Michigan State University at the recently-concluded 6th Symposium of the International Society of Root Research, which was attended by Dr. Hulugalle.

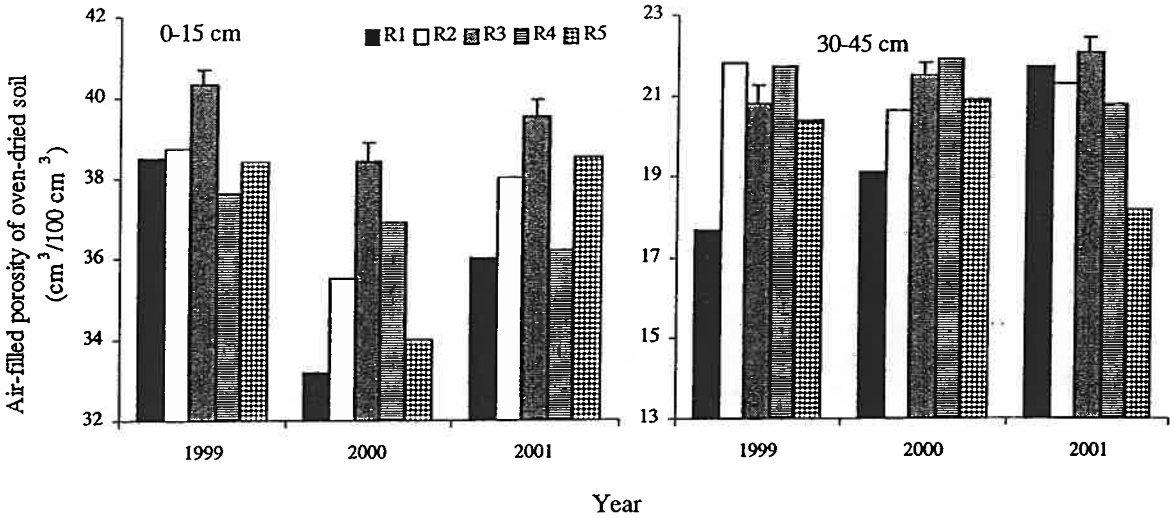

**Figure 2.** Effect of rotation on soil structure, measured as air-filled porosity of oven-dried soil, in the 0-15 cm and 30-45 cm depth at "Prospect", Warra, 1999 to 2001. R1–long-fallow cotton ; R2-sorghum-cotton ; R3 –double-cropped wheat-cotton ; R4 –chickpea-cotton ; R5 –wheat-cotton . Vertical bars are standard errors of the means for any one year.

Table 1. Cropping sequences sown at Warra between May 1998 and April 2001.

| Season | Long-fallow cotton (R1) | Cotton-sorghum (R2) | Double-cropped wheat-cotton (R3) | Cotton-chickpea (R4) | Cotton-wheat (R5) |
|---|---|---|---|---|---|
| **Winter 1998** | Fallow | Fallow | Fallow | Fallow | Wheat |
| **Summer 1998/99** | Cotton | Cotton | Cotton | Cotton | Fallow |
| **Winter 1999** | Fallow | Fallow | Wheat | Chickpea | Fallow |
| **Summer 1999/00** | Fallow | Sorghum | Fallow | Fallow | Cotton |
| **Winter 2000** | Fallow | Fallow | Fallow | Wheat | Fallow |
| **Summer 2000/01** | Cotton | Cotton | Cotton | Fallow | Fallow |

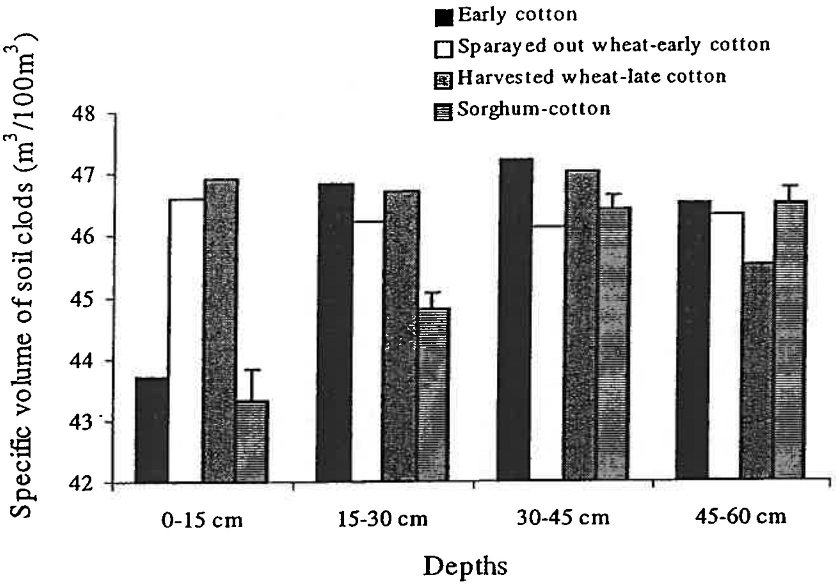

**Figure 3.** Effect of rotation on soil structure, measured as specific volume of oven-dried soil clods, in the 0-60 cm depth at "Elsden Farms", Emerald, February 2001. Vertical bars are standard errors of the means for any one depth.

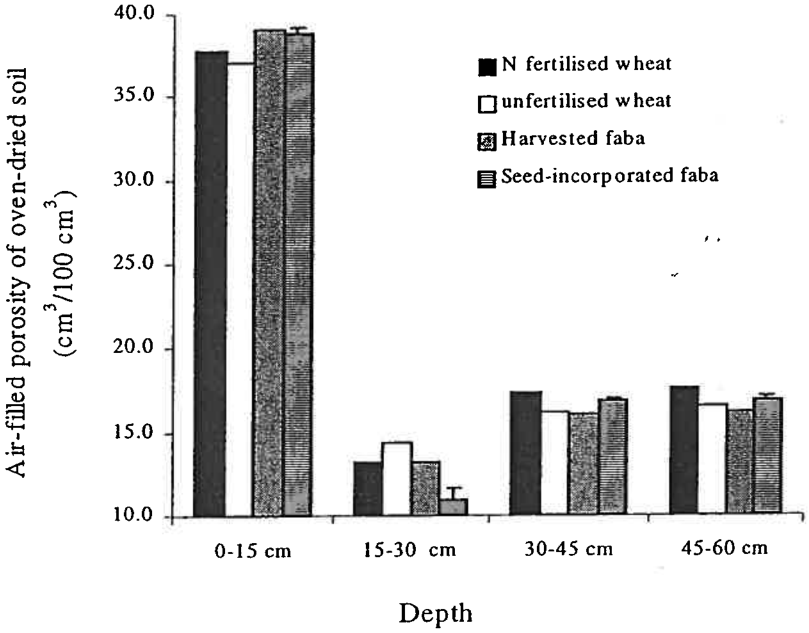

**Figure 4.** Effect of rotation on soil structure, measured as air-filled porosity of oven-dried soil, in the 0-60 cm depth at "Glenarvon", Wee Waa, May 2001. Vertical bars are standard errors of the means for any one depth.

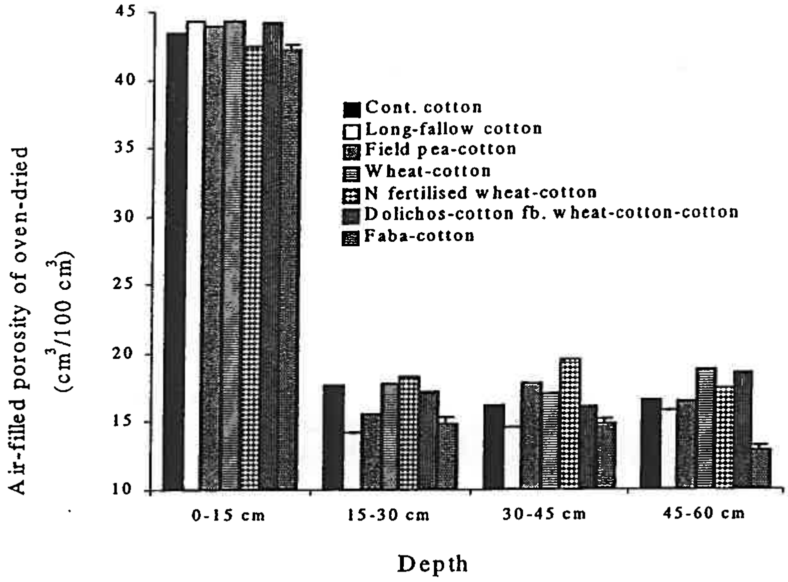

**Figure 5.** Effect of rotation on soil structure, measured as air-filled porosity of oven-dried soil, in the 0-60 cm depth at "Auscott", Warren, May 2001. Vertical bars are standard errors of the means for any one depth.

Soil aggregate stability, measured as dispersion index, did not differ between rotations (except at Warren in 1996). However, re-evaluation of data collected between 1996 and 2001 and plotting $EC_{1:5}$/exchangeable Na against dispersion index suggested that there were characteristic dispersion curves for each site and depth which were unaffected by crop rotation (Figure 6, Table 2). The only site where these curves changed with time was at Emerald, where the soil was a deep, black earth. Although there were no significant differences between depths at this site, moderate structural damage during bed renovation and fertiliser application under wet conditions in 1998 combined with further structural deterioration due to deep ripping in 2000 resulted in a shifting of the curve. We believe that the sharp increase in dispersion observed in 2001 is due partly to mechanical destabilization of soil aggregates caused by the deep ripping, an observation reported by many workers for a range of soil types in Australia, and partly to a reduction in EC/exchangeable Na due to a fall in EC from an average of 0.3 dS/m in 2000 to 0.16 dS/m in 2001. The latter was probably caused by increased leaching of nutrients and salts as a consequence of deep ripping. Furthermore, the large increase in in dispersion was limited to the depth of ripping, i.e. 45 cm (Fig. 7). These observations also suggest that over the long-term tillage systems play a

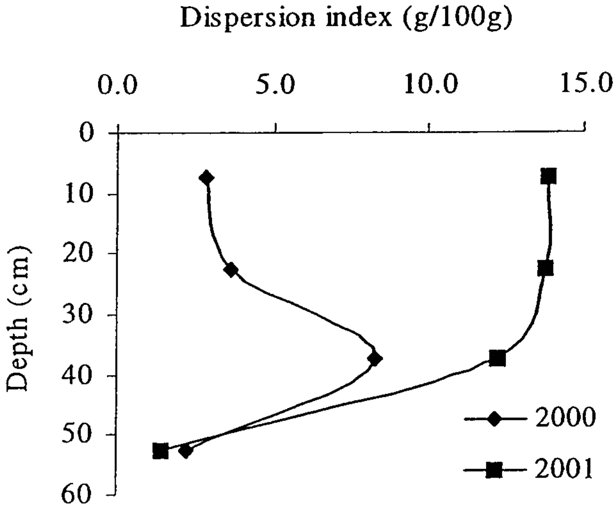

**Figure 7.** Change in dispersion index between 2000 and 2001 at Emerald

dominant role in aggregate stabilization in Vertosols, with crop rotations having only a minor effect.

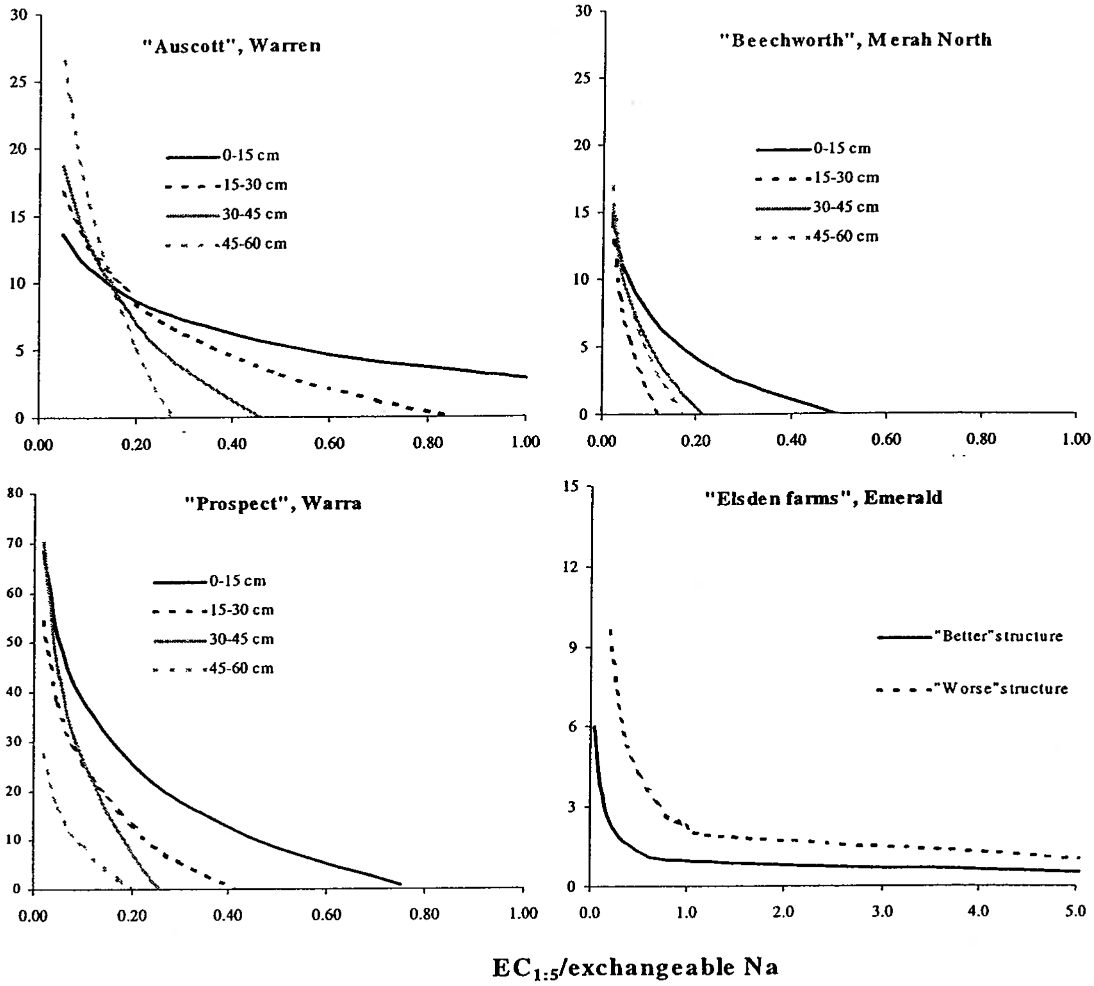

Table 2. Fitted equations for dispersion curves shown in Fig. 6.

| Site | Depth (cm) | Years | Equation | n | r |
|---|---|---|---|---|---|
| Auscott, | 0-15 | 1996-2000 | $y = 2.81 - 3.62[\ln (EC_{1:5}/\text{exch. Na})]$ | 63 | -0.51*** |
| Warren, | 15-30 | 1996-2000 | $y = -0.99 - 5.91[\ln (EC_{1:5}/\text{exch. Na})]$ | 63 | -0.67*** |
| NSW | 30-45 | 1996-2000 | $y = -6.96 - 8.48[\ln (EC_{1:5}/\text{exch. Na})]$ | 63 | -0.72*** |
| | 45-60 | 1996-2000 | $y = -19.92 - 15.49[\ln (EC_{1:5}/\text{exch.Na})]$ | 63 | -0.81*** |
| Beechworth, | 0-15 | 1996-2000 | $y = 3.37 - 4.68[\ln (EC_{1:5}/\text{exch. Na})]$ | 54 | -0.79*** |
| Merah North, | 15-30 | 1996-2000 | $y = -16.99 - 7.97[\ln (EC_{1:5}/\text{exch. Na})]$ | 54 | -0.66*** |
| NSW | 30-45 | 1996-2000 | $y = -9.96 - 6.53[\ln (EC_{1:5}/\text{exch. Na})]$ | 54 | -0.53*** |
| | 45-60 | 1996-2000 | $y = -13.98 - 7.89[\ln (EC_{1:5}/\text{exch. Na})]$ | 54 | -0.51*** |
| Prospect, | 0-15 | 1996-2000 | $y = -4.42 - 18.62[\ln (EC_{1:5}/\text{exch. Na})]$ | 45 | -0.68*** |
| Warra, | 15-30 | 1996-2000 | $y = -16.09 - 18.02[\ln (EC_{1:5}/\text{exch.Na})]$ | 45 | -0.57*** |
| Qld. | 30-45 | 1996-2000 | $y = -36.58 - 27.28[\ln (EC_{1:5}/\text{exch.Na})]$ | 45 | -0.57*** |
| | 45-60 | 1998-2000 | $y = -18.77 - 11.82[\ln (EC_{1:5}/\text{exch.Na})]$ | 30 | -0.49** |
| Elsden Farms | All depths | 1996-2001 | | | |
| Emerald, | 'Better' structure | | $y = 0.84(EC_{1:5}/\text{exch. Na})^{-0.66}$ | 72 | -0.72*** |
| Qld. | 'Worse' structure | | $y = 2.24(EC_{1:5}/\text{exch. Na})^{-0.90}$ | 72 | -0.71*** |

### *5.1.2 Soil organic carbon*

Similar to the results obtained from 1993-99 in the irrigated sites in NSW and from 1996-99 in the dryland sites in Qld., there were no significant differences between experimental treatments with respect to soil organic carbon sequestration in the 0-60 cm depth. However, there were some notable differences. At Warren, Merah North and Emerald, whereas soil organic carbon declined during the first years of these experiments, more recently organic carbon slowly increased (Merah North, Emerald) or remained stable (Warren) (Fig. 7). The minimum value reached at Merah North and Warren (grey clays) was in the order of 6 kg/m$^2$, and at Emerald (black earth) was about 8.5 kg/m$^2$. These trends can be clearly visualised by fitting linear functions to the early and late phases of these experiments thus (Y = soil organic C in 0-60 cm in kg/m$^2$, and t = time in Julian years):

*Warren*:
1993-1997: $Y = 1502.44 - 0.75t$, $r = -0.64^{***}$, $n = 68$;
1997-2001: $Y = 71.88 - 0.08t$, $r = -0.03$ns, $n = 98$.

*Merah North:*
1994-1997: $Y = 1270.50 - 0.63t$, $r = -0.63^{***}$, $n = 72$;
1997-2001: $Y = 0.14t - 265.89$, $r = 0.39^{***}$, $n = 90$;

*Emerald*:
1996-1999: $Y = 2015.50 - 1.00t$, $r = -0.74^{***}$, $n = 35$;
1999-2001: $Y = 0.44t - 874.33$, $r = 0.63^{***}$, $n = 27$.

In contrast with the trends at Warren, Merah North and Emerald, soil organic C in the 0-60 cm depth at Wee Waa remained relatively stable between 1993 and 2001 (Fig. 7), averaging 10.1 kg/m$^2$. This is about 60-70% higher than the minimum values reached in the other irrigated sites. The cause of this stability, which contrasts with results from other experimental sites in this project and regional trends in soil organic C (CRC project 1.2.1), is unknown. It may be due to a combination of better water quality, more sparing and rational irrigation schedules, reduced herbicide use (which impacts on soil organic C dynamics; see later discussion) and a natural resilience of the soil at this site in terms of soil health and microbial ecology.

A further variation from commonly reported trends in soil organic C was also observed at Warra, Qld. This was such that distinctive peaks in organic C were observed in some years (1996, 1999). Further data analysis indicated a significant correlation with summer (Jan. to March) rainfall, with maximum carbon sequestration occurring with a rainfall value of 370 mm (Fig. 8). Increasing rainfall upto 370 mm may cause more mineralisation of stubble from previous crops and more rhizodeposition during the growing period of the crop, both of which will increase soil organic C. Further increases in rainfall may result in waterlogging and reductions in microbial and root activity, and consequently a reduction in carbon sequestration. The minimum points in the curve at Warra are of the order of 6 kg/m$^2$ and hence, are similar to the minima observed at Warren and Merah North. The soils in all three sites are grey clays.

In summary, the rapid depletion of soil organic matter observed during the early years of the on-farm rotation systems experiments established in NSW and Qld., appears to have decreased, and in some cases recovery or stabilisation of soil organic matter reserves, albeit at a lower level has occurred. An exception to this pattern of soil organic C depletion followed by stabilisation and recovery is the experiment at "Glenarvon", Wee Waa, where no net decline in soil organic carbon has occurred between 1993 and 2001.

Short-term soil organic C dynamics in the bed was monitored in the long-term rotation/tillage experiment (16 years to date) at ACRI from January 2000 to July 2001. The results show that the cotton-wheat system resulted in far higher soil ($P = 0.001$) organic C values in the beds in

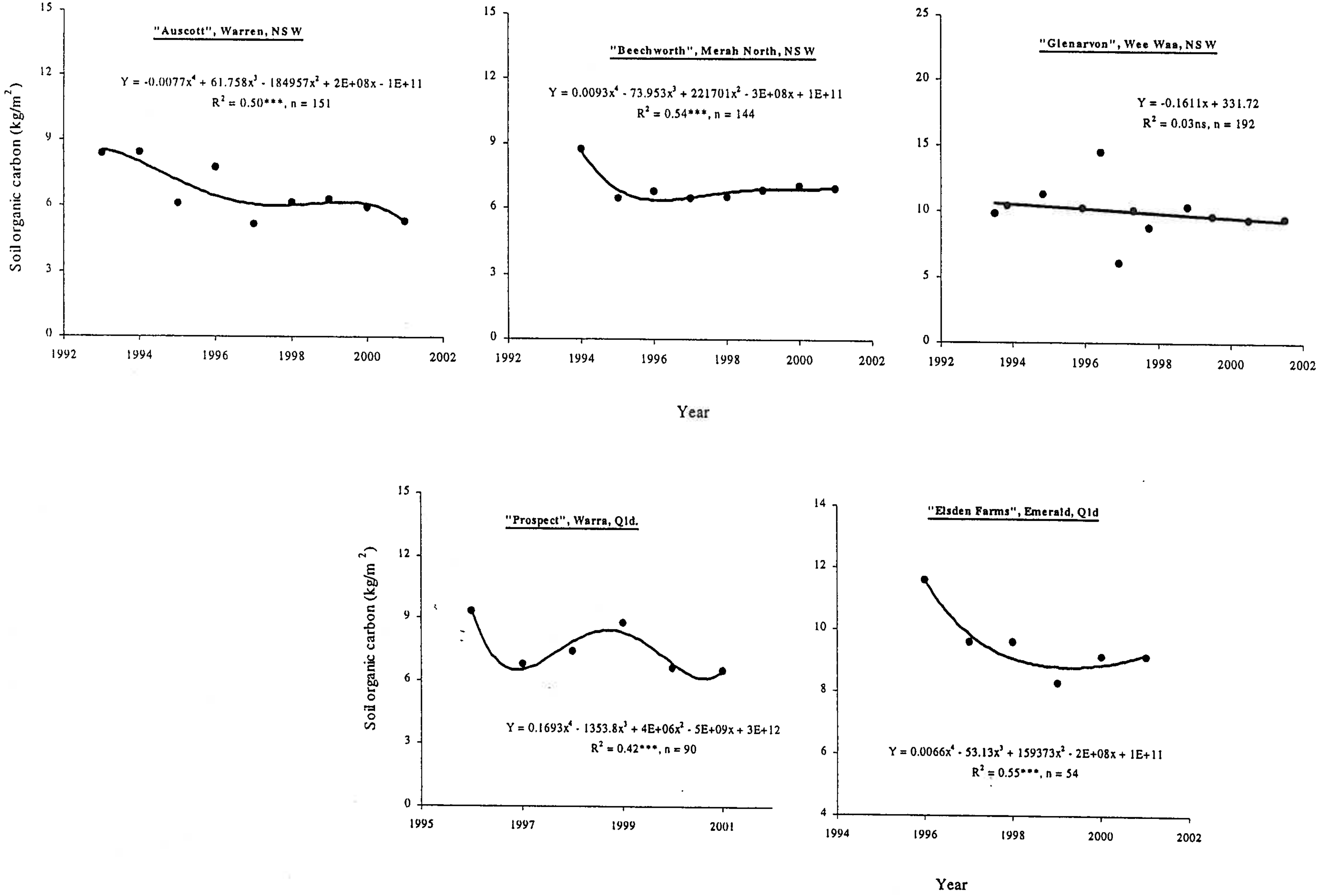

Figure 7. Changes in soil organic carbon (kg/m$^2$) in the 0-60 cm depths at the 3 irrigated sites in NSW and 2 dryland sites in Qld. Significant differences did not occur between experimental treatments. Data points are the average values for each year, and include data from 1993-1998. The curves and equations were derived from all measured values in each year, and are not based only on average values.

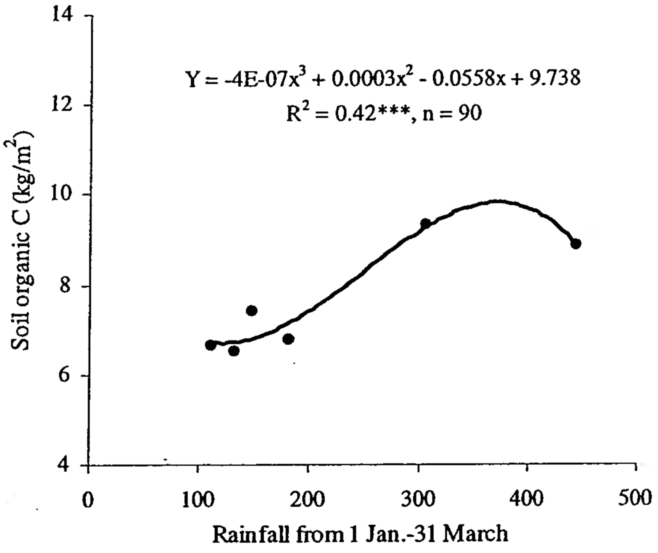

**Figure 8.** Effect of summer rainfall (1 January to 31 March) on soil organic carbon sequestration in the 0-60 cm depth

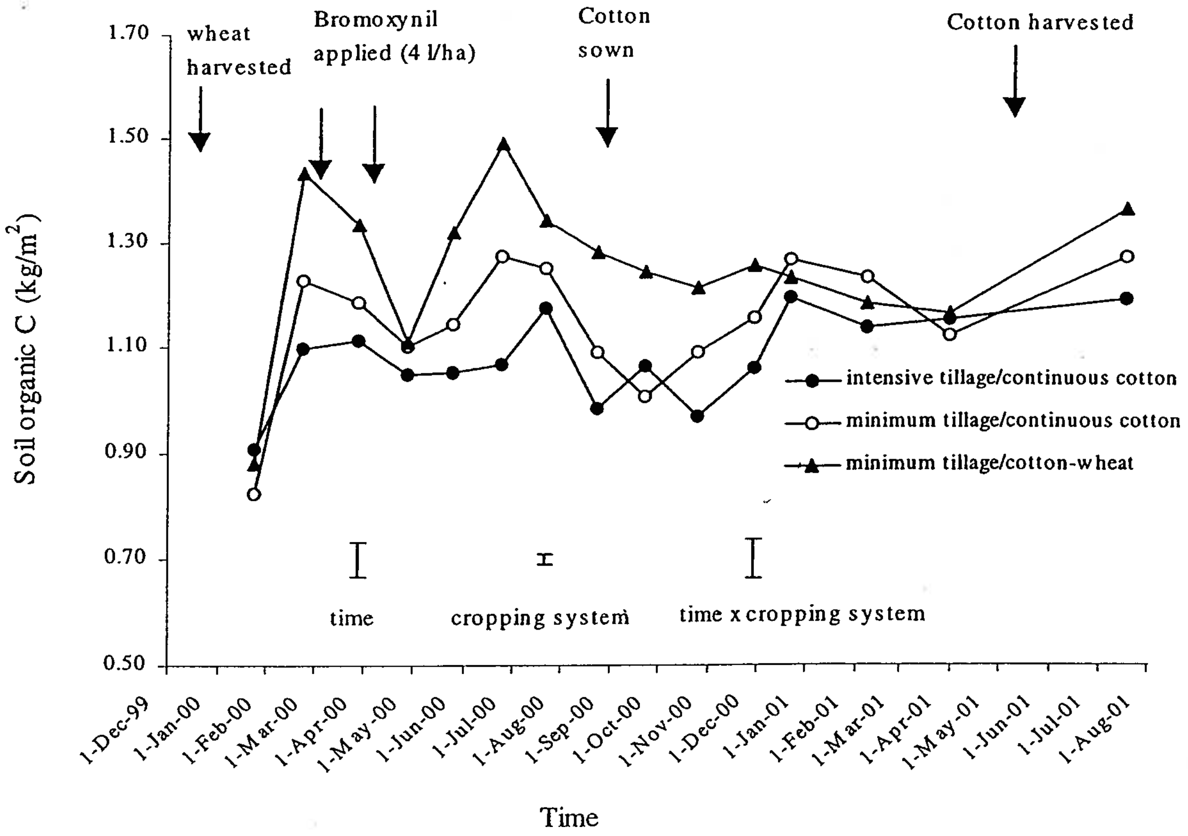

**Figure 9.** Variation in soil organic carbon in the bed (0-10 cm) between January 2000 and August 2001 in the tillage/rotation experiment, Field C1, ACRI, Narrabri. Vertical bars are standard errors of the means.

comparison with either of the continuous cotton treatments (Fig. 9). The minimum-tilled cotton also had higher soil organic C than did the intensively-tilled cotton. Whilst these trends are similar to the previous phase of the experiment (when wheat stubble was incorporated into the bed), the differences between the continuous cotton treatments and the cotton-wheat are far higher when wheat stubble is retained as standing stubble. This probably due to the reduction in stubble decomposition rates with the latter practice. The frequent sampling also highlighted the fluctuations which occur in soil organic C during a calendar year. In particular, soil organic C in the continuous cotton treatments increase sharply as the growth rate of the cotton crop increases during the cotton growing season (i.e. between December 2000 onwards). Consequently between January to March there were no significant differences between the experimental treatments. This may due to addition of soil organic C through rhizodeposition and leaf fall while the cotton crop is *in situ*.

A sharp fall in soil organic C also occurred after application of Bromoxynil to control volunteer cotton during the summer of 1999-2000 (cotton was not sown during the 1999-2000 cotton season). No other management operation occurred during this period. The greatest decreases occurred with minimum-tilled treatments, whereas that under intensively-tilled cotton was negligible (Fig. 9). While the detrimental effects of several cotton herbicides on soil microflora, and hence, stubble decomposition, have been documented before (CRDC Project SLM2C), this is the first-reported case of the interactive effects of tillage and cropping systems, and Bromoxynil on soil organic C. The causal mechanism is unknown. However, if the decomposition process is simplified as follows:

$$\textbf{Crop stubble} \rightarrow \textbf{Soil organic matter} \rightarrow \textbf{CO}_2$$

it can be speculated that if Bromoxynil interferes with the microbial processes involved with the first step, namely the breakdown of stubble to soil organic matter, but not with the second step, the breakdown of soil organic matter to carbon dioxide, temporary depletion of soil organic carbon could occur as observed. Once the herbicide was broken down or leached out, stubble breakdown would recommence, and soil organic C would recover to previous levels.

The key point of these series of observations is that during the fallow (uncropped) phase of a cotton-wheat rotation, standing wheat stubble can increase soil organic carbon more (by several times) than can be achieved by incorporating wheat stubble. However, during the cotton-growing season, there were negligible differences between tillage systems and crop rotations.

### *5.1.3. Sodicity*

Two indices of sodicity were evaluated: the traditional exchangeable sodium percentage, ESP, and the $EC_{1:5}$/exchangeable Na ratio. Results from Wee Waa (Table 3), Warren and Emerald showed that there were no significant differences between rotations or rotation history. Due to similarity in data trends only results from Wee Waa were included in this report. A small increase in sodicity occurred between 1999 and 2000 at Wee Waa, which decreased by 2001. The deep ripping which took place at this site probably caused this. Deep ripping tends to bring subsoil with higher Na concentrations to the surface. Significant differences between rotation crops with respect to $EC_{1:5}$/exchangeable Na but not ESP were observed at Merah North during 2000 and 2001. Comparative analysis of different sodicity indices have shown that the latter is the best indicator of structural stability in Vertosols (see article entitled "Measuring soil sodicity in cotton-growing soils" by N.R. Hulugalle in the "Australian Cotton grower", volume 22(4), pp. 56-58). These differences appear to have been caused by a combination of differing irrigation frequencies with the different rotation systems and poor quality (high SAR and Cl concentration) irrigation water (see later section). In addition, an increase in ESP and a decrease in $EC_{1:5}$/exchangeable Na was observed between 2000 and 2001 in all plots. This was similar to the response pattern observed in 1997 (see Final Report

Table 3. Effect of rotation history (1993-99) on sodicity indices in 0-60 cm depth at Wee Waa, NSW

| Ex-rotation crop | Depth (cm) | 1999 | | 2000 | | 2001 | |
|---|---|---|---|---|---|---|---|
| | | ESP (%) | EC$_{1:5}$/Exch. Na | ESP (%) | EC$_{1:5}$/Exch. Na | ESP (%) | EC$_{1:5}$/Exch. Na |
| N Fertilised wheat | 0-15 | 1.4 | 0.34 | 1.6 | 0.62 | 1.4 | 0.47 |
| | 15-30 | 2.0 | 0.15 | 2.4 | 0.38 | 1.8 | 0.36 |
| | 30-45 | 4.5 | 0.07 | 3.4 | 0.26 | 2.7 | 0.25 |
| | 45-60 | 3.3 | 0.11 | 4.2 | 0.20 | 3.8 | 0.21 |
| Unfertilised wheat | 0-15 | 1.4 | 0.34 | 2.1 | 0.48 | 1.4 | 0.45 |
| | 15-30 | 2.3 | 0.11 | 2.6 | 0.31 | 1.9 | 0.30 |
| | 30-45 | 4.4 | 0.07 | 4.2 | 0.20 | 2.7 | 0.23 |
| | 45-60 | 3.3 | 0.11 | 5.0 | 0.14 | 3.7 | 0.19 |
| Seed harvested faba | 0-15 | 1.4 | 0.35 | 2.1 | 0.49 | 1.4 | 0.41 |
| | 15-30 | 2.2 | 0.11 | 2.1 | 0.36 | 1.8 | 0.36 |
| | 30-45 | 4.4 | 0.06 | 3.7 | 0.23 | 2.6 | 0.24 |
| | 45-60 | 3.1 | 0.12 | 3.7 | 0.18 | 3.2 | 0.22 |
| Seed incorporated faba | 0-15 | 1.6 | 0.38 | 2.1 | 0.51 | 1.5 | 0.56 |
| | 15-30 | 2.2 | 0.12 | 2.9 | 0.33 | 1.8 | 0.30 |
| | 30-45 | 4.2 | 0.06 | 3.9 | 0.20 | 2.8 | 0.22 |
| | 45-60 | 3.2 | 0.10 | 5.0 | 0.17 | 3.8 | 0.17 |

| *AOV:* | P | se | P | se | P | se | P | se | P | se | P | se |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rotation crops, R | ns | 0.24 | ns | 0.016 | ns | 0.23 | ns | 0.019 | ns | 0.10 | ns | 0.023 |
| Depths, D | *** | 0.10 | *** | 0.012 | *** | 0.13 | *** | 0.010 | ** | 0.07 | *** | 0.013 |
| R x D | ns | 0.19 | ns | 0.024 | ns | 0.25 | ns | 0.021 | ns | 0.13 | * | 0.025 |

Table 4. Effect of rotation crop on sodicity indices in 0-60 cm depth at, Merah North, NSW

| Rotation crop | Depth (cm) | 1999 | | 2000 | | 2001 | |
|---|---|---|---|---|---|---|---|
| | | ESP (%) | EC$_{1:5}$/Exch. Na | ESP (%) | EC$_{1:5}$/Exch. Na | ESP (%) | EC$_{1:5}$/Exch. Na |
| Continuous cotton | 0-15 | 5.8 | 0.13 | 4.0 | 0.24 | 4.4 | 0.11 |
| | 15-30 | 10.2 | 0.08 | 7.5 | 0.13 | 7.7 | 0.07 |
| | 30-45 | 12.9 | 0.07 | 11.7 | 0.08 | 12.4 | 0.06 |
| | 45-60 | 16.9 | 0.05 | 13.9 | 0.06 | 15.6 | 0.04 |
| Winter vetch (1999) fb. sorghum (2000) | 0-15 | 5.7 | 0.12 | 5.3 | 0.12 | 5.5 | 0.08 |
| | 15-30 | 10.1 | 0.09 | 8.4 | 0.07 | 9.3 | 0.05 |
| | 30-45 | 13.4 | 0.07 | 12.0 | 0.06 | 14.0 | 0.04 |
| | 45-60 | 15.8 | 0.06 | 14.7 | 0.05 | 17.0 | 0.03 |
| Long-fallow cotton | 0-15 | 5.6 | 0.13 | 4.6 | 0.11 | 5.6 | 0.09 |
| | 15-30 | 10.1 | 0.08 | 7.6 | 0.09 | 8.8 | 0.06 |
| | 30-45 | 12.9 | 0.06 | 11.0 | 0.06 | 14.2 | 0.04 |
| | 45-60 | 15.6 | 0.06 | 13.5 | 0.05 | 17.0 | 0.04 |
| Unfertilised wheat | 0-15 | 5.2 | 0.12 | 4.1 | 0.14 | 5.1 | 0.14 |
| | 15-30 | 9.2 | 0.09 | 7.3 | 0.08 | 9.2 | 0.07 |
| | 30-45 | 12.7 | 0.07 | 11.3 | 0.07 | 14.4 | 0.05 |
| | 45-60 | 15.9 | 0.06 | 13.8 | 0.06 | 15.6 | 0.05 |
| Dolichos | 0-15 | 6.0 | 0.10 | 5.2 | 0.15 | 5.3 | 0.09 |
| | 15-30 | 9.7 | 0.08 | 8.8 | 0.08 | 9.6 | 0.05 |
| | 30-45 | 14.3 | 0.06 | 12.1 | 0.06 | 15.6 | 0.04 |
| | 45-60 | 16.8 | 0.05 | 14.8 | 0.05 | 18.8 | 0.04 |
| Fertilised (P+ K) dolichos | 0-15 | 4.8 | 0.15 | 4.0 | 0.19 | 4.3 | 0.19 |
| | 15-30 | 9.4 | 0.09 | 7.7 | 0.09 | 8.8 | 0.08 |
| | 30-45 | 12.7 | 0.07 | 10.9 | 0.06 | 14.3 | 0.05 |
| | 45-60 | 15.3 | 0.06 | 14.7 | 0.05 | 17.1 | 0.04 |

| *AOV:* | P | se | P | se | P | se | P | se | P | se | P | se |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rotation crops, R | ns | 0.41 | ns | 0.005 | ns | 0.52 | ** | 0.008 | ns | 0.79 | ns | 0.011 |
| Depths, D | *** | 0.21 | *** | 0.005 | *** | 0.21 | *** | 0.005 | *** | 0.29 | *** | 0.006 |
| R x D | ns | 0.50 | ns | 0.010 | ns | 0.51 | *** | 0.011 | ns | 0.71 | * | 0.013 |

for CRDC project DAN 108C), and suggests that cycles of deterioration and improvement in ground water quality occur at this site. Measurements of irrigation water quality during the growing season of 2000-01 confirmed this speculation. These cycles are thought to be strongly influenced by recharge through rainfall and regional flood events (Pers. comm, W. McLean, UNSW Groundwater Research Centre, Sydney, 2001).

Table 5. Effect of rotation crop on sodicity indices in 0-60 cm depth at "Prospect", Warra, Qld.

| Rotation crop | Depth (cm) | 1999 | | 2000 | | 2001 | |
|---|---|---|---|---|---|---|---|
| | | ESP (%) | EC$_{1:5}$/Exch. Na | ESP (%) | EC$_{1:5}$/Exch. Na | ESP (%) | EC$_{1:5}$/Exch. Na |
| Long-fallow cotton | 0-15 | 0.6 | 0.84 | 2.1 | 0.59 | 1.5 | 0.27 |
| | 15-30 | 1.2 | 0.36 | 3.8 | 0.32 | 3.4 | 0.17 |
| | 30-45 | 1.9 | 0.13 | 4.9 | 0.24 | 4.3 | 0.16 |
| | 45-60 | 2.8 | 0.10 | 7.7 | 0.17 | 5.3 | 0.12 |
| Sorghum | 0-15 | 0.4 | 1.18 | 2.1 | 0.40 | 2.0 | 0.22 |
| | 15-30 | 0.9 | 0.53 | 4.9 | 0.21 | 3.9 | 0.12 |
| | 30-45 | 1.6 | 0.15 | 7.3 | 0.15 | 5.5 | 0.11 |
| | 45-60 | 2.5 | 0.11 | 9.5 | 0.12 | 6.9 | 0.09 |
| Double-cropped wheat | 0-15 | 0.5 | 0.97 | 2.8 | 0.45 | 1.7 | 0.21 |
| | 15-30 | 1.2 | 0.44 | 4.2 | 0.26 | 2.8 | 0.16 |
| | 30-45 | 1.8 | 0.14 | 6.3 | 0.17 | 4.0 | 0.12 |
| | 45-60 | 2.9 | 0.10 | 8.5 | 0.15 | 5.5 | 0.10 |
| Chickpea | 0-15 | 0.4 | 1.33 | 2.1 | 0.58 | 1.6 | 0.23 |
| | 15-30 | 1.1 | 0.48 | 3.5 | 0.30 | 2.6 | 0.17 |
| | 30-45 | 1.7 | 0.16 | 5.6 | 0.20 | 3.9 | 0.15 |
| | 45-60 | 2.5 | 0.12 | 7.4 | 0.14 | 5.4 | 0.11 |
| Wheat | 0-15 | 0.5 | 0.92 | 2.1 | 0.48 | 1.9 | 0.19 |
| | 15-30 | 1.3 | 0.39 | 4.2 | 0.23 | 3.2 | 0.15 |
| | 30-45 | 1.9 | 0.13 | 5.7 | 0.18 | 4.7 | 0.13 |
| | 45-60 | 3.0 | 0.09 | 7.8 | 0.14 | 6.2 | 0.09 |
| *AOV:* | | P se | P se | P se | P se | P se | P se |
| Rotation crops, R | | ns 0.11 | ns 0.049 | ns 0.36 | ** 0.01 | * 0.23 | ns 0.012 |
| Depths, D | | *** 0.07 | *** 0.036 | *** 0.17 | *** 0.01 | *** 0.08 | *** 0.006 |
| R x D | | ns 0.15 | ns 0.081 | ns 0.38 | ns 0.03 | ns 0.18 | ns 0.013 |

Significant differences occurred between rotations with respect to ESP and EC$_{1:5}$/Exch. Na at Warra in 2000 and 2001, but not in 1999 (Table 5). However, these differences between rotations are small can be expected to have a negligible impact on soil structural stability. Larger differences (P = 0.001) occurred between years where sodicity increased between 1999 and 2000 followed by a small decrease in 2001. This may be related to differences in rainfall in the 3 months prior to sampling (444 mm in 1999, 113 mm in 2000 and 134 in 2001), and associated effects on carbon cycling (see earlier discussion on soil C and stubble decomposition at Warra). Microbial decomposition of soil organic matter and stubble is known to cause formation of carbonic acid, which in turn results in solubilization of native calcium carbonate and release of Ca into the exchangeable ion pool. This process results in reduction of ESP and an increase in EC$_{1:5}$/Exch. Na. Similar observations were made in the laboratory experiments on stubble decomposition which are described in a later section of this report.

### *5.1.4 Low exchangeable potassium*

Exchangeable K was low in both dryland sites (Warra and Emerald); generally between 4 to 5 time lower, than in the irrigated sites. These low values resulted in premature senescence at Warra, particularly when Ingard cotton varieties were sown. Premature senescence was not observed at Emerald probably due to the effects of drought and heavy insect damage in 1995-96 and 1997-98. Replacement of cotton-based rotations with a wheat-fallow cropping system in 2000 resulted a small, but nonetheless significant (P = 0.01), increase in exchangeable K of all depths at Emerald.

Even in the irrigated sites there were significant declines (P = 0.001) in the subsoil layers with time. Potassium concentrations in cotton reflected these changes. K concentration in mature vegetative tissues averaged 1.4% in 1997, 1.6% in 1999 and 1.1% in 2001 at Warren; 1.9% in 1997, 1.6% in 1999 and 1.3% in 2001 at Merah North; and 1.7% in 1995, 1.9% in 1997, 1.3% in 1999 and 1.2% in 2001 at Wee Waa. Significant (P = 0.05) differences occurred between rotation crops only at Warren when continuous cotton K concentrations were lower than those in cotton sown after rotation crops by an average value of 0.35% in 1997 and 0.25% in 1999. Tissue analyses at the dryland sites were not conducted by this project, but by other researchers from CSIRO and DPI, Qld.

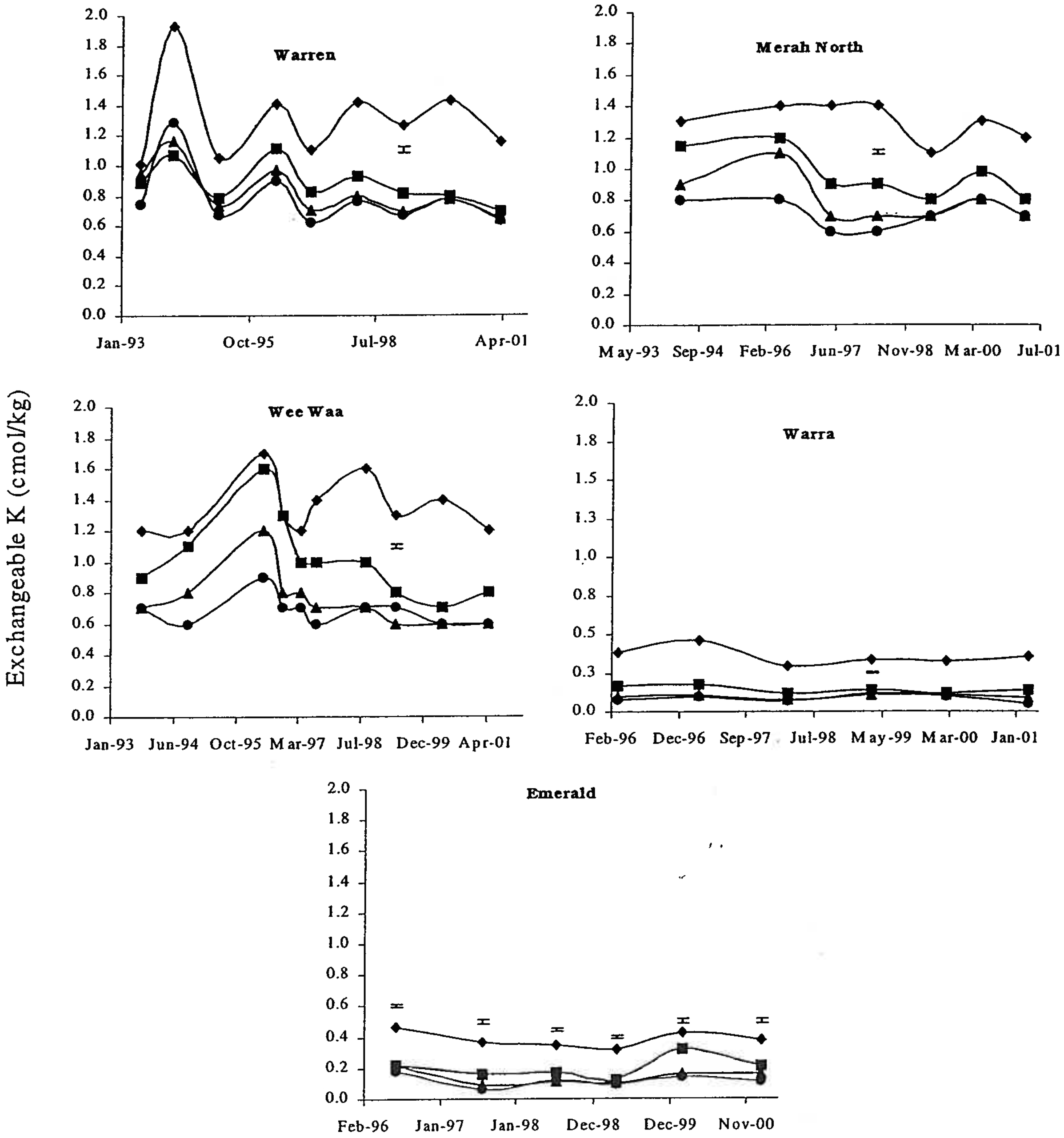

**Figure 10**. Variation of exchangeable K with time at the experimental sites. ◆ - 0-15 cm; ■ - 15-30 cm; ▲ - 30-45 cm; ● - 45-60 cm. Vertical bars in all locations except for Emerald are standard errors of the means (time x depth); Vertical bars in Emerald are standard errors of the means for depths at each time of measurement.

### *5.1.5 Deep drainage, and nutrient and salt leaching during 2000-01 cotton season*

Pre-season soil profile analyses at the three sites where drainage and nutrient leaching were evaluated indicated that salt (chloride) and sodicity levels were high at Merah North, but were low at Wee Waa and Field C1 at ACRI (Table 6).

Table 6. Pre-season soil properties in the 0-120 cm depth at ACRI, Wee Waa and Merah North

| Site | Depth (cm) | pH | EC (dS/m) | Chloride (mg/kg) | Nitrate (mg/kg) | Org. C (%) | Exch.Ca | Exch.Mg | Exch.Na | Exch.K | ESP (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | (cmol/kg) | | | | |
| ACRI | 0-30 | 7.4 | 0.24 | 149.3 | 43.5 | 0.71 | 20.6 | 9.5 | 0.6 | 1.2 | 2.3 |
| | 30-60 | 7.5 | 0.21 | 225.2 | 18.4 | 0.54 | 19.4 | 11.2 | 1.3 | 0.9 | 4.6 |
| | 60-90 | 7.6 | 0.24 | 276.8 | 32.4 | 0.48 | 18.1 | 12.9 | 1.9 | 1.0 | 6.6 |
| | 90-120 | 7.6 | 0.24 | 263.8 | 17.4 | 0.40 | 17.6 | 13.3 | 2.1 | 1.0 | 7.1 |
| Merah North/ Cont. Cotton | 0-30 | 7.2 | 0.34 | 174.4 | 39.5 | 0.68 | 22.3 | 14.7 | 2.5 | 1.1 | 6.6 |
| | 30-60 | 7.3 | 0.38 | 254.0 | 57.8 | 0.50 | 19.0 | 14.9 | 4.4 | 0.7 | 12.4 |
| | 60-90 | 7.4 | 0.41 | 344.8 | 32.2 | 0.42 | 18.7 | 15.2 | 6.1 | 0.7 | 16.3 |
| | 90-120 | 7.4 | 0.49 | 699.9 | 43.9 | 0.43 | 17.9 | 14.5 | 6.4 | 0.7 | 17.6 |
| Merah North /Dolichos | 0-30 | 7.3 | 0.26 | 244.1 | 57.1 | 0.56 | 19.9 | 15.1 | 4.4 | 0.8 | 12.1 |
| | 30-60 | 7.5 | 0.37 | 443.3 | 95.6 | 0.45 | 18.8 | 15.6 | 7.1 | 0.7 | 18.3 |
| | 60-90 | 7.5 | 0.54 | 1246.3 | 34.6 | 0.42 | 18.4 | 15.4 | 8.2 | 0.8 | 20.8 |
| | 90-120 | 7.4 | 0.78 | 3465.3 | 64.2 | 0.39 | 16.8 | 14.3 | 7.4 | 0.8 | 20.3 |
| Merah North /Wheat | 0-30 | 7.2 | 0.50 | 177.2 | 51.6 | 0.63 | 20.9 | 13.6 | 2.3 | 0.9 | 6.7 |
| | 30-60 | 7.4 | 0.38 | 301.1 | 116.8 | 0.50 | 19.1 | 15.4 | 4.6 | 0.6 | 12.9 |
| | 60-90 | 7.4 | 0.42 | 425.7 | 33.2 | 0.45 | 18.0 | 14.7 | 5.8 | 0.6 | 16.1 |
| | 90-120 | 7.4 | 0.44 | 1230.5 | 55.1 | 0.42 | 17.3 | 14.1 | 5.8 | 0.7 | 16.6 |
| Wee Waa | 0-30 | 7.2 | 0.26 | 221.8 | 13.3 | 0.72 | 19.1 | 10.7 | 0.9 | 0.8 | 3.2 |
| | 30-60 | 7.3 | 0.26 | 238.0 | 7.3 | 0.62 | 18.0 | 11.5 | 1.1 | 0.7 | 4.2 |
| | 60-90 | 7.4 | 0.30 | 205.2 | 6.5 | 0.51 | 16.8 | 12.4 | 1.5 | 0.8 | 5.7 |
| | 90-120 | 7.3 | 0.26 | 243.5 | 5.6 | 0.46 | 16.1 | 11.8 | 1.5 | 0.9 | 5.4 |

Chemical analyses of irrigation water at Merah North during also indicated that much of this salinity was due to the poor quality of the bore water used for irrigation. Quality of irrigation water was generally good at ACRI (river water) and Wee Waa (bore water). Nonetheless a flush of salts did occur in river water at ACRI in January 2001 (Table 7). It is also clear that there were significant amounts of nitrate-N in irrigation water at both Wee Waa and Merah North. Irrigation water is, therefore, a major source of N for the cotton crop (between 1-1.7 time as much as that added as fertiliser to soil).

Table 7. Quality of irrigation water at Merah North, ACRI and Wee Waa during 2000-01

| Date | Site | pH | Chloride (mg/l) | Nitrate-N (mg/l) | K (mg/l) | Ca (mg/l) | Mg (mg/l) | Na (mg/l) |
|---|---|---|---|---|---|---|---|---|
| 12-Oct-00 | ACRI | 8.7 | 32.0 | 29.2 | 5.3 | 20.4 | 22.3 | 41.9 |
| 5-Jan-01 | ACRI | 8.0 | 749.1 | 6.8 | NA | NA | NA | NA |
| 19-Jan-01 | ACRI | 7.6 | 308.9 | 2.8 | 3.7 | 21.9 | 18.6 | 34.9 |
| 19-Sep-00 | Merah North | 9.1 | 1785.7 | 6.0 | 2.1 | 14.1 | 13.6 | 54.4 |
| 6-Oct-00 | Merah North | 8.1 | 1625.9 | 43.9 | 1.6 | 14.5 | 8.8 | 36.6 |
| 13-Dec-00 | Merah North | 8.2 | 454.4 | 15.5 | 2.4 | 12.6 | 8.2 | 86.9 |
| 28-Dec-00 | Merah North | 8.1 | 319.5 | 57.2 | 2.3 | 15.1 | 11.4 | 59.5 |
| 9-Jan-01 | Merah North | 8.2 | 248.5 | 4.5 | 1.9 | 17.0 | 11.8 | 56.3 |
| 18-Jan-01 | Merah North | 8.2 | 237.9 | 2.6 | 2.0 | 13.8 | 12.0 | 68.5 |
| 29-Jan-01 | Merah North | 7.8 | 399.4 | 31.1 | 2.0 | 17.0 | 11.9 | 72.2 |
| 16-Feb-01 | Merah North | 8.2 | 35.5 | 37.6 | 2.4 | 13.1 | 9.0 | 41.2 |
| 21-Feb-01 | Merah North | 7.7 | 195.3 | 16.0 | 3.3 | 17.1 | 16.3 | 94.7 |
| 12-Oct-00 | Wee Waa | 7.9 | 351.5 | 3.0 | 4.2 | 20.9 | 20.1 | 39.9 |
| 16-Dec-00 | Wee Waa | 8.1 | 468.6 | 12.9 | 7.5 | 21.7 | 16.1 | 48.8 |
| 2-Jan-01 | Wee Waa | 8.2 | 387.0 | 5.3 | 6.2 | 21.5 | 13.3 | 33.3 |
| 15-Jan-01 | Wee Waa | 8.2 | 305.3 | 3.3 | 5.3 | 26.6 | 14.4 | 31.9 |
| 20-Feb-01 | Wee Waa | 8.2 | 44.4 | 95.4 | 4.7 | 23.7 | 13.7 | 26.5 |

A detailed report (38 pp) of deep drainage, nutrient and salt leaching during the cotton season of 2000-01 was prepared by Mr. Tim Weaver for Griffith University as part of the annual assessment for his PhD candidature. A copy is available on request. The key points which were highlighted the report are as follows:

- Deep drainage and nutrient leaching were both spatially and temporally highly variable.
- Excessive irrigation either early (pre-December) or late (post mid-March) resulted in deep drainage, whereas irrigation alone in mid-season did not cause deep drainage. The combination of irrigation followed by heavy rainfall, however, resulted in deep drainage during mid-season. Another cause of deep drainage was heavy and/or frequent early or late season rainfall. For example due to the absence of early season rainfall in 2001-02, there was negligible deep drainage whereas during 2000-01 the reverse was observed. Deep soil cracking, similar to that which occurred at ACRI during winter 2001, also results in excessive deep drainage due to by-pass (preferential) flow through soil cracks during irrigation events (Table 8).
- Cropping systems which resulted in better subsoil structure, lower sodicity or retained water in-field such as sowing cotton into standing wheat stubble resulted in higher deep drainage. This is a distinct advantage in saline soils, as any salts which have accumulated in the soil profile (eg. Merah North) can be leached out. At the same time nutrients such as nitrates can be leached out as a consequence of deep drainage. A summary of deep drainage measured during the 2000-01 cotton season and the 2001 winter rotation season are given in Table 8 and the nutrient and salts leached out of the cotton root zone during the 2000-01 cotton season are given in Table 9.

Table 8. Deep drainage (in mm) determined with the chloride mass balance method and seasonal water inputs (rainfall and irrigation, in mm) during the 2000-01 cotton season and the 2001 winter rotation season. Wheat was sown in all sites as the rotation crop.

| | 2000-01 cotton season | | | 2001 winter rotation season | | |
|---|---|---|---|---|---|---|
| Site and cropping system | Deep drainage * | Rainfall | Irrigation | Deep drainage* | Rainfall | Irrigation |
| ACRI (Cotton sown into standing wheat stubble) | 151 (21) | 517 | 200 | 106 (34) | 212 | 100 |
| Wee Waa (Cotton-wheat, stubble incorporated) | 118 (12) | 579 | 400 | 46 (9) | 341 | 200 |
| Merah North (Cont. cotton, stubble incorporated) | 98 (10) | 300 | 700 | 52 (8) | 330 | 300 |
| Merah North (Cotton-wheat, stubble incorporated) | 76 (8) | 300 | 700 | 44 (7) | 330 | 300 |
| Merah North (Cotton-dolichos, stubble incorporated) | 19 (2) | 300 | 700 | 13 (2) | 330 | 300 |

*. Value in parentheses is deep drainage expressed as % of total seasonal water inputs (rainfall + irrigation)

Table 9. Nutrients and salts leached out of cotton root zone (kg/ha) during 2000-01 cotton season.

| Site and cropping system | Cl | $NO_3$-N | K | Ca | Mg | Na |
|---|---|---|---|---|---|---|
| ACRI (Cotton sown into standing wheat stubble) | 2491 | 200 | 8 | 27 | 79 | 417 |
| Wee Waa (Cotton-wheat, stubble incorporated) | 1146 | 130 | 5 | 22 | 64 | 286 |
| Merah North (Cont. cotton, stubble incorporated) | 10,457 | 174 | 5 | 70 | 77 | 1102 |
| Merah North (Cotton-wheat, stubble incorporated) | 3529 | 129 | 3 | 19 | 71 | 599 |
| Merah North (Cotton-dolichos, stubble incorporated) | 3561 | 23 | 1 | 32 | 30 | 264 |

- The costs and benefits of nutrients and salts leached out of the cotton root zone were quantified by equating them to the value of a specific fertiliser or soil amendment. For example, the amount of nitrate-N leached was calculated in terms of its equivalent amount in anhydrous ammonia applied. The net differences between the costs (nutrients lost, Table 10) and benefits (salts leached, Table 11) were the estimated value of nutrients and salts leached through in deep drainage. As K was equated to two sources of fertiliser, KCl and $KNO_3$, two benefit-cost values were derived (Table 12). The fertilisers and soil amendments used in the calculations are as follows:

* Nitrate-N was equated to anhydrous ammonia
* Potassium was equated to either KCl or $KNO_3$.
* Calcium, magnesium and sodium were equated to gypsum
* Cl was equated to the amount of yield increase which could be expected to occur due to the observed amount of Cl being leached out of the soil profile. This was done by deriving a soil Cl-cotton yield response curve.

Table 12. Estimated net value of nutrients and salts leached out of 120 cm depth. Benefits-costs (1) is when potassium loss has been equated to $KNO_3$, and Benefits-costs (2) is when it was equated to KCl.

| Site and cropping system | Benefits-Costs (1) ($/ha) | Benefits-Costs (2) ($/ha) |
|---|---|---|
| ACRI (Cotton sown into standing wheat stubble) | -6.64 | 9.34 |
| Wee Waa (Cotton-wheat, stubble incorporated) | -66.94 | -57.16 |
| Merah North (Cont. cotton, stubble incorporated) | 1063.17 | 1073.83 |
| Merah North (Cotton-wheat, stubble incorporated) | 937.77 | 943.61 |
| Merah North (Cotton-dolichos, stubble incorporated) | 18.23 | 20.82 |

Table 10. Estimated values of nutrients leached out of 120 cm depth (costs)

| Site and cropping system | Costs | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | N value* | | K1 value[#] | | K2 value[+] | | Ca value** | |
| | Equiv. in anhydrous, kg/ha | \$/ha | Equiv. in $KNO_3$, kg/ha | \$/ha | Equiv. in KCl, kg/ha | \$/ha | Equiv. in gypsum, kg/ha | \$/ha |
| ACRI (Cotton sown into standing wheat stubble) | 243.58 | 170.51 | 20.32 | 23.97 | 14.99 | 7.94 | 115.18 | 8.51 |
| Wee Waa (Cotton-wheat, stubble incorporated) | 158.97 | 111.28 | 12.46 | 14.66 | 9.19 | 4.87 | 93.30 | 6.90 |
| Merah North (Cont. cotton, stubble incorporated) | 211.84 | 148.29 | 12.81 | 15.67 | 9.45 | 5.01 | 302.17 | 22.36 |
| Merah North (Cotton-wheat, stubble incorporated) | 156.76 | 109.73 | 7.77 | 8.88 | 5.73 | 3.04 | 82.39 | 6.10 |
| Merah North (Cotton-dolichos, stubble incorporated) | 27.87 | 19.51 | 3.01 | 3.76 | 2.22 | 1.17 | 137.02 | 10.14 |

*. assuming 1 t anhydrous ammonia =\$700
#. assuming 1kg potassium nitrate = \$1.18
+. assuming 1kg potassium chloride (muriate of potash) = \$0.53
**. assuming gypsum = \$70/t + spreading =\$10/ha at a rate of 2.5 t/ha

Table 11. Estimated values of salts leached out of 120 cm depth (benefits)

| Site and cropping system | Benefits | | | | | |
|---|---|---|---|---|---|---|
| | Mg value[ϕ] | | Na value*** | | Cl value^ | |
| | Equiv. in gypsum, kg/ha | \$/ha | Equiv. in gypsum, kg/ha | \$/ha | Est. increase in future lint yield, ba/ha | \$/ha |
| ACRI (Cotton sown into standing wheat stubble) | 340.29 | 25.18 | 894.16 | 66.17 | 0.30 | 105.00 |
| Wee Waa (Cotton-wheat, stubble incorporated) | 276.35 | 20.45 | 614.18 | 45.45 | 0.00 | 0.00 |
| Merah North (Cont. cotton, stubble incorporated) | 330.83 | 24.48 | 2,364.93 | 175.00 | 3.00 | 1,050.00 |
| Merah North (Cotton-wheat, stubble incorporated) | 302.77 | 22.41 | 1284.78 | 95.07 | 2.70 | 945.00 |
| Merah North (Cotton-dolichos, stubble incorporated) | 130.47 | 9.65 | 567.42 | 41.99 | 0.00 | 0.00 |

**. assuming gypsum = \$70/t + spreading =\$10/ha at a rate of 2.5 t/ha
ϕ. assuming 1 Ca = 1 Mg; this underestimates the benefit of gypsum re. ionic strength increase; other costs as before
***. assuming 1 Ca = 2 Na; this underestimates the benefit of gypsum re. ionic strength increase; other costs as before
^. Value of a bale of cotton lint = \$350

- Salt and nutrient movement in surface runoff and in deep drainage out of the root zone was also reflected in the EM-38 measurements made during 2000-01. The EM38 surveys conducted at the ACRI site in February and September 2000, and in May 2001 (Fig. 11) show that $EC_a$ values were higher at the tail-drain end of the field. This may be due to the higher clay content resulting in impeded drainage and wetter soil. The $EC_a$ results obtained in February 2000 were almost half those measured in September 2000 and May 2001. Better water infiltration due to the standing wheat stubble in the furrows and mineralisation of the wheat stubble may have caused these differences between times of measurement. The $EC_a$ profiles in May 2001 were very similar to the readings in September 2000 although there was an increase in the area of higher values at the tail-drain end of the field. Nutrients from fertiliser and mineralised wheat stubble may have been deposited at the tail-drain end of the experiment causing the higher $EC_a$. Where standing stubble is absent (i.e. incorporated) most of these nutrients are transported with runoff water into water storages, and presumably re-enter the fields in re-cycled irrigation water (see Table 7).

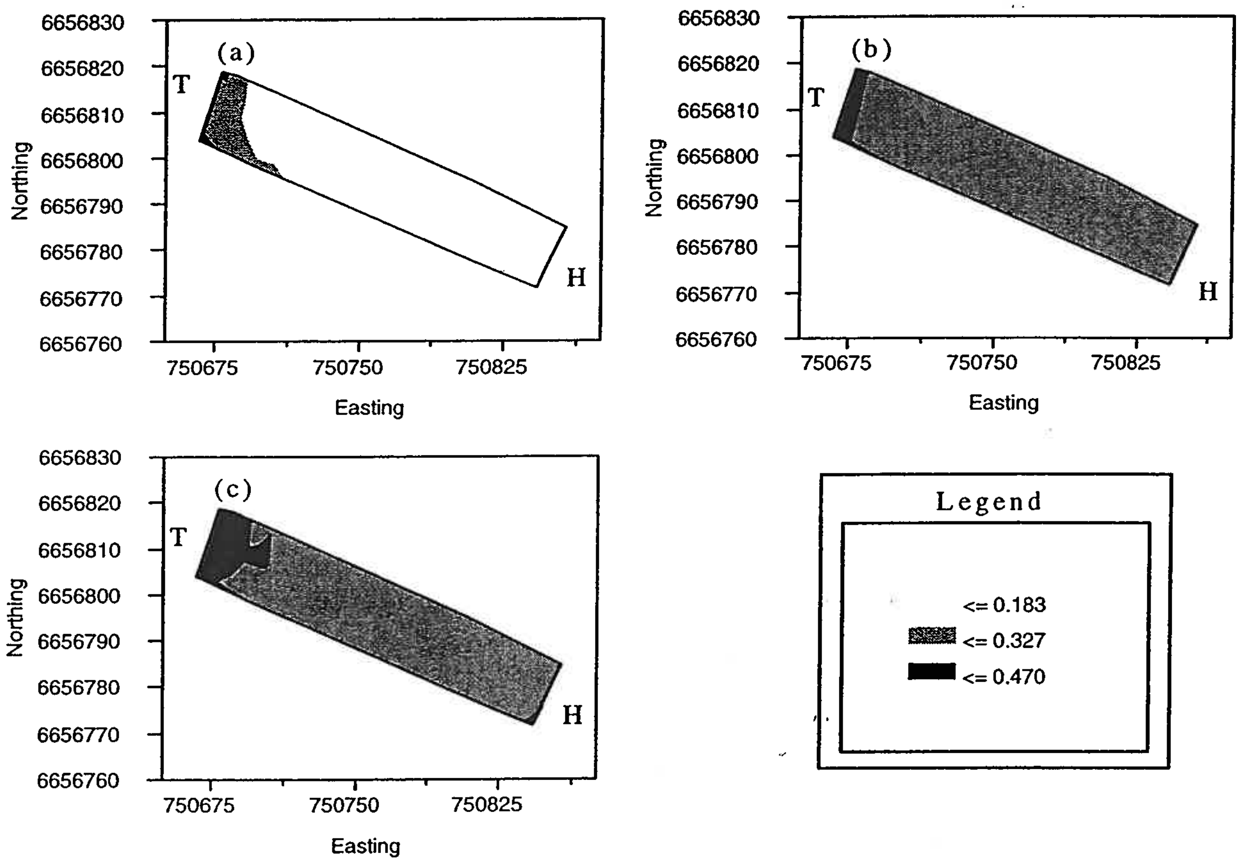

**Figure 11.** $EC_a$ (dS/m) contour maps for the site at the ACRI, a cotton-wheat rotation with cotton sown into standing wheat stubble in a "minimum tillage system": Feb. 2000 (a), Sept. 2000 (b) and May 2001 (c). (T = Tail-drain, H= Head-ditch).

EM38 results for Wee Waa (Fig. 12) and Merah North (Fig. 13) are given in $EM_H$ values (soil conductance), as $E_a$-$EM_H$ calibration curves were unsatisfactory. The contour plots for Wee Waa is similar to that of ACRI (Fig. 11). The tail drain and head ditch were higher than the centre of the field. These areas of the field have lower drainage and water ponds at these areas.

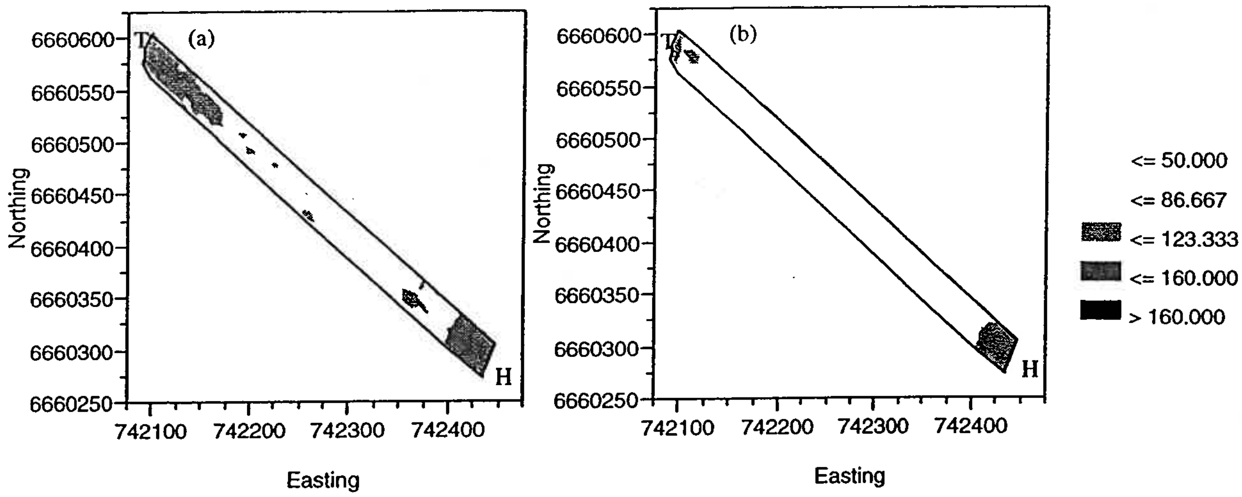

**Figure 12.** $EM_H$ (mS/m) contour maps for 'Glenarvon' near Wee Waa in a cotton-wheat rotation with stubble incorporation: Oct. 2000 (a) and May 2001 (b). (T = Tail-drain, H= Head-ditch).

The contour plots for Merah North (Fig. 13) changed between September 2000 and May 2001. They indicate a decrease in soil conductance for continuous cotton and cotton-wheat, presumably due to leaching of salts out of the root zone in deep drainage. In the continuous cotton treatment a ridge of high readings was also observed in both surveys taken. This indicates an area of higher clay content in that treatment. The cotton-dolichos rotation, however, did not change greatly between 2000 and 2001, and suggests that drainage was low and leaching of salts and cations negligible during the 2000-01 season. This may be due to the poorer subsoil structure (Fig. 1) and higher sodicity (Table 6) of the dolichos-cotton rotation.

- The difference in $EM_H$ between times of measurement ($\Delta EM_H$, ms/m) was related to the deep drainage (D, mm) estimated with the chloride mass balance method thus:

  $D = 138.76 - 126.46 \times \Delta EM_H$, $S_b = 21.46$, n=29 , $R^2 = 0.56^{***}$ ($S_b$ = standard error of the slope)

  This provides an easy and rapid method whereby deep drainage can be estimated in the field using only EM38 measurements. However, the precision of the estimates can be improved by including variables such as clay content and sodicity (i.e. ESP). Stepwise multiple regression analysis indicated that variation in drainage during the 2000-01 cotton season was explained by a combination of $\Delta EM_H$ and clay content as follows (best-fit equations):

  $D = 136.93 + (610.90 \times \Delta EM_H) - (10.95 \times \text{Clay content} \times \Delta EM_H)$
  s.e.e = 37.59, $R^2 = 0.62^{***}$ (s.e.e = standard error of the estimate)

  or a combination of $\Delta EM_H$, clay content and exchangeable sodium percentage (ESP, %) thus:

  $D = 135.45 + (456.90 \times \Delta EM_H) - (7.29 \times \text{Clay content} \times \Delta EM_H) - (6.47 \times \text{ESP} \times \Delta EM_H)$
  s.e.e = 37.05, $R^2 = 0.64^{**}$ (s.e.e = standard error of the estimate)

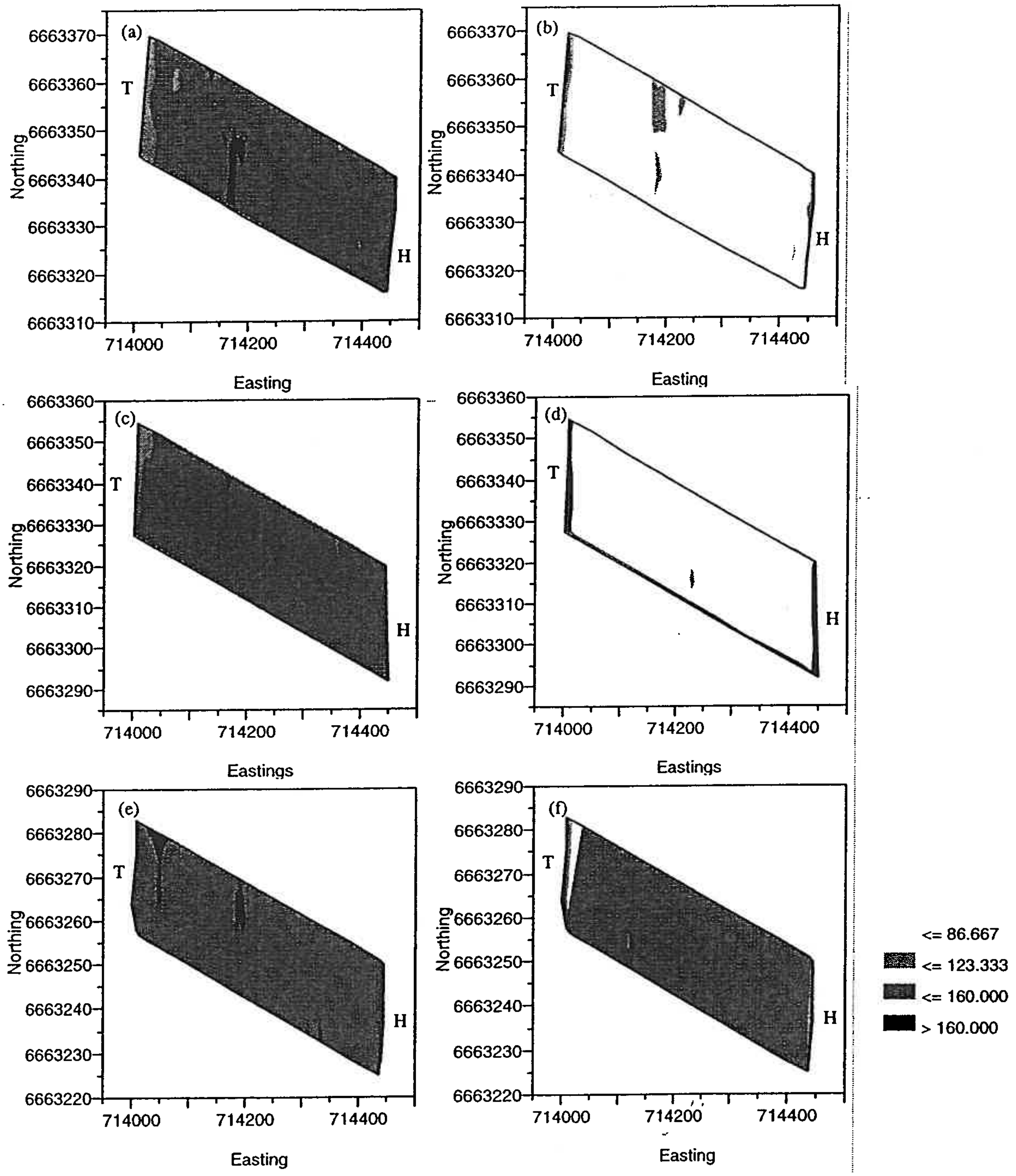

**Figure 13.** $EM_H$ (mS/m) contour maps for 'Beechworth', Merah North: Nov. 2000 (a) Continuous Cotton with stubble incorporation, (c) Cotton-Wheat rotation with stubble incorporation and (e) Cotton-Dolichos with stubble incorporation, and May 2001 (b) Cont. Cotton with stubble incorporation, (d) Cotton-Wheat rotation with stubble incorporation and (f) Cotton-Dolichos with stubble incorporation. (T = Tail-drain, H= Head-ditch).

- Drainage (and the entire water balance) was modelled with WaterMod 2.1, an interactive computer model. The required inputs for the model are soil water retention characteristics, saturated hydraulic conductivity characteristics, date of sowing, maximum dry matter production and theoretical water use efficiency, surface mulch, rainfall, irrigation, potential evaporation and soil depth. The outputs are crop growth pattern, transpiration, soil evaporation, profile water content, runoff, hydraulic conductivity and drainage out of the specified soil depth. All outputs are provided as change in depth and time during the growing season. The model, although overestimating early season drainage and underestimating mid- and late season drainage, confirmed our field observations that the major contributory factors to deep drainage was frequent and heavy early season rainfall or irrigation which was followed soon after by heavy rainfall. Irrigation alone did not result in mid-season (January-February) drainage but could cause early season drainage when cotton water use was low. A similar, although somewhat muted, pattern also occurred late in the cotton season (March). These predictions were supported during the 20001-02 season, when early season rainfall was negligible and early season drainage was also found to be very low. Measurements in 2001-02 were made in a field adjacent to the long-term experiment at Merah North where drainage was measured in 2000-01.

- The nitrate-N lost in deep drainage can be recovered by sowing a cereal crop such as wheat after cotton. An example is shown below using the data from Wee Waa. Wheat has a denser root system in the subsoil than do tap-rooted crops such as chickpea or faba bean (Fig. 14, Table 12). The addition of fertiliser to the wheat crop improved N recovery by increasing subsoil root growth. The amount of N recovered by the wheat crop was also positively correlated to the amount of rainfall received early in the cotton season (i.e. October and November) (Fig. 15). In other words, high early season rainfall results in high amounts of N being leached out of the cotton root zone, and consequently the wheat rotation crop recovers high amounts of N. The reverse occurs when there is low early season rainfall. The N taken up by the wheat crop is released on decomposition of the wheat stubble, and is subsequently taken up by the following cotton crop (see Final Reports for CRDC Projects DAN 83C and 108C). The best fit equations for the curve shown in Figure 15 were:

+N wheat: N uptake (kg/ha) = $-478.41 + 126.84 \ln R$, $s_b = 22.96$, $n = 12$, $r = 0.87^{***}$;
-N wheat: N uptake (kg/ha) = $-146.43 + 46.61 \ln R$, $s_b = 21.03$, $n = 12$, $r = 0.59^{*}$;

where R is cumulative early cotton season (October and November) rainfall (mm), $s_b$ is standard error of the slope and r is correlation coefficient. Comparison of the curves with analysis of variance indicated that total regression ($P = 0.001$), slopes ($P = 0.05$) and intercepts ($P = 0.05$) differed significantly.

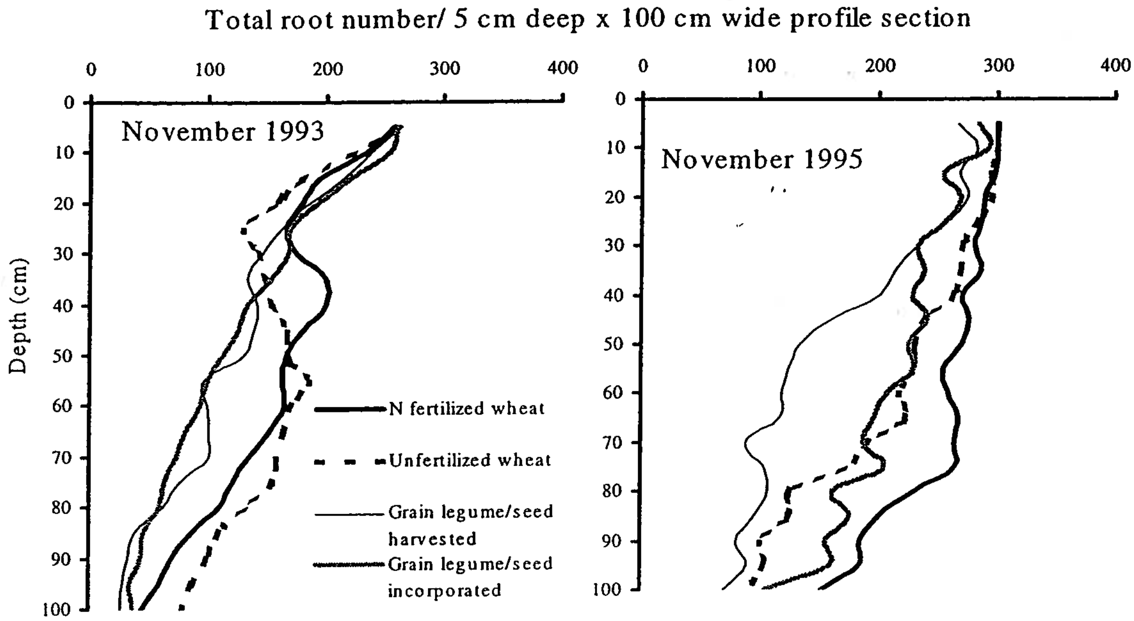

**Figure 14**. Root densities in a 100 x 100 cm profile face under wheat and grain legume crops, November 1993 and 1995. Chickpea was the legume sown in 1993 and faba bean was the legume in 1995

Table 13. Comparison of fitted model ($y = ae^{-bx}$) to root growth of rotation crops in 1993 and 1995 (y is root number in a 5 cm deep x 100 cm wide section, x is depth, a is the intercept, b is the slope, r is the correlation co-efficient, and se(b) is the standard error of the slope)

| Year | Rotation crop | a | b | se(b) | r |
|---|---|---|---|---|---|
| 1993 | N fertilised wheat | 5.68 | -0.0141 | 0.0011 | -0.86*** |
| | Unfertilised wheat | 5.40 | -0.0083 | 0.0015 | -0.58*** |
| | Seed harvested grain legume | 5.79 | -0.0236 | 0.0018 | -0.87*** |
| | Seed incorporated grain legume | 5.80 | -0.0253 | 0.0029 | -0.75*** |
| 1995 | N fertilised wheat | 5.82 | -0.0056 | 0.0006 | -0.77*** |
| | Unfertilised wheat | 6.00 | -0.0136 | 0.0013 | -0.82*** |
| | Seed harvested grain legume | 5.87 | -0.0193 | 0.0027 | -0.69*** |
| | Seed incorporated grain legume | 5.78 | -0.0092 | 0.0016 | -0.60*** |

| *Analysis of variance:* | Total regression | Intercepts | Slopes |
|---|---|---|---|
| Between rotation crops for 1993 | *** | *** | *** |
| Between rotation crops for 1995 | *** | *** | *** |
| Between 1993 and 1995 for N fertilised wheat | *** | *** | *** |
| Between 1993 and 1995 for unfertilised wheat | *** | *** | ** |
| Between 1993 and 1995 for seed harvested legume | ** | ** | ns |
| Between 1993 and 1995 for seed incorporated legume | *** | *** | *** |

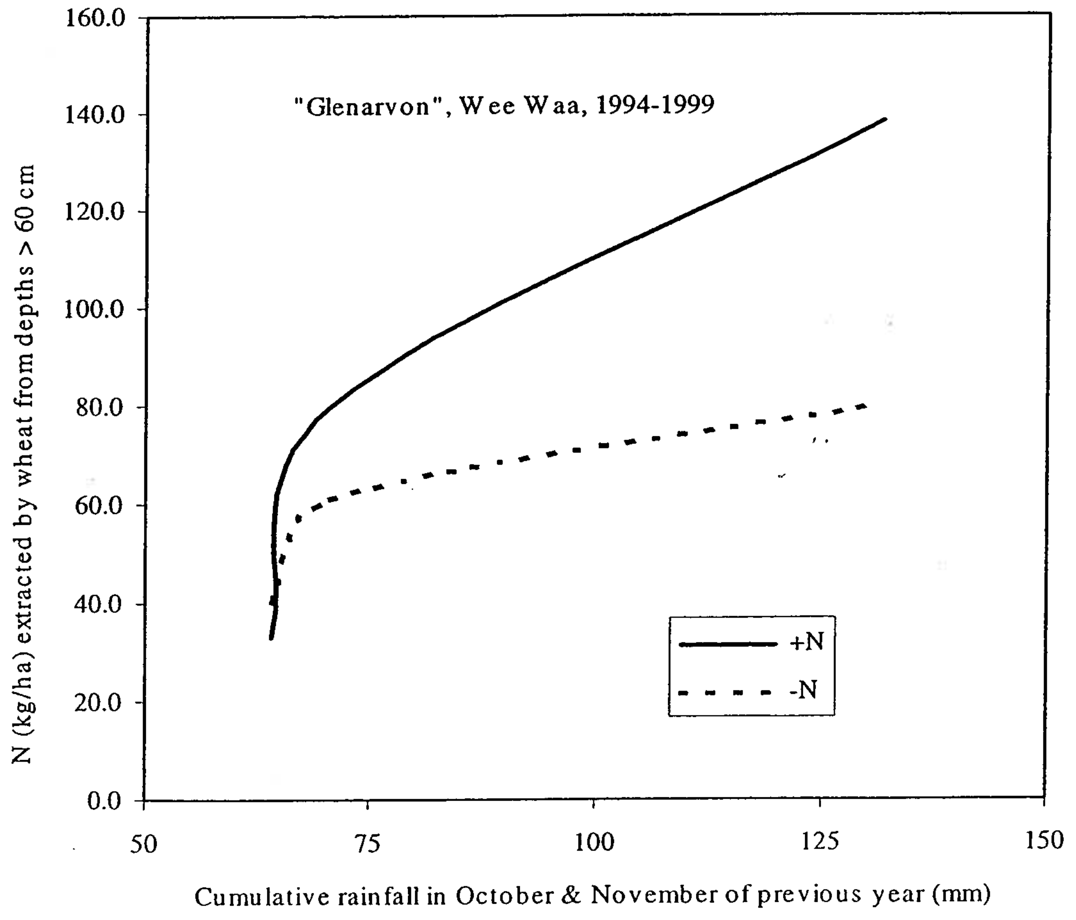

Fig. 15. N recovered by N fertilised (+N) and unfertilised (-N) wheat crops sown after cotton at "Glenarvon", Wee Waa

### *4.1.6. Soil chemical changes during decomposition of rotation crop stubble (laboratory and field experiments)*

Soil chemical changes during stubble decomposition in the alkaline Vertosols are characterised by:

(1) Decrease in soil pH (due to carbonic acid formed by dissolution of carbon dioxide in water; the latter is formed during microbial decomposition of stubble);
(2) Decrease (i.e. solubilization) of native carbonates, primarily calcium carbonate in Vertosols;
(3) Increase in organic C, $EC_{1:5}$, $EC_{1:5}$/exchangeable Na ratio and exchangeable K, and a decrease in exchangeable Ca.
(4) Decrease in exchangeable Na with wheat and to a lesser extent cotton in the highly sodic soil from Merah North, but not with high legume stubble. The absence of any change by addition of high N residues to the sodic Merah North soil is surprising, but is confirmed by the higher sodicity after a legume (dolichos) rotation (Table 6). The causes for these differences between rotation crop stubble in the Merah North soil is unknown and requires further evaluation and analysis. In the non-sodic soils from ACRI and Wee Waa, however, differences occurred only between cotton and all other rotation crop stubble.

The abovementioned chemical changes (1, 2 and 3) in the non-sodic soils appear to be modified by amount and quality (N, S, P, other nutrients, lignin, C:N ratio etc.) of the stubble. For example, pH with cotton stubble does not change whereas with faba stubble it decreases. This is because the low N content of the cotton stubble ensures that decomposition occurs very slowly, and consequently pH does not change.

In summary, the soil chemical changes occurring concurrently with stubble decomposition observed in both laboratory and field experiments raise many questions, and cannot be explained entirely on presently available knowledge. Further detailed review, evaluation and analysis of the data, and possibly further laboratory and field experimentation may be required to provide an explanation for these results.

### *4.2. Cotton Lint Yield and Profitability in Irrigated Sites*

Replacement of the different rotations with cotton-wheat sequences in 1999 at Warren and Wee Waa did not result in any differences in cotton lint yields. At the same time, residual effects of the rotations imposed from 1993 to 1999 were not evident in either of these sites. Mean lint yield in 2000-01 was 7.5 ba/ha (average gross margin at $495/bale for 2000-01 was $2,125/ha) at Wee Waa and 8.0 ba/ha at Warren. Boll production was, however, affected by past rotation history at Warren (Fig. 16), although this did not translate into yield. This may be due to a high degree of boll drop prior to maturity. Comparison of the curves with regression analysis indicated that the lowest rate of boll production occurred with continuous cotton ($P = 0.05$). This difference could not be ascribed to either a soil physical or chemical cause, nor to differences in black root rot infestation, which was similar in all plots by 2001 (D. Nehl, pers. comm.). We suggest that other unknown soil biological factors may have caused these differences.

Unlike in the other sites, cotton lint yield and profitability have declined at Merah North (Fig. 17). The lint yields differed between rotations with lowest and highest yields occurring in continuous cotton and cotton-wheat rotation plots, respectively (Table 13). Mean lint yield during 2000-01 was 4.3 ba/ha and the mean gross margin was $175/ha. The gross margin rankings for 2000-01 were cotton-wheat, cotton-sorghum (previously cotton-faba bean), cotton-dolichos, continuous cotton, cotton-dolichos plus phosphorus and potassium fertiliser and long-fallow cotton. The negative gross margins in the last two rotations were due to application of 7.5 t/ha of gypsum in 2000. Excluding the two treatments that had 7.5 t/ha of gypsum added in 2000, the average gross margin/ha at Merah North was $341/ha (using a cotton lint price of $495/bale). The soil, water and tissue analyses conducted over the years suggest that the yield decline may be due to the combined effects of high sodicity, increasing salinity of irrigation water and subsequent chloride accumulation in soil, and decreasing potassium uptake. It is interesting to note that although soil Cl levels were high, its concentration in cotton tissues were lower than in non-salinised sites. This suggests that cotton was able to exclude Cl, but at a cost in terms of plant growth. The reduction in cotton growth also suggests the mechanism of chloride exclusion may require substantial amounts of energy.

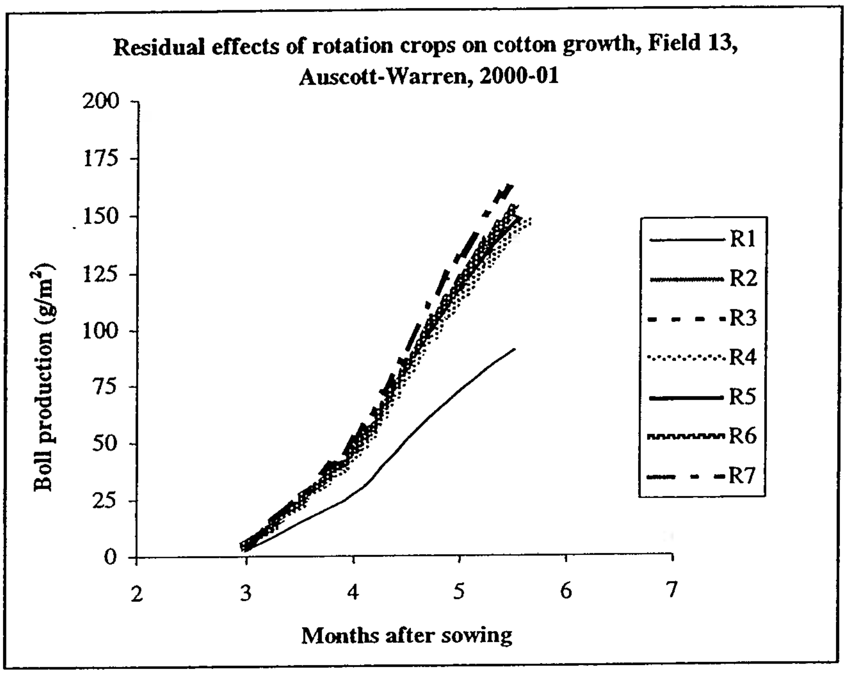

**Figure 16.** Effect of rotation crop on boll production by cotton; R1- continuous cotton; R2- long fallow cotton; R3- Cotton-field pea; R4- Cotton-low input wheat; R5- Cotton-high input wheat; R6 - Cotton-wheat- dolichos fb. Cont. cotton; R7 - Cotton-wheat-dolichos fb. Cotton-faba

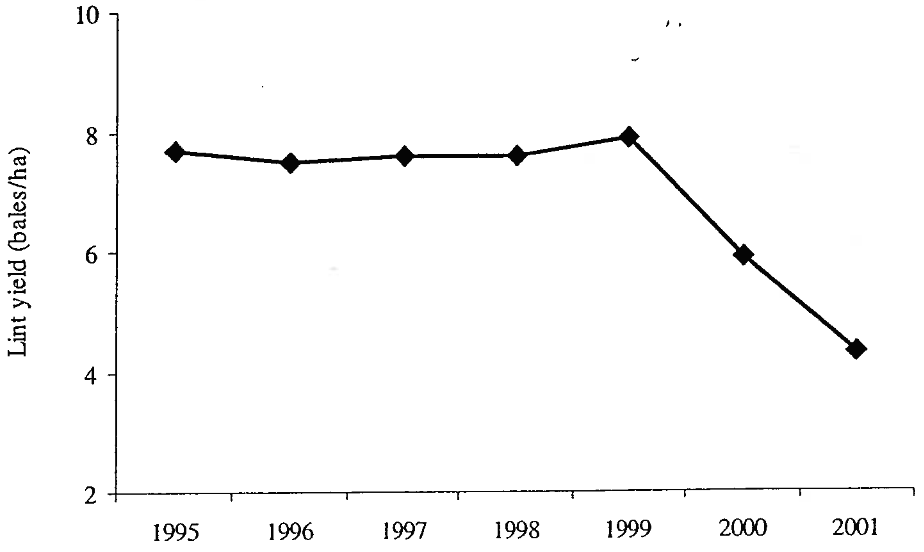

**Figure 17.** Change in average cotton lint yield at Merah North, 1995-2001

Table 13. Gross margins for Merah North site, 2000-01 season

| Rotation | Cont. cotton | Cotton-faba | Long fallow cotton | Cotton-wheat | Cotton-dolichos | Cotton-dolichos /P+K fert. | Refugia |
|---|---|---|---|---|---|---|---|
| Crop | cotton | cotton | cotton | cotton | cotton | cotton | Pigeon peas 5% |
| Lint (bales/ha)* | 3.94 | 4.43 | 4.05 | 4.59 | 4.12 | 4.57 | |
| Seed (t/ha) | 1.46 | 1.64 | 1.50 | 1.70 | 1.53 | 1.69 | |
| Income ($/ha) | 2,060 | 2,319 | 2,116 | 2,398 | 2,156 | 2,393 | - |
| Variable Costs ($/ha) | 1,928 | 1,916 | 2,429 | 1,887 | 1,856 | 2,398 | 261 |
| Gross Margin/ha ($) | 132 | 403 | (313) | 511 | 300 | (5) | (261) |
| Gross Margin/ML irrigation water ($) | 17 | 52 | (40) | 66 | 39 | (1) | na |

*Yield details provided by Mr. G. Roberts

### *4.2.1 Financial Analysis*

Cumulative gross margins and total gross margins compared to variable costs indicate which rotations have performed the best financially over the trial period. Gross margins were calculated using the input operations and yield results for each system. The commodity and individual input prices used were the same for each season (e.g. $495/tonne for cotton lint). This was to prevent fluctuations in commodity prices and input prices concealing rotation effects on the gross margins.

The time period under consideration at Merah North and Wee Waa was from the 1993-94 summer (cotton) season to the 2000-01 summer (cotton) season. At Merah North the experiment was terminated in 2001 with wheat grown during winter 2001 and sorghum during summer 2001-02 in all plots. Individual treatment yields were not recorded for 2001 and 2001-02 and so are not included in the gross margin analysis. At Wee Waa individual rotation treatments were discontinued from 1999 onwards, and all plots were sown with a cotton- N fertilised wheatnrotation.

Table 14: Cumulative results for Merah North 1993-94 to 2000-01

| Treatment | Cont. cotton | Cotton-faba | Long fallow cotton | Cotton-wheat | Cotton-dolichos | Cotton-dolichos /P+K fert. |
|---|---|---|---|---|---|---|
| Number of cotton crops | 8 | 5 | 4 | 4 | 4 | 4 |
| Cumulative lint yield (bales/ha) | 47.5 | 28.8 | 27.5 | 27.6 | 26.8 | 28.1 |
| Average lint yield per crop (bales/ha) | 5.9 | 5.8 | 6.9 | 6.9 | 6.7 | 7.0 |
| Cumulative cotton seed yield (t/ha) | 16.7 | 17.9 | 9.8 | 9.8 | 9.6 | 10.0 |
| Average cotton seed yield per crop (t/ha) | 2.1 | 3.6 | 2.5 | 2.5 | 2.4 | 2.5 |
| Cumulative grain yield (t/ha) | | - | - | 5.8 | - | - |
| Cumulative Costs | 15,729 | 11,298 | 9,627 | 9,603 | 9,522 | 10,497 |
| **Cumulative gross margin ($/ha)** | **10,676** | **5,216** | **5,317** | **6,379** | **5,334** | **4,840** |
| Cumulative irrigation water use (ML/ha) | 50.2 | 35.0 | 25.5 | 29.0 | 28.7 | 28.7 |
| **Average gross margins/ML** | **214** | **150** | **209** | **221** | **187** | **170** |

At Merah North, continuous cotton had the most cotton crops of all the systems which was a direct influence on total gross margin/ha over the span of the trial. The gross margin rankings for 1993-2001 were continuous cotton, cotton-wheat, cotton-dolichos, long-fallow cotton, cotton-faba bean and cotton-dolichos plus phosphorus and potassium fertiliser. When compared on a variable cost basis (Figure 18), continuous cotton has also been the most expensive to grow. If using variable costs/ha as a proxy for risk, continuous cotton could to be said to be the more risky option and more vulnerable to vagaries of price, climate variability and crop disease.

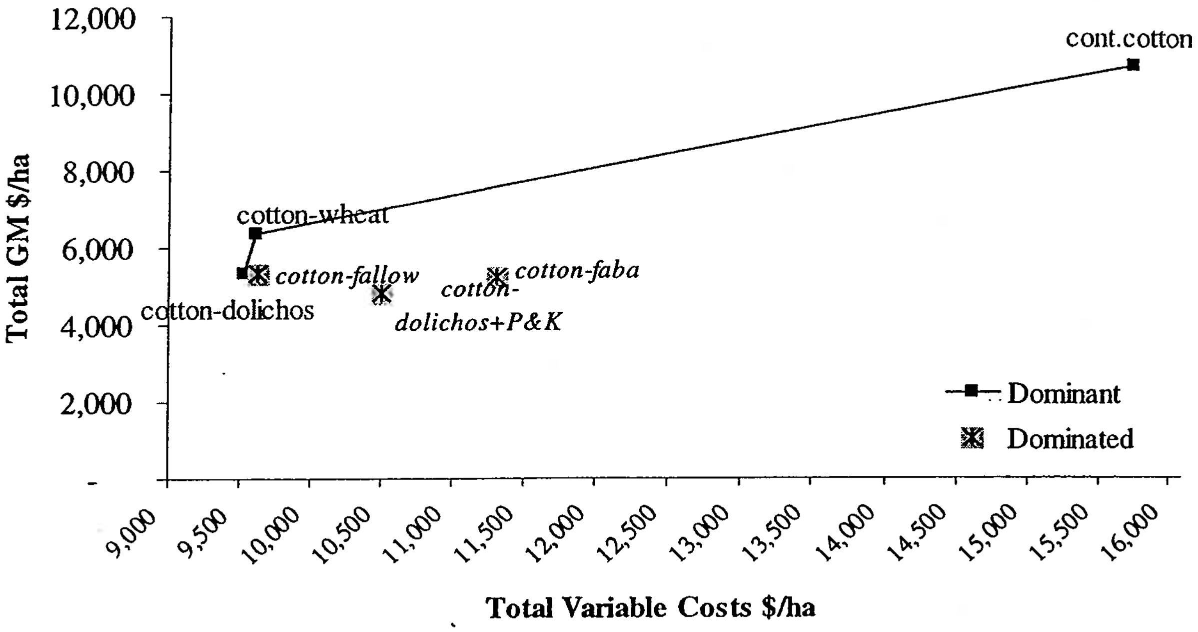

**Figure 18.** Cumulative variable cost/gross margin comparison for at Merah North

Sensitivity testing using $400 and $600 per bale of cotton lint was undertaken. Using a cotton price of $400 bale reduced the gross margins but did not change their rankings (Table 15). Using a cotton price of $600 per bale altered the rankings a little with the rankings being continuous cotton, cotton-wheat, cotton-faba bean, cotton-dolichos, long-fallow cotton and cotton-dolichos plus phosphorus and potassium fertiliser.

Table 15. Sensitivity testing for the rotations at Merah North

| Rotation | Cotton price ( $/bale) | Cont. cotton | Cotton-faba | Long fallow cotton | Cotton-wheat | Cotton-dolichos | Cotton-dolichos /P+K fert |
|---|---|---|---|---|---|---|---|
| Cumulative gross margin ($/ha) | 495 | 10,676 | 5,216 | 5,317 | 6,379 | 5,334 | 4,840 |
| **Rank** | | 1 | 5 | 4 | 2 | 3 | 6 |
| Cumulative gross margin ($/ha) | 400 | 6,085 | 2,506 | 2,720 | 3,750 | 2,755 | 2,176 |
| **Rank** | | 1 | 5 | 4 | 2 | 3 | 6 |
| Cumulative gross margin ($/ha) | 600 | 15,747 | 8,210 | 8,185 | 9,282 | 8,186 | 7,785 |
| **Rank** | | 1 | 3 | 5 | 2 | 4 | 6 |

At Wee Waa, the gross margin rankings for 1993-2001 were cotton-fertilised wheat cotton-unfertilised wheat, cotton-legume (seed harvested) and cotton-legume (seed incorporated) (Table 16).

Table 16: Cumulative results for Wee Waa from 1993-94 to 2000-01

| Rotation | Cotton-N fertilised wheat | Cotton-unfertilised wheat | Cotton-legume (seed harvested) | Cotton-legume (seed incorporated) |
|---|---|---|---|---|
| Cumulative lint yield (bales/ha) | 31.9 | 31.9 | 30.7 | 31.1 |
| Average annual lint yield | 8.0 | 8.0 | 7.7 | 7.8 |
| Cumulative cotton seed yield (t/ha) | 11.1 | 11.1 | 11.0 | 10.8 |
| Average cotton seed yield | 2.8 | 2.8 | 2.8 | 2.7 |
| Cumulative grain yield (t/ha) | 18.70 | 14.31 | 5.90 | na |
| Cumulative costs ($/ha) | $9,718 | $9,373 | $9,425 | $9,352 |
| **Cumulative gross margin ($/ha)** | **$10,243** | **$10,035** | **$8,344** | **$8,231** |
| Cumulative irrigation water use (ML/ha) | 27.10 | 20.10 | 24.10 | 24.10 |
| **Average gross margin/ML** | **$378** | **$499** | **$346** | **$342** |
| Number of cotton crops | 4 | 4 | 4 | 4 |

When compared on a variable cost basis (Figure 18), there was only $366/ha difference in cumulative variable costs between the most expensive and least expensive rotation over the 8 years of the trial. The cotton-unfertilised wheat rotation was only $21/ha more expensive compared to the cotton-legume (seed incorporated) rotation, but the former returned an extra $1,084/ha in total gross margin.

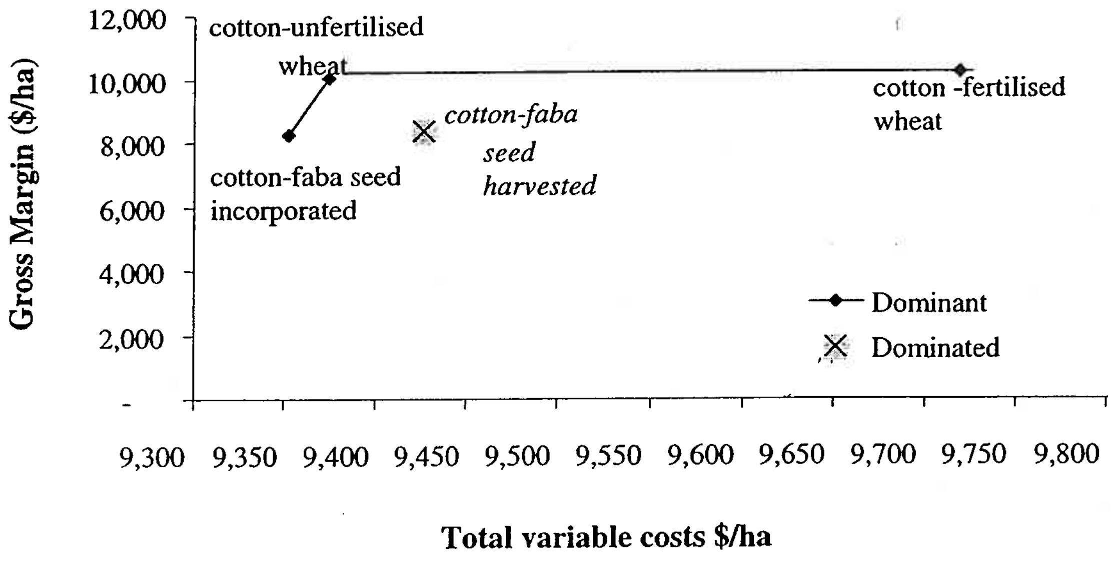

**Figure 18.** Cumulative variable cost/gross margin comparison for the rotations at Wee Waa

Altering the cotton price between $400 per bale and $600 per bale (Table 17) did not alter the ranking by total gross margin.

Table 17. Sensitivity testing for the rotations at Wee Waa

| Rotation | Cotton price ($/bale) | Cotton-N fertilised wheat | Cotton-unfertilised wheat | Cotton-legume (seed harvested) | Cotton-legume (seed incorporated) |
|---|---|---|---|---|---|
| Cumulative gross margin ($/ha) | 495 | 10,243 | 10,035 | 8,344 | 8,231 |
| **Rank** | | 1 | 2 | 3 | 4 |
| Cumulative gross margin ($/ha) | 400 | 7,260 | 7,023 | 5,473 | 5,342 |
| **Rank** | | 1 | 2 | 3 | 4 |
| Cumulative gross margin ($/ha) | 600 | 13,538 | 13,367 | 11,516 | 11,425 |
| **Rank** | | 1 | 2 | 3 | 4 |

The time period under consideration at Warren was from the 1993 winter rotation season to the 2000-01 summer cotton season. Individual experimental treatments ceased in 1999, with all plots being sown with a cotton-fertilised wheat rotation thereafter. The gross margin rankings for 1993-2001 were continuous cotton, unfertilised dolichos-wheat-cotton, N fertilised wheat-cotton, fallow-cotton, unfertilised wheat-cotton, field pea-cotton and K+P fertilizer dolichos-wheat-cotton-faba. (Table 18).

Table 18. Cumulative results for Warren from winter 1993 to summer 2000-01

| Rotation | Cont. cotton | Long-fallow cotton | Cotton-fertilised wheat | Cotton-unfertilised wheat | Cotton-wheat-dolichos/K+P fertilizer fb.cotton-faba | Cotton-field pea | Cotton-wheat-dolichos fb. cotton-dolichos fb. wheat-cotton-cotton |
|---|---|---|---|---|---|---|---|
| Cumulative lint yield (bales/ha) | 49.6 | 34.3 | 33.9 | 32.0 | 33.4 | 33.5 | 41.9 |
| Average annual lint yield | 7.1 | 8.6 | 8.48 | 8.00 | 8.34 | 8.37 | 8.38 |
| Cumulative cotton seed yield (t/ha) | 17.9 | 12.6 | 12.5 | 11.8 | 12.3 | 12.3 | 15.3 |
| Average cotton seed yield | 2.2 | 3.2 | 3.1 | 3.0 | 3.1 | 3.1 | 3.1 |
| Cumulative grain yield (t/ha) | 3.8 | 4.6 | 11.1 | 9.5 | 7.8 | 4.8 | 8.0 |
| Average wheat protein % | na | na | 14.0% | 11.1% | 9.8% | na | 11.0% |
| Cumulative variable costs ($/ha) | $13,988 | $7,944 | $8,490 | $8,101 | $9,066 | $8,328 | $11,493 |
| **Cumulative gross margin ($/ha)** | **$14,884** | **$11,283** | **$11,708** | **$11,086** | **$6,806** | **$10,778** | **$12,493** |
| Cumulative irrigation water use (ML) | 36.4 | 17.4 | 18.6 | 17.4 | 17.6 | 17.4 | 26.8 |
| **Average gross margin/ML** | **$408** | **$648** | **$629** | **$637** | **$387** | **$619** | **$465** |
| Number of cotton crops | 8 | 4 | 4 | 4 | 4 | 4 | 5 |

When compared on a variable cost basis (Figure 19), there was a large difference in cumulative variable costs between the most expensive (continuous cotton $13,988) and least expensive (fallow-cotton $7,944) rotation over the 8 years of the trial. The more expensive rotations could be considered more vulnerable to the vagaries of commodity prices, climate and crop disease outbreaks since they rely on a greater level of investment in variable costs to produce their returns.

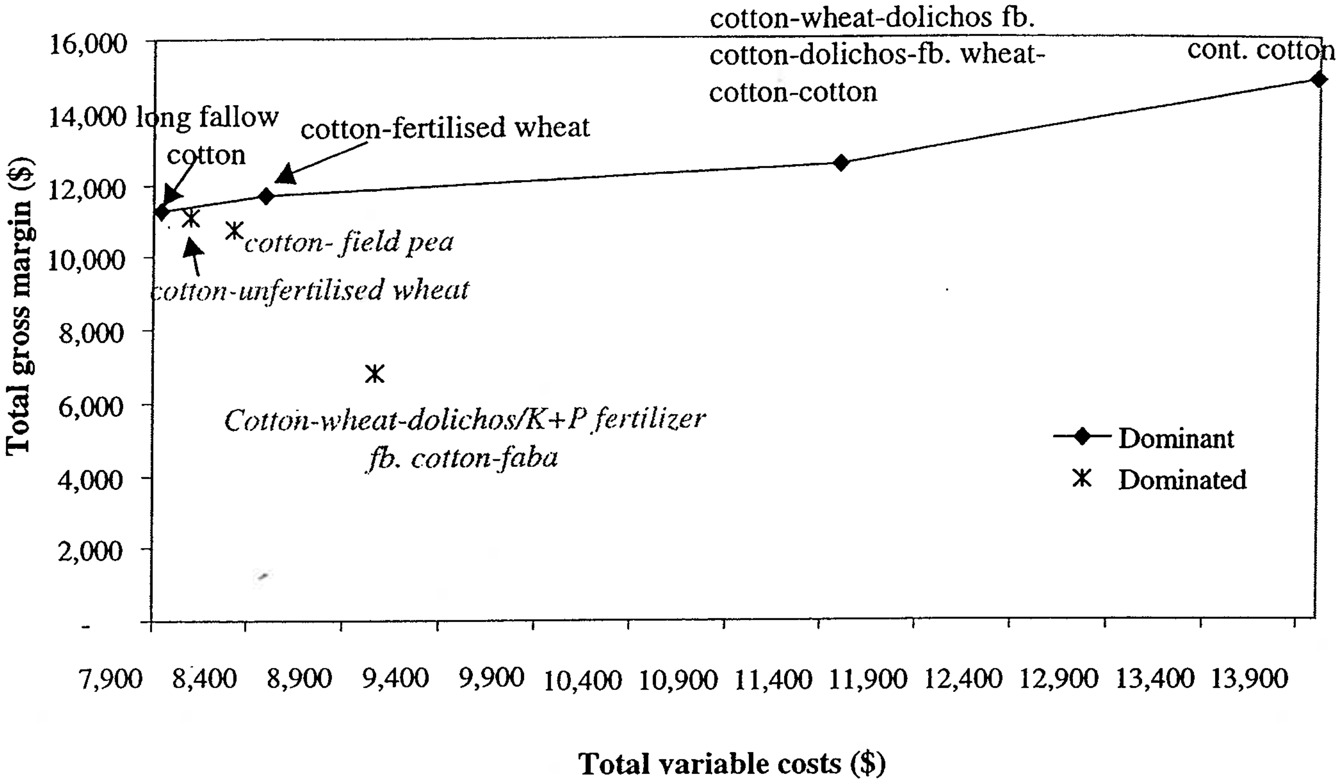

**Figure 19.** Cumulative variable cost/gross margin comparison for the rotations at Warren

Altering the cotton price between $400 per bale and $600 per bale (Table 19) did not alter the ranking by total gross margin.

Table 19: Sensitivity testing for the rotations at Warren

| Rotation | Cotton price ($/bale) | Cont. cotton | Long-fallow cotton | Cotton-fertilised wheat | Cotton-unfertilised wheat | Cotton-wheat-dolichos/K +P fertilizer fb.cotton-faba | Cotton-field pea | Cotton-wheat-dolichos fb. cotton-dolichos fb. wheat-cotton-cotton |
|---|---|---|---|---|---|---|---|---|
| Cumulative gross margin ($/ha) | 495 | 14,884 | 11,283 | 11,708 | 11,086 | 6,806 | 10,778 | 12,493 |
| **Rank** | | 1 | 4 | 3 | 5 | 7 | 6 | 2 |
| Cumulative gross margin ($/ha) | 400 | 9,990 | 8,100 | 8,513 | 8,005 | 4,883 | 7,605 | 8,544 |
| **Rank** | | 1 | 4 | 3 | 5 | 7 | 6 | 2 |
| Cumulative gross margin ($/ha) | 600 | 20,295 | 14,801 | 15,237 | 14,493 | 8,929 | 14,285 | 16,858 |
| **Rank** | | 1 | 4 | 3 | 5 | 7 | 6 | 2 |

## 5. Conclusions and recommendations

- In general, compared with other rotation crops, wheat was more profitable, easier to manage and resulted in better soil structure and lower sodicity, higher deep drainage and salt leaching in sites irrigated with poor quality water. Some exceptions did occur; e.g. in the saline-sodic soil at Merah North soil structure in long-fallow cotton was similar to that in cotton-wheat rotations.
- Deep drainage, nutrient and salt leaching in irrigated soils varied, depending on climate, numbers of deep cracks, stubble management, crop rotation, subsoil structure, clay content and sodicity. In general, sites with better structure, and lower clay content and sodicity, and where wheat stubble was retained *in-situ* as standing stubble had higher drainage and leaching during the cotton season. Furthermore the major proportion of seasonal deep drainage was caused by frequent and/or high early cotton season rainfall or high rates of early season irrigation. Irrigation alone at mid-season resulted in relatively small amounts of drainage. Nonetheless, when irrigation was followed by a high rainfall event significant amounts of drainage did occur. Causal factors for late season drainage were the same as for early season drainage. Where soil or irrigation water salinity was high such as Merah North, high rates of drainage and salt leaching was an advantage. However, where water and soil quality was good, high rates of deep drainage and leaching were less beneficial. Better subsoil structure, lower sodicity, high deep drainage and salt leaching were generally associated with cotton-wheat or continuous cotton at Merah North, whereas poorer structure, higher sodicity and low drainage and salt leaching was a feature of cotton-dolichos.
- Nutrient losses, particularly N, with deep drainage can be wholly or partially recovered by sowing a wheat crop after cotton. The amount of N recovered by the wheat was positively correlated with rainfall received during October and November of the previous cotton season. The efficiency of N recovery was improved by fertilising the wheat crop.
- Residual effects of rotation crops with respect to soil structure, N recycling and boll production by cotton at Warren were evident three years after the different rotation systems were replaced by a single cropping system (cotton-wheat at Warren and Wee Waa, wheat-fallow at Emerald) in all plots.
- Soil organic carbon (SOC), which decreased sharply in all sites except at Wee Waa during the initial 3-4 years of the experiments either stabilised or has started to increase slowly. An exception is the Wee Waa site, where SOC has been stable for the past 9 years and between 45% and 68% higher than in the other sites. Rotation crops did not have any effect on soil organic C in the on-farm experiments, but did so in the long-term tillage-rotation experiment at ACRI. For example, at the start of the 2000-01 cotton season in October 2000, minimum-tilled cotton sown into standing wheat stubble resulted in about 20% higher SOC than minimum-tilled continuous cotton.
- In all sites, exchangeable soil K decreases with time were reflected in falling leaf K concentrations in cotton. Decreasing K uptake led to premature senescence at Warra. The falling soil K caused low K/Na ratio in cotton plants when irrigated with saline sodic water at Merah North. This was one of the contributory factors to yield decline at this site. The decrease in soil K indicates that replacement through degradation of clay minerals is not keeping pace with K extraction by the cotton crops (i.e. "a mining effect").
- Major yield and profitability losses occurred at Merah North due to irrigation with saline bore water and associated decline in soil quality. Major causes of yield losses were chloride and sodium toxicity. These observations contradict the widely-held view that cotton is highly salt-tolerant.

*Suggested areas of future research*

- In spite of fertiliser application, exchangeable K has declined in soil. The cause for this decline needs to be investigated. The decline in K parallels the decline in SOC, and some reseachers (Dr. R. Dalal, QDNRE) have suggested a possible link. Furthermore anecdotal evidence from the Darling Downs suggests that application of cow manure minimises premature senescence and increases soil K levels. These speculations need to be verified in field experiments.
- Identify wheat 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. Related research in identifying wheat varieties which are optimal for different tillage systems of southern and central NSW is currently being conducted by Dr. Margret McCully of CSIRO, and some linkages could be established.
- Identify causal factors for deep drainage in a wide range of soil types and environments where cotton is grown. What are the long- and short-term consequences of salt and nutrient leaching in irrigated Vertosols on ground water quality?
- 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.
- Derivation of a sensitivity index for crop growth and yield of cotton and associated rotation crops with respect to salinity, sodicity and its components (EC, Na, Cl, $HCO_3$, $CO_3$) based on field data and not only on greenhouse experiments.
- Role of soil microflora and macrofauna on aggregation in sodic Vertisols. This should be based on field studies and not restricted to laboratory experiments.

## 6. New methods and techniques

- The drop-cone penetrometer method for evaluating soil plastic limit was modified. The modifications included changes to the wetting-up procedure and using computer-generated curves for evaluating the minima of the depth of penetration vs. soil water content curves. A comparative study of the traditional "thread" method and the modified drop-cone method was published in "Communications in Soil Science and Plant Analysis" (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).
- A conventional anhydrous ammonia applicator was modified to enable application of gas through standing wheat stubble into cotton beds using easily available components and at a significant cost reduction when compared with commercially available models. An article describing the modification was published in the "Australian Cottongrower" (Weaver, T., Finlay, L., Hulugalle, N., and Magann, D. 2000. Injecting anhydrous ammonia into standing wheat stubble. Aust. Cottongrower, 21(5), 64).
- Evaluation of three sodicity indices showed that dispersion index was best described by the ratio of $EC_{1:5}$/exchangeable Na. An article was published in the "Australian Cottongrower" (Hulugalle, N. R. 2001. Measuring soil sodicity in cotton-growing soils. Aust. Cottongrower, 22(4), 56-58).

## 7. Problems encountered

No problems were encountered during the past three years. All stated objectives were met.

## 8. 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:

- Cotton-wheat was the "best" rotation system with respect to soil structure, reduction of sodicity, leaching of salts, recycling of leached nutrients, ease of management and profitability. While other rotation systems could provide higher yields, overall profitability was best with wheat rotation crops.

- The residual effects of the rotation crops, particularly with respect to soil structure, were present for up to 3 years after the rotation treatments ceased. This implies that if structural maintenance was the main reason for using wheat as a rotation crop, given the long-term stability of the structure created by wheat, it need not be sown every year. However, wheat may be required to extract any N leached during the preceding cotton season. Again, given the correlation between N leaching and early season rainfall, wheat may be sown only in seasons where high and frequent early cotton season rainfall occurs.
- Cotton growth and yield can be significantly reduced by salinity. Previously, cotton was thought to be highly salt-tolerant. The mechanism where by yield reduction occurs appears to be specific ion effects (Cl and Na toxicity) rather than an osmotic effect.
- Deep drainage and nutrient leaching were identified as being significant in irrigated Vertosols. Previously they had been thought to be negligible. The initial findings made by this project were reported in an article in "Australian Cottongrower", and precipitated presentation of similar findings by other researchers. This has resulted in a virtual paradigm shift in the cotton industry with respect to deep drainage.
- The long-term decrease in subsoil K and K uptake by cotton is of concern. Discussions with Dr. Philip Wright (previously NSW Agriculture's agronomist at ACRI specialising in K nutrition) suggests that while soil K in the irrigated sites has not decreased to values where premature senescence and fibre quality decline could be expected, that in the dryland sites appears to be marginal for cotton production. This difference may be due to K inflow with irrigation water. For example, K inputs in irrigation water during the 2000-01 season were 13 kg/ha at ACRI, 20 kg/ha at Merah North and 28 kg/ha at Wee Waa.

## 9. Training

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

| Student | Degree | University | Years | Project title |
|---|---|---|---|---|
| T. B. Weaver | PhD | Griffith University, Nathan, Qld. | 2000-to date | Deep drainage and leaching in irrigated Vertosols |
| K. R. Jackson | B.Agr.Sci. (Hons.) | University of Queensland, St. Lucia, Qld. | 2000-01 | Drainage profiles of an irrigated Vertosol under a cotton-wheat rotation |
| N. J. Waters | B.Agr.Sci. (Hons.) | University of Queensland, St. Lucia, Qld. | 2000-01 | Water use efficiency of irrigated cotton grown under different tillage system |
| J. Gleeson | B.Agr.Sci. (Hons.) | University of Sydney, Sydney | 2001-02 | Effect of tillage systems and controlled traffic on furrow soil properties, and cotton growth and water use |
| P. Roberts | B.Agr.Sci. (Hons.) | University of Sydney, Sydney | 2001-02 | Measuring cotton root growth with a minirhizotron |

## 10. 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. Significant contribution was also made to the CRDC-sponsored poster on "Rotation Crops", which as since been disseminated to cottongrowers. In addition collaboration with Mr. Mark Hickman, Industry Development Officer, has commenced to prepare an Australian Cotton CRC research review on measuring and impact of sodicity in grey clays.

Specific details of published articles and oral presentations are given below:

*Technical journals*

- **Chan, K.Y., and Hulugalle, N.R. (1999).** Changes in some soil properties due to tillage practices in rainfed hardsetting Alfisols and irrigated Vertisols of eastern Australia. Soil Till. Res., 53, 49-57.
- **Hulugalle, N.R. (2000).** Carbon sequestration in irrigated Vertisols under cotton-based farming systems. Comm. Soil Sci. Plant Anal., 31, 645-654.
- **Hulugalle, N.R., Entwistle, P.C., Cooper, J.L., Scott, F., Nehl, D.B., Allen, S.J. and Finlay, L.A. (1999).** Sowing wheat or field pea as rotation crops after irrigated cotton in a grey Vertosol. Aust. J. Soil Res., 37, 867-90.
- **Hulugalle, N.R., Entwistle, P.C., Scott, F. and Kahl, J. (2001).** Rotation crops for irrigated cotton in a medium-fine, self-mulching, grey Vertosol. Aust. J. Soil Res., 39, 317-328.
- **Hulugalle, N.R., Entwistle, P.C., Weaver, T., Scott, F., and Finlay, L.A. (2002).** Cotton-based rotation systems in a sodic Vertosol under irrigation: effects on soil quality and profitability. Aust. J. Exp. Agric., 42, In press.
- **Hulugalle, N.R., Weaver, T.B., Finlay, L.A., and Entwistle, P.C. (2001).** Physical and chemical properties of soil near cracks in irrigated Vertisols sown with cotton-wheat rotations. Arid Land Res. Mngmnt. 15, 13-22.
- **Nkem, J.N., Lobry de Bruyn, L.A., Grant, C., and Hulugalle, N.R. (2000).** The impact of ant bioturbation and foraging activities on surrounding soil. Pedobiologia, 44, 609-621.
- **Nkem, J.N., Lobry de Bruyn, L.A., Hulugalle, N.R., and Grant, C.D. (2002).** Changes in invertebrate populations over the growing cycle of an N-fertilised and unfertilised wheat crop in rotation with cotton in a grey Vertosol. Appl. Soil Ecol., 20, 69-74.
- **Rochester, I.J., Peoples, M.B., Hulugalle, N.R., Gault, R.R., and Constable, G.A. (2001).** Using legumes to enhance nitrogen fertility and soil condition in cotton cropping systems. Field Crops Res., 70, 27-41.
- **Surapaneni, A., Olsson, K.A., Burrow, D.P., Beecher, H.G., Ham, G.J., Stevens, R.M., Hulugalle, N.R., McKenzie, D.C., Rengasamy, P. (2002).** Knowledge gaps in sodicity research for major agricultural industries. Aust. J. Exp. Agric., 42, 379-387.
- **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.

*Conference papers*

- **Hulugalle, N.R., and Entwistle, P.C. (2001).** Root growth of wheat and legumes sown in rotation with cotton in a Vertisol. Proc. 6th Symposium of International Society for Root Research, 11-15 November 2001, Nagoya, Japan, pp. 548-549. (Japanese Society for Root Research, Nagoya, Japan).
- **Hulugalle, N.R., Entwistle, P.C., Weaver, T., Scott, F., and Finlay, L.A. (2000).** Cotton rotation systems in a grey clay: effects on soil quality and profitability. In "Sodicity Issues in Agricultural Industries – Current Research and Future Directions", Proc. Sodicity Conference, 28 February- 1 March 2000, Tatura, Vic., Australia, p. 22. (ISIA, Tatura, Vic. Australia).
- **Hulugalle, N.R., Entwistle, P.C., Weaver, T., Scott, F., and Finlay, L.A. (2000).** Soil quality and profitability in a sodic, grey clay in Merah North, NSW, due to sowing rotation crops and applying gypsum. Proc. 10th Australian Cotton Conference, 16-18 August 2000, Brisbane, Qld., Australia, pp. 301-307. (Australian Cotton Grower's Research Association, Orange, NSW, Australia).
- **Hulugalle, N.R., Nehl, D.B., Weaver, T., Finlay, L.A., Tennakoon, S., and. Tann, C. (2000).** Effect of tillage system and wheat rotation crop on soil properties, cotton disease

and pest incidence, water use and growth in a Vertisol after winter flooding. Proc. 15th Conference of International Soil Tillage Organization, 2-7 July 2000, Fort Worth, TX, USA, Ed. J.E. Morrisson, Jr. (Texas Agricultural Experimental Station/USDA-ARS, Temple, TX, USA).

- **Rohde, K., Hulugalle, N.R., Yule, D., Entwistle, P.C., Weaver, T., and Finlay, L.A. (2000).** Bed width and cropping system effects on soil properties, runoff and erosion in a rainfed Vertisol. Proc. 15th Conference of International Soil Tillage Organization, 2-7 July 2000, Fort Worth, TX, USA, Ed. J.E. Morrisson, Jr. (Texas Agricultural Experimental Station/USDA-ARS, Temple, TX, USA).
- **Weaver, T.B., Hulugalle, N.R., Finlay, L.A., Jackson, K., and Ghadiri, H. (2001).** Salinity and drainage profiles under a cotton-wheat rotation in an irrigated Vertosol. Paper presented at Conference on Electromagnetic Techniques for Resource Management, 3-5 July 2001, Yanco, NSW, Australia.

### *Cotton industry magazines and extension publications*

- **Anonymous (2000).** "Which rotation crop?" Article in the October 2000 *Cotton Magazine* of the *Narrabri Courier*.
- **Cross, A. (1999).** Soil research paying off for cotton industry. NSW Agriculture Media Release, 23 November 1999 (http://www.agric.nsw.gov.au/news/releases/soil.res.htm).
- **Cross, A. (2002).** Impact of salinity under investigation. NSW Agriculture Today, 4 April 2002, p. 7; and NSW Agriculture Media Release, 12 April 2002 (http://www.agric.nsw.gov.au/reader/12961)
- **Hulugalle, N., Weaver, T., and Nehl, D. (2001).** Residual effects of rotation history on cotton growth and soil quality. Macquarie Valley Cotton Trial Reports 2000-2001, (Ed. K. Rourke), pp. 41-43. (Macquarie Valley Cotton Growers Association/NSW Agriculture, Australian Cotton CRC/CRDC, Narrabri, NSW).
- **Hulugalle, N.R. (2001).** Measuring soil sodicity in cotton-growing soils. Aust. Cottongrower, 22(4), 56-58.
- **Hulugalle, N.R., and Weaver, T. (2000).** Leaching in cracking clays. Aust. Cottongrower, 21(3), 60-64.
- **Scott, F. (1999).** Gross margins of NSW cotton rotation trials. Australian Cottongrower, 20(4), 66-70.
- **Weaver, T., Finlay, L., Hulugalle, N., and Magann, D. (2000).** Injecting anhydrous ammonia into standing wheat stubble. Aust. Cottongrower, 21(5), 64.
- In addition to the above annual contributions have been made to the Lower Namoi field day handbooks.

### *Oral presentations*

- **Hulugalle, N.R. (1999).** Seminar entitled "Current research in cotton-based farming systems of eastern Australia" was given at Merlewood Research Station, Institute of Terrestrial Ecology, Grange-over-Sands, Cumbria (16/9/99), and Silsoe College, Cranfield University, Silsoe (23/9/99) during a visit to the UK during September 1999.
- **Hulugalle, N.R. (2000).** Presentation during field tour of CRC/CRDC Farming Systems Forum, 5-6 December 2000, Dalby, Qld., on soil management issues and changes in soil quality at the CRC's farming systems experiment at "Prospect", Warra, due to sowing rotation crops.
- **Hulugalle, N.R. (2000).** Presentation to Australian Cotton CRC Soil Workshop on 23/6/2000 on soil carbon sequestration and global warming issues.
- **Hulugalle, N.R. (2000).** Presentations on (a) C sequestration in cotton-based farming systems (experimental results) and (b) proposal on root dynamics and soil C sequestration

at workshop held on 4/9/2000 between Australian Cotton CRC, Greenhouse Gas CRC and AGO on greenhouse gas emissions and possible joint projects.

- **Hulugalle, N.R. (2001).** Root systems of wheat sown in rotation with cotton can affect some soil physical properties. Paper presented at a workshop on wheat roots on 13 November 2001 during the 6th Symposium of the International Society for Root Research, Nagoya, Japan, 11-15 November 2001.
- **Hulugalle, N.R. (2002).** Presentation during Walgett cotton field day (8/3/02) on sodicity and laser-levelling
- **Hulugalle, N.R. (2002).** Presentation to Sydney University final year crop science students on field instrumentation for cotton systems (13/3/02).
- In addition to the above, annual presentations are given at the ACCRC's annual review, during 2001 to the ACRI's Centre of Excellence board of management, and during 2002 to NSW Agriculture Plant Industries' board of management.

## 11. Links to Other Projects

- DAN156C – Diseases of cotton VII
- DAN153C – Managing black root rot of cotton
- CRC 19C – Identification and remediation of nutritional stresses in cotton crops
- CRC 32C – Purchase of minirhizotron for the study of root dynamics in cotton-based farming systems
- CRC 37C – Measuring the influence of water quality on drainage through irrigated cotton soils
- CSP 116C – Developing integrated farm water management for cotton production
- CSP 142C – Phosphorus and potassium nutrition of cotton
- DAN 145 C – Operational costs for cotton experiments III
- DAN 144C – Industry development officer – Gunnedah
- CSP 139C – Application of crop simulation with the Australian Cotton Industry
- CRC 5.1.5 - Coordination and promotion of innovative farming systems
- CRC3.1.5.AC – Sustainable weed management systems for cotton

## 12. Addressing CRDC's outputs

The project's primary objective is to identify cropping systems (i.e. rotation crops) which maintain and improve soil quality (i.e. sustainability of soil resources) and profitability. Compared with other rotation systems, it is clear that over the long-term, the cotton-wheat system is the most profitable while at the same time it has the potential to improve soil quality (e. g. soil structure, N recycling, sodicity).

As an example, the project has been able to identify the effects of deteriorating ground water quality on soil quality, i. e. sodicity, salinity and accumulation of toxic ions such as chloride, and their consequences on cotton yields and gross margins at the Merah North site. Accumulation of chloride and sodium were highest with the dolichos systems, whereas they were less with wheat rotation crops or continuous cotton. Studies on nutrient leaching conducted at 3 of the sites (ACRI, Wee Waa, and Merah North) also showed that nitrate leaching was relatively high in all 3 sites, and that irrigation water could be a major source of nitrates. We believe that this was mainly due to inefficient use of nitrates by the cotton and hence, recirculation of nitrates in irrigation waters. The costs and benefits related to nutrient leaching were discussed in an earlier section of this report. Nitrate leaching and its potential consequences on ground water quality have implications for the CRDC's "community" output.

Other issues that will impinge on the sustainability of cotton systems are: (1) declining soil K and K uptake by cotton; and (2) declining soil organic C.

The project has addressed the issue of "people" 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. Two honours students from the University of Queensland and two honours students from Sydney University conducted research on subjects such as root growth, nutrient leaching and drainage, and effects of tillage system and wheel-trafficking on crop water use and furrow soil properties. Details of their projects were summarised under "Training". In addition between 1999 and 2002, the project hosted 6 work experience students from years 11 and 12 at Narrabri and Wee Waa High Schools.

## 13. Acknowledgements

Messrs J. Kahl (Merced Farming Pty. Ltd., Wee Waa, NSW), C. Hogendyke ("Auscott", Warren, NSW), D. and J. Grellman ("Beechworth", Merah North, NSW), J. Bidstrup ("Prospect", Warra, Qld.), T. Elsden ("Elsden Farms", Emerald, Qld.), their families and staff are thanked for provision of land to conduct the trials, management expertise and continuing support and interest. Messrs B. Reddan (Manager, ACRI) and D. Magann (Farm Supervisor, ACRI) for support with respect to on-station experiments, and laboratory and office facilities. We gratefully acknowledge the support provided by Ms. D. McCallister, management information systems officer, with respect to the financial reporting of this project.

## 14. 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. Consequently, there are no intellectual property considerations.

## 15. Appendix 1: Budget

| **Item** | **1999-00** | **2000-01** | **2001-02** |
|---|---|---|---|
| | | **($)** | |
| **A. STAFFING** | | | |
| *Technical officer*: | | | |
| Salary | 40356 | 41576 | 43101 |
| Payroll tax | 2946 | 3035 | 3146 |
| Workers comp. | 1211 | 1247 | 1293 |
| Leave loading | 605 | 624 | 647 |
| Employer's super. | 2825 | 3326 | 3448 |
| Extended leave | 1614 | 1663 | 1724 |
| *Temporary labour*: | | | |
| Salary | 9020 | 9020 | 9020 |
| Payroll tax | 659 | 659 | 659 |
| Workers comp. | 270 | 270 | 270 |
| Holiday/termination | 1082 | 1082 | 1082 |
| Leave loading | 135 | 135 | 135 |
| Employer's super. | 631 | 722 | 722 |
| **TOTAL** | **61354** | **63359** | **65246** |
| **B. TRAVEL** | | | |
| Sustenance country | 4407 | 4407 | 4723 |
| Cotton conference | - | 789 | - |
| **TOTAL** | **4407** | **5196** | **4723** |
| **C. OPERATING** | | | |
| Lab equipment | 1000 | 1000 | 1000 |
| Lab expenses | 7680 | 7680 | 7680 |
| Soil and plant tissue chemical analyses | 17820 | 17820 | 17820 |
| Vehicle expenses | 7920 | 7920 | 7920 |
| Field expenses | 4000 | 4000 | 4000 |
| Crop husbandry | 1000 | 1000 | 1000 |
| Computer supplies | 500 | 500 | 500 |
| Recruitment expenses | 1500 | - | - |
| Library services support | 1243 | 1198 | 1600 |
| **TOTAL** | **42663** | **41118** | **41520** |
| **D. CAPITAL** | 0 | 0 | 0 |
| **TOTAL REQUESTED** | **108424** | **109673** | **111489** |

**TOTAL FUNDS REQUESTED (1999-2002): $329,586 (ex-GST)**