96/041 C 1999 DAN108C

Report Purpose: **Final Report**

Commencement date: 1/7/96	**Completion date**: 30/6/99	Office Use only: Date of receipt:

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

Field of Research: Soils/Farming systems **Field code**: 2.1.6 **CRDC Project code**: DAN 108C

Responsible directors: Mr. D. Anthony/Mr. D. Hamilton

Organisation: NSW Agriculture
Administrative contact: Mr G. Denney, Manager (External Funds).
Telephone: 02-63913541 Fax: 02-63913527
Email: graham.denney@agric.nsw.gov.au
Postal Address: NSW Agriculture, Head Office,
161, Kite Street,
Orange, NSW 2800

Project supervisors:
Dr M. Blumenthal, Program Leader (Soil Management)
Telephone: 02-63913185 Fax: 02-63913206
Email: martin.blumenthal@agric.nsw.gov.au
Postal Address: NSW Agriculture, Head Office,
161, Kite Street,
Orange, NSW 2800

Mr D. Gibb, Program Leader (Cotton)
Telephone: 02-67991500 Fax: 02-67931186
Email: dallasg@mv.pi.csiro.au
Postal Address: NSW Agriculture, Australian Cotton Research Institute,
Locked Bag 1000, Narrabri, NSW 2390

Principal Researcher: Dr. N.R. Hulugalle,
CRC for Sustainable Cotton Production and NSW Agriculture,
Australian Cotton Research Institute,
Locked Bag 1000, Narrabri, NSW 2390
Telephone: 02-67991533 Fax: 02-67991503
E-mail: nilantha@mv.pi.csiro.au

Research staff:

Dr. N.R. Hulugalle (Chemist - Soils and Project Leader); **Mr. P. Entwistle** (1996-1997), **Mr. A. Redfern** (1998) and **Mr. T. Weaver** (1998-to date) (Technical Officer - Soils); **Mr. L. Finlay** (Technical assistant - Soils); **Mr. J.N. N'Kem** (1997-1998) (World Bank/UNE Research Fellow); Australian Cotton Research Institute, Narrabri, NSW 2390. Telephone: 0267-991500; Facsimile: 0267-931186.

Mr. J.L. Cooper (Research Agronomist) and **Mr. R. Pither** (Technical assistant); Agricultural Research Centre, Trangie, NSW 2823. Telephone: 0268-887404; Facsimile: 0268-887201.

Mr. I. Patrick (1996) and **Ms. F. Scott** (1996-to date), (Economists); NSW Agriculture, Tamworth Centre for Crop Improvement, Calala Lane, Tamworth, NSW 2340. Telephone: 0267-631100; Facsimile: 0267-631222.

COTTON RESEARCH AND DEVELOPMENT CORPORATION

FINAL REPORT

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

DAN 108C

July 1996 to June 1999

Dr. N.R. Hulugalle, Australian Cotton Research Institute, Narrabri, NSW 2390
Mr. J.L. Cooper, Agricultural Research Centre, Trangie 2823
Ms. F. Scott, Tamworth Centre for Crop Improvement, Tamworth 2340

ISBN 0 7347 1083 6

NSW Agriculture

COTTON RESEARCH AND DEVELOPMENT CORPORATION

DAN 108C

Long-Term Effects of Cotton Rotations on the Sustainability of Cotton Soils 1996-1999

N.R. Hulugalle, Chemist (Soils), Australian Cotton Research Institute, Narrabri, NSW 2390
J.L. Cooper, Agronomist, NSW Agriculture, Agricultural Research Centre, Trangie 2823
F. Scott, Economist, NSW Agriculture, Tamworth Centre for Crop Improvement, Tamworth 2340

SUMMARY

A survey of cotton growers in 1992 (CRDC Project DAN 76C) showed widespread interest in the use of rotation crops, plus a need for more information about the benefits of legume rotations and the effect of rotation management on subsequent cotton crops. To investigate the effect of rotation crop type and management on soil properties, cotton growth and yield, and economic returns, 3 irrigated field trials (at Merah North, WeeWaa and Warren in NSW), and 2 dryland trials (at Warra and Emerald in Queensland) were set up in 1993. During the first phase of this project monitoring of soil and crop growth was limited to the irrigated sites in NSW (CRDC Project DAN 83C). From 1996-1999 monitoring of soil properties was done in all five experimental sites. The rotations sown at each site included continuous cotton, long-fallow cotton, N fertilized and unfertilized cereals such as sorghum and wheat, double-cropped cereals (in the dryland sites), winter and summer legumes such as lablab, faba and field pea. In all sites rotation crop stubble was incorporated. Minimum tillage systems were used at Warren, Merah North and Emerald, reduced tillage at Wee Waa and conventional tillage at Warra. Soil measurements were made in all sites with the aim of detecting changes in structure and fertility which could affect the soil's ability to produce a profitable crop of cotton. Changes in soil moisture, crop growth, development and yield of all rotation crops and cotton; and economic returns were also monitored. Additional observations were made (a joint project with UNE/World Bank fellow Mr. J. N'Kem) during the rotation phase in 1997 at Wee Waa on soil faunal populations and their effects on soil physical and chemical properties.

Amelioration of soil compaction was best where wheat was sown. This was because the fine, fibrous roots of the wheat was able to penetrate the large numbers of soil micropores which occur in a compacted soil, thereby intensifying the wetting/drying process more than the thicker and lower numbers of roots of tap-rooted rotation crops. The long crop duration (approx. 6-7 months) also increases the number of wetting/drying cycles that a soil under the wheat is subjected to in comparison with a lesser number of wetting/drying cycles with a short-duration crop. Increases in sub-soil salinity were observed at Warren and Merah North, but not at Wee Waa. Salinity increased most during the cotton phase of a rotation. Soil organic matter (SOM) decreased with time in all treatments at Warren and Merah North but remained unchanged at Wee Waa. In the dryland sites, at Warra SOM was higher after chickpea, whereas no differences were evident between rotations at Emerald. Short-term increases in soil N were substantial after leguminous crops in all sites. Legumes (their seed material in particular) had an allelopathic effect on cotton growth and yield at Wee Waa. Fluctuation in exchangeable Ca, Mg and K were observed at Warren, Merah North, WeeWaa and Warra between years. With respect to Ca and Mg this was caused by a combination of an interaction between calcium and magnesium carbonates and SOM, and reversible displacement of exchangeable Ca and Mg by agrochemicals during the cotton phase of the rotation. The changes in exchangeable K were directly related to SOM, although the mechanism involved has not been clarified as yet. Soil faunal numbers, particularly ants, were higher in the fertilized wheat plots at Wee Waa. Ant mounds facilitated infiltration; and their soil had higher levels of exchangeable Ca, P, N and organic matter, and was less sodic than the surrounding soil. Surfaces of ant mounds were, however, more compacted than adjacent soil. In the irrigated sites, gross margins/ha were in the order of continuous cotton > cotton-fertilized wheat > cotton-unfertilized wheat > long-fallow cotton $\geq$ cotton-legumes. When gross margins were evaluated on the basis of ML of irrigation water supplied, they were in the order of cotton-unfertilized wheat $\geq$ cotton-fertilized wheat > long-fallow cotton $\geq$ cotton-legumes >> continuous cotton at Warren and Wee Waa, and long-fallow cotton > cotton-legumes fb. cotton-wheat > cotton-lablab = continuous cotton > cotton-faba at Merah North.

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

N.R. Hulugalle, J.L. Cooper, and F. Scott

Abstract

The effects of rotation crops and their management on soil properties of Vertisols, and cotton yield and profitability were evaluated from 1996 to 1999 in 3 irrigated field experiments in NSW, and 2 dryland experiments in Queensland. The rotations sown at each site were as follows:

Warren: Continuous cotton, long-fallow cotton, N fertilized wheat, unfertilized wheat, lablab, faba, field pea. The lablab was replaced with continuous cotton from 1997 onwards. Irrigated cotton was sown after the rotation crops.

Merah North: Continuous cotton, long-fallow cotton, unfertilized wheat, lablab, lablab (with P & K removed by cotton replaced as fertilizer applied after lablab was harvested), faba. Irrigated cotton was sown after the rotation crops.

Wee Waa: N fertilized and unfertilized wheat, faba where grain was either harvested or incorporated during land preparation. Irrigated cotton was sown after the rotation crops.

Warra: long-fallow cotton, sorghum, wheat, chickpea, double-cropped wheat. Dryland cotton was sown after the rotation crops.

Emerald: wheat-sorghum, sorghum, wheat, long-fallow cotton, wheat (sprayed before maturity). Dryland cotton was sown after the rotation crops.

Minimum tillage was used at Warren, Merah North and Emerald, reduced tillage at Wee Waa and conventional tillage at Warra. In all sites rotation crop stubble was incorporated. Soil properties monitored to a depth of 0.6 m included total organic matter and physical fractions, plastic limit, strength, dispersion, air-filled porosity, exchangeable Ca, Mg, K and Na, pH, $CaCO_3$ and electrical conductivity. Nitrate-N was monitored only at Wee Waa and Warren. Additional observations were made (a joint project with UNE/World Bank fellow Mr. J. N'Kem) during the rotation phase at Wee Waa on soil faunal populations and their effects on soil physical and chemical properties. Profile water content to 1.2 m, nutrient uptake, crop growth, cotton lint yield and fibre quality were also quantified. Economic returns were evaluated by comparing cumulative gross margins.

Amelioration of soil compaction was best with wheat. This was because the fine, fibrous roots of the wheat was able to penetrate the large numbers of soil micropores which occur in a compacted soil, thereby intensifying the wetting/drying process more than the thicker and lower numbers of roots of the tap-rooted rotation crops. The long crop duration (6-7 months) also increases the number of wetting/drying cycles that the soil under wheat is subjected to in comparison with a lesser number of wetting/drying cycles with a short-duration crop. Rotating a nitrogen-fixing leguminous crop with cotton increased soil N status. In comparison with harvesting, incorporating legume grain did not increase soil N. Incorporating legume grain slowed emergence, and reduced nutrient uptake, yield and fibre quality of the following cotton due to allelopathic effects. N applied as fertilizer to cereal rotation crops was immobilized in the short-term, but mineralization in subsequent years resulted in its mobilization. Deep rooted cereal crops were able to scavenge soil nutrients from below the root zone of the cotton. Nutrient uptake by cotton was improved by practices which improved subsoil physical properties and increased root activity such as: sowing a rotation crop with a fibrous root system, long crop duration and high frequency of wetting/drying cycles; and minimum tillage and controlled/reduced vehicular traffic which maintained continuity of vertical pores into the sub-soil. Increases in salinity occurred at Warren and Merah North, but not at Wee Waa, with greatest increases occurring during the cotton phase of a rotation. The increase in salinity was followed by an increase in sodicity at Merah North. Soil organic matter (SOM) decreased with time in all treatments at Warren and Merah North but remained unchanged at Wee Waa. In the dryland site at Warra, organic C was higher with the chickpea rotation, whereas no discernible trend occurred at Emerald. Fluctuations in exchangeable Ca, Mg and K occurred between years in all irrigated sites and at Warra. Laboratory and subsidiary experiments suggested that changes in exchangeable Ca and Mg were caused by: (1) an interaction between calcium and magnesium carbonate dissolution and SOM decomposition; and (2) reversible displacement of Ca and Mg by agrochemicals during the cotton phase of the rotation. The changes in exchangeable K were directly related to SOM levels, although the mechanism has not been elucidated. Soil faunal numbers, particularly ants, were higher in the fertilized wheat plots at Wee Waa. Ant mounds facilitated infiltration; their soil had higher levels of exchangeable Ca, P, N and SOM, and was less sodic than surrounding soil. Surfaces of ant mounds were, however, more compacted than the surrounding soil. In the irrigated sites, gross margins/ha were in the order of continuous cotton > cotton-fertilized wheat > cotton-unfertilized wheat > long-fallow cotton $\geq$ cotton-legumes, whereas gross margins/ ML of irrigation water supplied, were in the order of cotton-unfertilized wheat $\geq$ cotton-fertilized wheat > long-fallow cotton $\gtrsim$ cotton-legumes >> continuous cotton at Warren and Wee Waa, and long-fallow cotton > cotton-legumes fb. cotton-wheat > cotton-lablab = continuous cotton > cotton-faba at Merah North.

Table of Contents

1. Introduction

Vertisols (Vertosols, Usterts) are the most common cotton growing soils in 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 utilizing rotation crops and their management as a tool in land preparation for cotton. A survey conducted by Mr. Cooper 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 summarizes results obtained over the period 1996-1999 from 5 irrigated and dryland on-farm experiments in New South Wales and Queensland on rotation crop management which commenced in 1993.

2. Aims and Objectives

Determine the effect of cotton rotation crops and their management on soil quality, nutrient uptake and cycling, and growth and yield of succeeding cotton, and profitability of each rotation crop-cotton sequence on Vertisols used for irrigated and dryland cotton production in New South Wales and Queensland.

3. Methodology

Field Experiments

The effects of rotation crops and their management on soil properties of Vertisols, and cotton productivity and profitability were evaluated from 1996 to 1999 in 3 irrigated field experiments in NSW, and 2 dryland experiments in Queensland. The rotations sown at each site were as follows:

Warren: Continuous cotton, long-fallow cotton, N fertilized wheat, unfertilized wheat, lablab, faba, field pea. The lablab was replaced with continuous cotton from 1997 onwards. Irrigated cotton was sown after the rotation crops.

Merah North: Continuous cotton, long-fallow cotton, unfertilized wheat, lablab, lablab (with P & K removed by cotton replaced as fertilizer applied after lablab was harvested), faba. Due to late land preparation in 1993 the unfertilized wheat was sown with a lablab-faba-cotton sequence before the planned wheat-cotton sequence commenced. Irrigated cotton was sown after the rotation crops.

Wee Waa: N fertilized and unfertilized wheat, faba where grain was either harvested or incorporated during land preparation. Irrigated cotton was sown after the rotation crops.

Warra: long-fallow cotton, sorghum, wheat, chickpea, double-cropped wheat. Dryland cotton was sown after the rotation crops.

Emerald: wheat-sorghum, sorghum, wheat, long-fallow cotton, wheat (sprayed before maturity). Dryland cotton was sown after the rotation crops.

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

Sampling & Measurements

Soil was sampled from the 0.00-0.15 m, 0.15-0.30 m, 0.30-0.45 m and 0.45-0.60 m layers in all sites from 1996 to 1999. Four soil pits were dug in each plot either by spade or with a backhoe. Two soil clods were taken along their natural cleavage planes from the 0.00-0.15 m, 0.15-0.30 m, 0.30-0.45 m and 0.45-0.60 m layers of each pit (average clod volume at field moisture content was 175 x 10^{-6} m^3). 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 (by automated colorimetry after extraction with 1M KCl); exchangeable Ca, Mg, K and Na (after extraction with alcoholic 1M NH_4Cl at a pH of 8.5);

and dispersion. 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 total particulate 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 0.00-0.15 m was expressed as weighted mean of bulk density evaluated from clods and aggregates in beds. Soil strength to a depth of 0.45 m was measured at regular intervals with a 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 0.20-1.20 m 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.

Plant samples were taken at regular intervals at Wee Waa and Warren during the crop 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.

The effects of wheat rotation crops at Wee Waa on diversity and seasonal variation in activity of soil and epegeic invertebrates and their effects on soil properties were evaluated during 1997 by Mr. J.N. N'Kem, a research fellow from the University of New England (who was funded by the World Bank) by taking soil cores and using pitfall traps. Details of the methodology are given in N'Kem *et al.* (1999) (see section 9, p. 10).

Economic 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 (eg $495/tonne for cotton lint). This was to prevent fluctuations in commodity prices and input prices concealing rotation effects on the gross margins.

4. Key Results and Discussion

Changes in Soil Quality Indices

Maintenance and improvement of soil structure

In all sites use of minimum tillage, controlled traffic, maximizing the number of wetting/drying cycles, and intensifying of soil drying resulted in a gradual improvement of soil structure with time. Rotation crops had a negligible effect on soil structure when the above-mentioned management techniques were practiced. When structural damage did occur, however, differences emerged between rotation crops with respect to their ameliorative abilities (see following section).

Amelioration of soil compaction

Amelioration of soil compaction was best with wheat in both dryland and irrigated sites. An example is shown for the 0.15-0.30 m depth at Warren (Fig. 1). This was because the fine, fibrous roots of the wheat was able to penetrate the large numbers of soil micropores which occur in a compacted soil, thereby intensifying the wetting/drying process more than the thicker and lower numbers of roots of the tap-rooted rotation crops. Water extraction patterns measured at Merah North, Wee Waa and Warren indicated that depth of water extraction was shallower and that a lesser amount of water was extracted by the legumes. The long crop duration (6-7 months) also increases the number of wetting/drying cycles that the soil under wheat is subjected to in comparison with a lesser number of wetting/drying cycles with a shorter-duration crop. Leguminous rotation crops were less effective than wheat in structural amelioration because of their shorter growth duration, greater sensitivity to low levels of salinity, and inability to dry out the soil as much as wheat. Where soil compaction was insignificant, rotation crops had no effect on soil structural indices such as air-filled porosity.

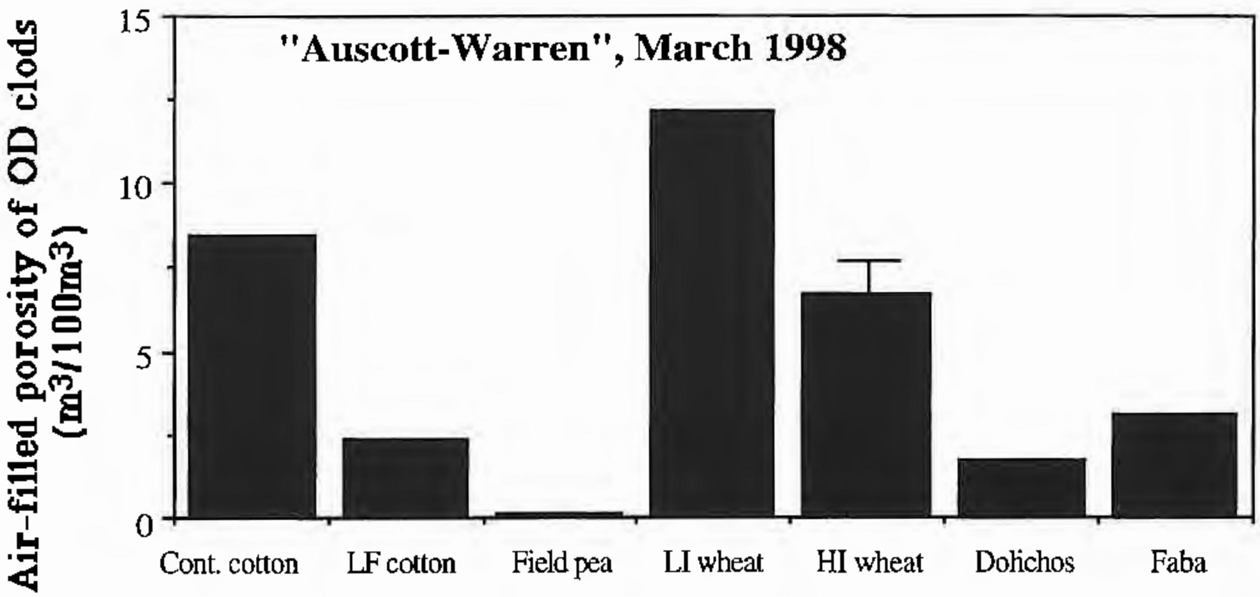

Figure 1. **Effect of rotation crop on air-filled porosity of oven-dried (OD) clods from the 0.15-0.30 m depth at "Auscott-Warren", March 1998. LI, low- input; HI, high input; LF, long-fallow; vertical bar is the standard error of the means.**

Effects of leguminous rotation crops on Nitrate-N

Nitrate-N values before sowing cotton were always higher with leguminous rotation crops. An example of nitrate-N changes in the 0-0.60 m depth with time is shown for "Glenarvon", Wee Waa, from mid-1993 to late-1998 (Fig. 2).

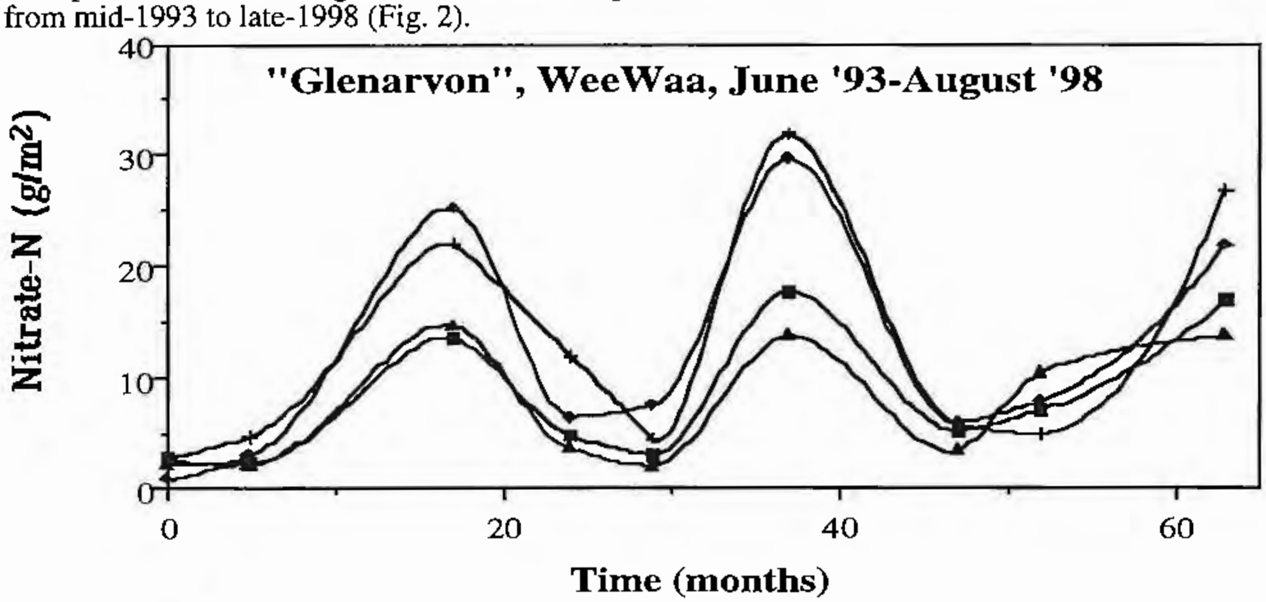

Figure 2. **Variation of soil nitrate-N in 0-0.6 m depth with time (June 1993-August 1998). ■ - fertilized wheat; ▲ - unfertilized wheat; ◆ - grain legume/seed harvested; + - grain legume/seed incorporated. Significant differences ($P < 0.001$) occurred between rotation crops and between times of sampling. Significant interactions ($P < 0.001$) also occurred betwen times and rotation crops.**

However, with time the differences between legumes and cereal rotation crops decreased. This was because: (a) the peak high values of nitrate-N which were observed after the legumes and before sowing cotton were not maintained due to denitrification and leaching losses. (The proportion of nitrate-N lost by leaching was likely to be higher in sites of higher sand content, eg. Warren, and during extended periods of high rainfall); (b) increases in root zone salinity to levels which were inhibitory to leguminous crops and consequently nitrogen fixation, but not wheat. Increases in salinity occurred only at Warren and Merah North. (See later discussion); and (c) increases in soil nitrate-N occurred where wheat was sown, albeit at a much lower rate than with the legumes. The increases in soil nitrate-N in wheat rotation systems is due to mineralization and release of N from the wheat residues. The N in fertilized wheat residues can be attributed to fertilizer applied to the wheat and residual N fertilizer applied to the previous cotton crop, whereas that in unfertilized wheat comes only from residual N fertilizer applied to the previous cotton crop. The difference in nitrate-N between fertilized and unfertilized wheat is not large (~ 3-5 g/m²) (Figs. 2 and 3), and suggests that a significant amount of residual N may be present at the depths > 0.6 m, probably due to leaching of applied fertilizer. When soil compaction occurred, however, leaching was reduced or absent, and accumulation of nitrate-N took place in the 0-0.6 m depth. An example of this is between March 1997 and March 1998, when compaction occurred in the 0.15-0.30 m depth at "Auscott-Warren" (Fig. 3). Accumulation in the 0-0.6 m depth also occurred when uptake of nitrate-N by cotton was reduced by root diseases such as black root rot.

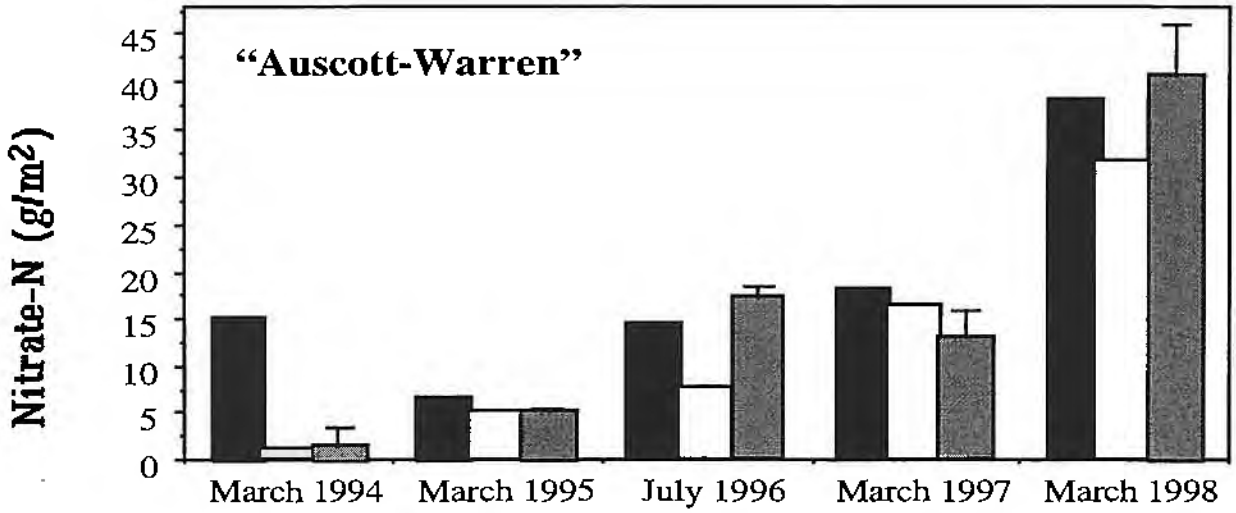

Figure 3. Nitrate-N in the 0.0-0.6 m depth during March 1994, March 1995, July 1996, March 1997 and March 1998. ■ - green manured field pea; □ - unfertilized wheat; ▩ - fertilized wheat. Vertical bars are the standard errors of the means for rotation crop effects at each time of sampling.

Changes in organic carbon

Soil organic C in 0-0.6 m depth of the irrigated sites were unaffected by rotation crops but declined with time at Warren and Merah North, but not at Wee Waa. Regression equations for the 3 sites are as follows:

Warren: OC = 7.69 -0.032t, s.e.(b) = 0.006, n = 126, r = -0.49***;
Merah North: OC = 8.79exp(-0.005t), s.e.(b) = 0.001, n = 90, r = -0.43***;
WeeWaa: OC = 10.68-0.014T, s.e. (b) = 0.001, n = 144, r = -0.13n.s.

where OC is organic C in kg/m², t is time in months, and s.e.(b) is standard error of the slope. The absence of any effects of the rotation crops on soil organic carbon is thought to be due to several interacting factors which are summarized below:

a) The relatively high C/N ratios of cotton residues (40-80) means that their decomposition is very slow, and that there is a "store" of partially-decomposed residues from previous cotton crops remaining in the soil. Organic C from these residues may be added continuously to the soil by their slow decomposition and mineralization. Consequently the differential effects of cereals and legumes on soil organic C reported from monocultures of cereals and legumes are "muffled" in these soils, and the manifestation of any significant differences may require much longer periods of time than in these experiments.

b) Minimum tillage and residue retention replaced intensive tillage and residue burning in 1993. Reduction of tillage intensity and retention of crop residues reduce carbon losses from soil, and may, therefore, have dominated decomposition processes at this site such that it minimized any effect of rotation crop on soil organic C.

c) Movement of crop residues, and soil organic C with dry soil and as dissolved organic C in irrigation and rain water from the topsoil to the subsoil via soil cracks, and differential swelling and shrinking in different soil horizons may have caused redistribution of soil organic carbon from surface to sub-soil horizons; ie. "soil inversion". Additional measurements at Wee Waa and ACRI show that organic carbon levels at the bottom of a soil crack is about 20% higher than in the bulk soil.

The general decline in organic C at Warren and Merah North compared with the absence of any significant changes at Wee Waa are due primarily to changes in tillage systems from intensive to minimum tillage at Warren and Merah North, and from intensive to reduced tillage at WeeWaa. Research in other soil types show that associated with the change from an intensive to minimum tillage systems is a change in cellulolytic microflora from bacterial-dominated to a less efficient fungal-dominated. While these changes are yet to be documented in irrigated cotton-based systems (current project of Dr. S. Putcha) it is likely that in view of the recalcitrant nature of cotton residues these "declines" are of a short-term nature.

In the dryland site at Warra some trends have emerged with respect to soil organic C. During 1998 organic C in the 0-0.6 m depth of plots sown with the leguminous rotation crop, chickpea (8.9 kg/m^2) was more ($P < 0.05$) than those in plots sown with either long-fallow cotton (7.0 kg/m^2) or cereal rotation crops (7.0 kg/m^2). As measurements at this site have been taken only since 1996 it is difficult to say whether this trend will continue. No significant trends in soil organic C were evident at Emerald, presumably due to the low cropping intensity which was caused by the drought conditions at this site during the preceding 5 years.

Changes in salinity

Salinity was not affected by sowing rotation crops, but changed with time at "Auscott-Warren" and "Beechworth", Merah North, but not at "Glenarvon", WeeWaa and the two dryland sites in Queensland. At Warren only small increases ($P < 0.01$) occurred between 1993 and 1996 (Fig. 4). Between 1996 and 1997, however, a sharp increase ($P < 0.001$) occurred in the 0.45-0.60 m depth, with smaller increases in the 0-0.45 m depth. This may be due to irrigation with saline water at some time during the 1996-1997 cotton growing season. The relatively high value in the 0.45-0.60 m depth at Warren and the lower values in the 0-0.45 m depth suggests that much of the salt has been leached into the deeper soil horizons. The absence of such a "bulge" in 1998 suggests that leaching has continued. This view is supported by the deep core samples taken by Ms. T. Willis and Mr. J. Friend at this same site (CRDC Project DAN 99C) which indicate that a chloride "bulge" is present in the 1.0-1.95 m depth. In summary, therefore, significant leaching appears to take place at the experimental site at Warren.

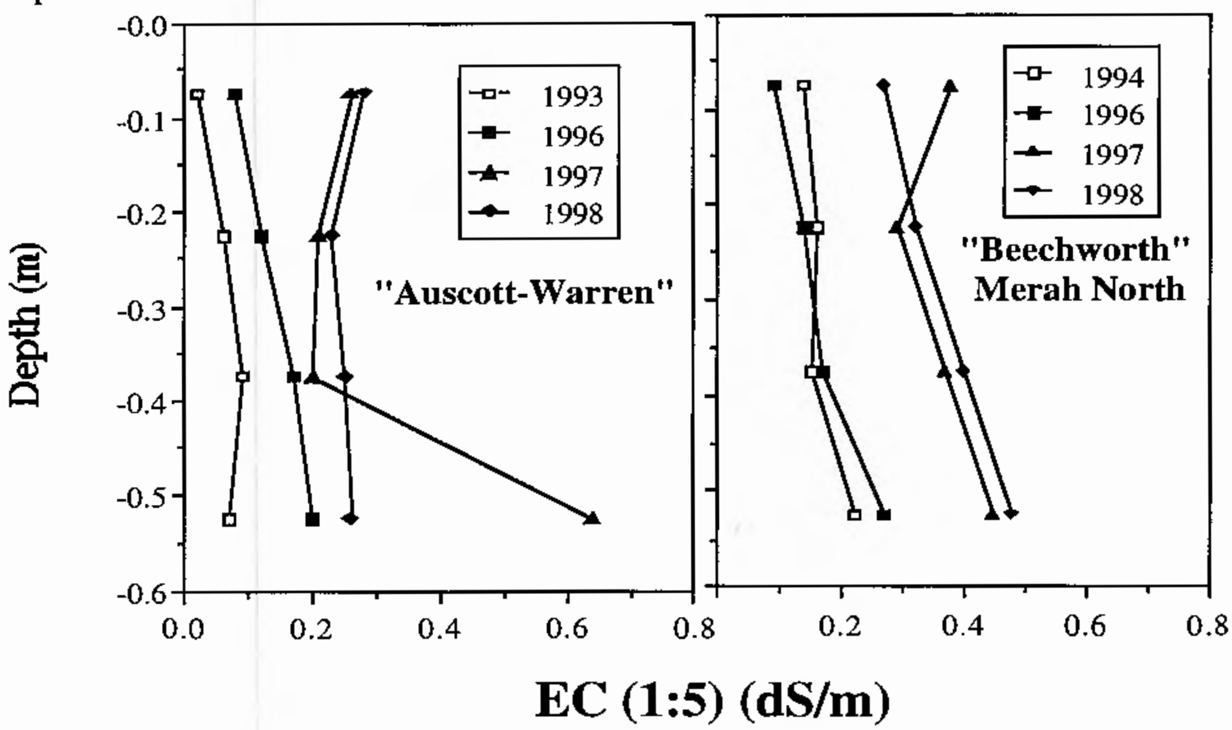

Figure 4. Variation of salinity with time at "Auscott-Warren" and "Beechworth", Merah North. Salinity is shown as the electrical conductivity of a 1:5 soil:water suspension.

At Merah North salinity did not change between 1994 and 1996 (Fig. 4). Between 1996 and 1997, however, a sharp increase in salinity ($P < 0.001$) occurred in all depths and is probably caused by continuous irrigation with saline bore water (SSP, sodium saturation percentage, was 68% in June 1997). No further changes took place thereafter. Unlike at Warren there is no indication of leaching, and is probably due to the fact that the soil at Merah North is a heavy clay (sand, silt and clay contents in the 0-0.6 m depth were 19%, 17% and 64%, respectively) whereas that at Warren is a medium clay (sand, silt and clay contents in the 0-0.6 m depth were 33%, 15% and 52%, respectively). Continuing irrigation with low quality bore water would have further exacerbated the problem. At both Warren and Merah North the EC values which occurred during 1997 and thereafter are inhibitory to the leguminous rotation crops which were used at these sites.

Changes in exchangeable cations

Fluctuations in exchangeable Ca, Mg and K occurred between years in all irrigated sites and at Warra. Laboratory and additional measurements in a field experiment established at ACRI by Dr. Grant Roberts, post-doctoral fellow in weed science, suggest that changes in exchangeable Ca and Mg were caused by: (1) an interaction between calcium and magnesium carbonate dissolution and SOM decomposition. To summarize, the process involves solubilization of native carbonates by H^+ released by (a) crop residue and soil organic matter mineralization, and (b) ionization of carbonic acid formed by dissolution of carbon dioxide, a product of microbial respiration; and release of Ca^{2+} and Mg^{2+}, which may either become adsorbed onto the clay minerals or remain in soil solution; and (2) reversible displacement of Ca and Mg by agrochemicals during the cotton phase of the rotation. Measurement of exchangeable cations in a herbicide experiment established by Dr. G. Roberts indicated that application of all common herbicides decreased exchangeable Ca and Mg by about 20% when compared with values in plots where weed control took place by cultivation only. Measurements are continuing at this site. (The involvement of soil microbial populations in this process is also suggested by the results of Drs. Putcha and Gupta from the same experiment). A pot experiment indicated that similar changes are negligible or absent in soils where SOM levels are relatively high.

The changes in exchangeable K were directly related to SOM levels, although the mechanism has not been elucidated as yet. Similar observations were also made in an earlier experiment on dolichos residue management conducted on a sodic, alkaline clay at "Auscott-Narrabri", near Narrabri. Dr. Donald McLeod of the University of New England, Armidale, has speculated that these observations may be due to displacement of K from the inter-lamellar spaces of the montmorillonite by hydronium ions, a product of SOM decomposition. Dr Ram Dalal (of QDNR) also observed a similar relationship between total K and SOM in a paper published in 1986 (Dalal, R.C., and Mayer, R.J. 1986. Long-term trends in fertility of soils under continuous cultivation and cereal cropping in southern Queensland. II. Total organic carbon and its rate of loss from the soil profile. *Australian Journal of Soil Research* **24**, 265-79), and he too speculated that mineralogical factors were contributing to these observations.

Cotton Growth and Yield in Irrigated Sites

Cotton lint yield

Cotton lint yields were lowest at Warren and second lowest at Merah North where continuous cotton was sown. The major factors which contributed to reducing lint yield ranged from black root rot and higher soil strength at Warren to higher soil compaction at Merah North. At Wee Waa and Merah North, lint yields were lowest after faba bean and chickpea (see following section). Lint yields were highest at Wee Waa and Warren, and second highest at Merah North where a cereal crop such as wheat had been sown, with high yields also occurring with field pea (at Warren) and fertilized lablab (at Merah North).

Allelopathic effects of leguminous rotation crops on the following cotton

Cotton emergence, growth, and lint yield and fibre quality were reduced at Wee Waa due to allelopathic effects (Table 1). Additional pot experiments and germination studies indicated that legume seeds were the main cause of these growth reductions.

Table 1. Effect of rotation crop on cotton lint yield and quality, 1994-95 and 1996-97 seasons. The cotton varieties used were CS-50 in 1994-1995, and CS 8-S in 1996-1997.

Rotation crop	Lint yield (bales/ha)		Micronaire (µg/in")		Fineness (millitex)		% mature fibres	
	'94-'95	'96-'97	'94-'95	'96-'97	'94-'95	'96-'97	'94-'95	'96-'9
Fertilized wheat	8.8	7.6	3.5	3.6	152	154	82.1	78.5
Unfertilized wheat	9.0	7.9	3.5	3.7	154	155	80.7	79.5
Faba bean/ grain harvested	8.0	7.1	3.3	3.4	145	145	80.3	73.5
Faba bean/grain incorporated	8.2	7.1	3.3	3.3	149	148	79.9	76.6
P <	0.05	0.01	0.05	0.001	0.05	0.05	n.s.	0.01

Average cotton lint yield after faba was also reduced at Merah North. Compared with continuous cotton yields reduction at Merah North was of the order of 10%. In general, in all sites wheat rotation crops which were subjected to good management practices (fertilizer, optimum plant populations, irrigation when water was available) tended to improve lint yield in subsequent cotton crops. Legumes such as lablab at Merah North and field pea at Warren also improved yield (but not profits, see later discussion).

Nutrient uptake by cotton

Nutrient uptake by cotton can be improved by practices which increase subsoil root activity such as: (1) sowing a rotation crop with a long crop duration and a high efficiency with respect to water extraction such as wheat; (2) high frequency of wetting/drying cycles; (3) reducing vehicular traffic; (3) applying N fertilizer to a preceding cereal rotation crop or sowing a leguminous rotation crop. Legumes improved nutrient uptake by the following cotton only when they did not have any allelopathic effects on the latter. Note that most of these practices can either directly or indirectly improve soil structural attributes.

Management problems associated with leguminous rotation crops in irrigated systems

The following points are based primarily on comments made by Mr. James Kahl, manager of "Glenarvon" at Wee Waa. We gratefully acknowledge his contribution.

- Legumes will not tolerate as wide a range of seedbed preparation methods and sowing conditions as much as the cereals. However, cereals need to be sown into moist soil as watering up tends to burst the seed, far more so than with legumes.
- Legumes are more difficult to manage during their growth phase due to a limited choice of effective herbicides and a high probability of insect pressure. Cereal rotation crops do not have these problems.
- High levels of applied fertilizer are necessary for best results from cereals (this is a cost consideration only).
- Harvesting of legumes is slower, harder to achieve a satisfactory result (eg. harvesting losses) and more expensive.
- Managing legume stubble is far easier than incorporating high yielding cereal stubble into the soil.
- Legume regrowth is much more expensive to deal with than cereal regrowth.
- Achieving best returns from legumes is difficult as there is no established futures market and the numbers of alternative buyers present in the marketplace are few. Consequently growers are forced to become price takers.
- Due to delays associated with picking cotton, post-harvest cultivation for Heliothis pupae control and inclement weather, legumes cannot be sown until well past their optimum sowing date. For example with faba bean, sowing after cotton can be delayed as late as early June whereas the optimum sowing date for faba bean in northern NSW is usually late April. Yields are therefore, poor. Yield penalties associated with late sowing of wheat are minute in comparison, and consequently returns are higher.

Economic returns

Highest cumulative gross margins/ha were observed with continuous cotton. Among rotation crops, wheat gave the highest gross margins with N fertilized wheat being more profitable than unfertilized wheat (Table 2). When cumulative gross margins/ML of irrigation water supplied was evaluated for Warren highest returns occurred with unfertilized wheat > fertilized wheat > field pea = long-fallow cotton. Lowest gross margin/ML of irrigation water occurred with continuous cotton. At Wee Waa highest gross margins/ML of irrigation water occurred with wheat, with N fertilized wheat being marginally greater than unfertilized wheat. At Merah North, however, lowest gross margins/ML of irrigation water occurred with faba bean and highest with long-fallow cotton. (The low gross margins with faba bean and continuous cotton may in part be caused by the very low cotton yields which occurred after laser levelling in the winter of 1993. These were the only treatments in which cotton was sown during 1993. All other treatments did not have a cotton crop until 1994). At the same site when unfertilized lablab - faba - cotton was followed by wheat - cotton, gross margins/ML of irrigation water were second to that of long-fallow cotton. In general, it can be said that among rotation crops wheat is a more efficient user of land and water resources than other rotation crops, particularly legumes. Continuous cotton is, however, the most efficient user of land in non-saline soils (such as Warren) whilst at the same time it is a relatively inefficient user of water resources. In moderately saline and very sodic soil (such as Merah North) long-fallow cotton is a more efficient user of water than the rotation system which had wheat in it. It should be noted that due to land levelling in 1993, the latter treatment had fewer wheat crops than were sown at Wee Waa and Warren. A further point which should be noted is that among all the crops studied in this project cotton is the best adapted to saline soils. It is not entirely surprizing, therefore, that a low intensity cotton production system such as long-fallow cotton is an efficient user of water resources in a moderately saline soil.

Table 2. Profitability, shown as cumulative gross margins from 1993 to 1998, for different rotations at "Glenarvon", Wee Waa; "Auscott-Warren", Warren; and "Beechworth", Merah North.

Rotation	Number of cotton crops	Average annual lint yield (Bales/ha)	$/ha	$/ML of irrigation water
"Glenarvon", WeeWaa:				
Fertilized wheat - cotton	2	8.5	5840	409
Unfertilized wheat - cotton	2	8.2	5585	400
Faba/harvested - cotton	2	7.7	3842	299
Faba/seed incorporated - cotton	2	7.6	3652	312
"Auscott-Warren", Warren:				
Continuous cotton	5	6.9	9464	333
Long-fallow cotton	2	8.3	5066	539
Field pea - cotton	2	9.0	5128	546
Low input wheat - cotton	2	8.5	5878	625
High input wheat - cotton	2	9.1	6186	584
Fertilized lablab - wheat - cotton fb. faba - cotton	2	8.6	5120	483
Unfertilized lablab - wheat - cotton fb. unfertilized lablab - cotton fb. continuous cotton	3	8.7	7135	379
"Beechworth", Merah North:				
Continuous cotton	5	6.1	7772	164
Faba -cotton	3	5.5	3364	167
Long-fallow cotton	2	7.6	4477	360
Unfertilized lablab - faba - cotton fb. wheat - cotton	2	7.9	4896	308
Unfertilized lablab - cotton	2	7.5	4088	261
Fertilized lablab - cotton	2	7.9	3988	255

5. Additional Experiments Conducted to Clarify Observations Made in Main Farming Systems Experiments

1. The effect of soil cracks on soil fertility indices such as organic C and exchangeable cations in cotton fields was evaluated in 3 sites: unfertilized wheat plots at Wee Waa (November 1997), and a degraded pasture (February 1999) and a cotton field sown with a wheat-cotton rotation (November 1997) at the ACRI. In all sites soil was sampled by digging pits with a backhoe to a depth of 1.5 m in every unfertilized wheat plot to evaluate the effect of soil cracks on organic C, exchangeable cations, texture and aggregate stability. Organic C was about 20% higher in the bottom of soil cracks in comparison with that in the bulk soil. Higher values of clay and plastic limit were also observed in soil from cracks.
2. The effect of herbicides on exchangeable cation levels and organic C were evaluated in an experiment established at ACRI by Dr. Grant Roberts and in a laboratory experiment. This was in response to the observations from all the farming systems experiments which indicated that values of exchangeable Ca and Mg fell during the cotton phase of a rotation. Organic C and exchangeable cations were measured in soil taken from the surface 0.15 m of Dr. Roberts' field experiment. It was observed that in comparison to weed control by cultivation (mechanical or manual), chemical weed control resulted in values of exchangeable Ca and Mg which were approximately 15-20% lower. It was surmised that this was due to their displacement by adsorption of herbicides onto clay particles. This observation has been frequently reported in the literature. In the pot experiment

which used a soil from a lucerne paddock which had a higher level of organic C (1.3% vs. 0.9%), a similar displacement did not occur. We suggest that this was because the herbicides (Roundup) became adsorbed onto the organic matter, instead of the clay particles. The measurements have been repeated in 1999 on samples taken from the field trial.

3. Data collected over the period 1993-1999 from a long-term experiment of tillage systems (minimum and intensive) and cropping systems (continuous cotton and cotton-wheat rotation) at ACRI have been utilized by Drs. Tennekoon and Milroy to derive a crop water use model. This model is now being applied to the farming systems experiments at Warren, Beechworth and Warra. This information was included as a joint paper in the proceedings of the 1998 Australian Cotton Conference. Data collected from the Wee Waa site from 1993-1998 is being utilized by Dr. Milroy to derive a model of crop growth, water and nitrogen use. Mr. Dirk Richards is evaluating the APSIM module for soil organic carbon using data collected from 1996-1998 at the Warra experiment.

6. Conclusions and Recommendations

1. In terms of ameliorating soil compaction, nutrient recycling, cotton lint yield maintenance, ease of management, efficient use of irrigation water supplied and profitability, wheat was the best rotation crop in non-saline soils. Leguminous crops, although ineffectual in ameliorating soil compaction and prone to management problems were best with respect to increasing soil N rapidly. In moderately saline soil a low intensity cotton production system such as long-fallow cotton performed best. This underscores the fact that suitable rotation crops for saline soils are at present unavailable. The literature suggests that among all the crops studied in the project cotton is the most salt-tolerant.
2. Highest cumulative gross margins/ha occurred with continuous cotton. Among rotations cotton-wheat resulted in the highest gross margins/ha with addition of N fertilizer to the wheat resulting in small increases. In non-saline soils, highest gross margins/ML of irrigation water supplied occurred with cotton-wheat and lowest with continuous cotton. In moderately saline soil, long-fallow cotton resulted in the highest cumulative gross margin/ML of irrigation water and was followed by the rotation which had included a wheat crop. Lowest gross margin/ML of irrigation water occurred with cotton-faba bean.
3. Lint yield declines were observed with continuous cotton.
4. Minimum tillage, controlled traffic, maximizing wetting/drying cycles and intensifying soil drying were very effective in maintaining good soil structure. Where structural deterioration occurred, however, cereal rotation crops such as wheat were very effective in its amelioration. Minimum tillage and controlled traffic did not, however, increase soil organic C in the medium-term (6 years). Where minimum tillage was imposed reductions in soil organic C occurred
5. Increases in soil salinity was observed in two of the irrigated sites. At Warren due to the greater sand content and moderate sodicity these increases in salinity were generally reversed by leaching of salts out of the root zone, whereas at Merah North leaching was absent due to high clay content and high sodicity. The increased salinity at Merah North was followed by further increases in sodicity. The increases in salinity and sodicity at Merah North were attributed to irrigating with bore water with a high SSP.

Suggested future areas of research

1. Identifying and evaluating salt-tolerant varieties of commonly used rotation crops in field trials. Many commercial cotton fields which have a history of irrigation with poor quality water such as saline bore water or waste water derived from sewage would be suitable for such trials. Rotation crops which can grow in saline soil and at the same time remove excess sodium and chloride could be identified for use in such soils. This is also a frequent query which I receive from cottongrowers who have salinity problems in their soil.
2. Linking soil quality (soil physical, chemical and biological properties) with microbiologically dominated crop residue decomposition processes in cotton-based farming systems is essential if we are to determine issues pertaining to soil sustainability. At present there is one project (that of Dr. Subbu Putcha) which is evaluating soil microbiological processes in crop residue decomposition. There is, however, no linkage to the associated soil physical and chemical processes. It is the combination of these processes which determine soil quality and sustainability.

7. New Methods and Techniques

Two new techniques were developed/adapted by this project for evaluating soil structure:

1. The use of a sediment density meter for evaluating soil dispersion, and expressing dispersion as dispersion curves. The technique was first described in a paper entitled "Measuring dispersion

with an electronic sediment density meter by P.C. Entwistle, N.R. Hulugalle and L.A. Finlay" which was presented at the 2nd National Conference of the Australian Plant and Soil Analysis Council in Launceston, November 23-26 1997.

2. The "white paint" technique previously described by Dr. A. Koppi of Sydney University was used to highlight *in-situ* soil structural features. A photograph was then taken of the exposed profile face with a digital camera, downloaded onto a computer and e-mailed to Ms. Elizabeth Roesener at Sydney University, where she was able to analyze the soil structural attributes using the SOLICON 3.0 software package. This procedure is far more rapid and inexpensive in comparison with the previously used procedure which involved removal of the entire profile face and transporting it to Sydney, where it was "fixed" using a resin and then photographed with a video camera under UV light prior to analysis. This technique has been described in 2 papers: "Residual effects of tillage and crop rotation on soil properties, soil invertebrate numbers and nutrient uptake in an irrigated Vertisol sown to cotton by N.R. Hulugalle, P.C. Entwistle and L.A. Lobry de Bruyn" which was published in the December 1997 issue of the journal "Applied Soil Ecology"; and "Effect of tillage system and cotton-based cropping system on long-term cotton lint yields in an irrigated Vertisol by N.R. Hulugalle, P.C. Entwistle and L.A. Lobry de Bruyn" which was presented at the 14th Conference of the International Soil Tillage Research Organization in Pulawy, Poland, 27 July-1 August 1997.

In addition, modifications to the drop-cone penetrometer method of determining plastic limit are on-going. The modifications include: 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.

8. Problems Encountered

1. Mr. Peter Entwistle, the technical officer in this project left in late December 1997 and was replaced by Mr. Alan Redfern in April 1998. Mr. Redfern in turn, left in August 1998 and was replaced by Mr. Tim Weaver in December 1998. The staff turnover during 1998 delayed implementation of some of our project objectives. Additional costs were also incurred with the recruitment process.
2. The implementation of a new accounting system by NSW Agriculture in 1996 and associated software problems resulted in the absence of financial reporting for nearly 10 months after the project commenced.
3. The heavy rainfall and subsequent flooding during July 1998 significantly delayed implementation of some of our project objectives.

9. Communication of Results

Technical Journals:

Hulugalle, N.R., Entwistle, P.C., Cooper, J., Allen, S.J., and Nehl, D.B. (1998). Effect of long-fallow on soil quality and cotton lint yield in an irrigated, self-mulching, grey Vertosol in the central-west of New South Wales. Aust. J. Soil Res., **36**, 621-40.

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., In Press.

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**, In Press.

Nkem, J. N., Lobry de Bruyn, L. A., Grant, C., and Hulugalle, N. R. (1999). The impact of ant bioturbation and foraging activities on surrounding soil. Pedobiol., In Press.

Nkem, J. N., Lobry de Bruyn, L. A., Grant, C., and Hulugalle, N. R. (1999). Soil macro-invertebrates distribution under an intensive cotton (*Gossypium hirsutum* L.)-based rotational system at two levels of nitrogen applications on a clay soil. Submitted to "Applied Soil Ecology".

Hulugalle, N.R. (1999). Carbon sequestration in irrigated Vertisols under cotton-based farming systems. Submitted to "Communications in Soil Science & Plant Analysis".

Rural Industry Journals and Newspapers:

Hulugalle, N.R., Entwistle, P., Eveleigh, R., and Patrick, I. (1996). Applying N fertilizer to wheat rotation crops: Effects on soil strength, cotton growth and yield. Aust. Cottongrower, **17(5)**, 58-60.

Hulugalle, N.R., and Entwistle, P. (1996). Long-term effects of minimum tillage and wheat rotation crops on soil structure, water extraction and cotton lint yield in a poorly-structured grey clay. Aust. Cottongrower, **17(6)**, 62-65.

Hulugalle, N.R., and Entwistle, P. (1997). Long-term cotton trials challenge rotation choices. Aust. Cottongrower, **18(2)**, 27-30.

Hulugalle, N.R., and Entwistle, P. (1997). Crop duration affects soil quality. Aust. Cottongrower, **18(3)**, 60-61.

Hulugalle, N.R., Rohde, K., Yule, D., Entwistle, P.C., and Finlay, L.A. (1999). Dryland farming systems trial results. Aust. Cottongrower, **20(2)**, 77-79.

Scott, F. (1999). Gross margins of NSW cotton rotation trials. Aust. Cottongrower, **20(2)**, In Press.

Hulugalle, N.R. (1996). "Cotton-wheat rotation shows real benefits". *Narrabri Courier* of 19 December 1996, p. 12.

Hulugalle, N.R., and Rea, M. (1998). "Fertilized wheat is a top rotation for irrigated cotton". *Cotton Magazine '98 Review*, p. 46. Published by the *Narrabri Courier* on 21 July 1998.

Hulugalle, N.R. (1998). "Sampling postponed, but analysis continued". *Cotton Magazine* of 12 November 1998, p. 8. Published by the *Narrabri Courier*.

In addition to the above, local newspapers from Tamworth, Gunnedah and Moree have also featured some of the findings of this project.

Conferences and Workshops:

Hulugalle, N.R., Entwistle, P., Cooper, J.L., and Allen, S.J. (1996). Effect of long-fallow in cotton-based farming systems on soil properties of an Entic Chromustert. Proc. of Australian and New Zealand National Soils Conference, 1-4 July 1996, Melbourne, Vic., Australia, Ed. N.C. Uren, Vol. 2, pp. 131-132. (Australian Soil Science Society Inc., Melbourne, Vic., Australia).

Hulugalle, N.R., Cooper, J.L., Entwistle, P., Eveleigh, R., Kay, A., and Patrick, I. (1996). Managing wheat rotation crops: Effects of N fertilizer on soil properties, nutrient uptake by cotton and cotton lint yield. Proc. 8th Australian Cotton Conference, 14-16 August 1996, Broadbeach, Qld., Australia, pp. 479-484. (Australian Cotton Grower's Research Association, Wee Waa, NSW, Australia).

Cooper, J.L., Hulugalle, N.R., and Entwistle, P. (1996). Effects of rotation crops on soil properties and cotton yield in the Macquarie valley of NSW. Proc. 8th Australian Cotton Conference, 14-16 August 1996, Broadbeach, Qld., Australia, pp. 485-488. (Australian Cotton Grower's Research Association, Wee Waa, NSW, Australia).

Marshall, J., Thomson, S., Rochester, I., Constable, G., Hickman, M., Hulugalle, N., Charles, G., Allen, S., and Cooper, J. (1996). The benefits of rotation cropping for cotton. Proc. 8th Australian Cotton Conference, 14-16 August 1996, Broadbeach, Qld., Australia, pp. 463-467. (Australian Cotton Grower's Research Association, Wee Waa, NSW, Australia).

Chan, K.Y., and Hulugalle, N.R. (1997). Changes in soil quality due to tillage practices in rainfed hardsetting Alfisols and irrigated Vertisols of Eastern Australia. Proceedings of 14th Conference of International Soil Tillage Research Organization, 27 July - 1 August 1997, Pulawy, Poland, Vol. 1, Eds. M. Fotyma, A. Jozefuciuk, L. Malicki, and J. Borowiecki, pp. 151-154. (IUCN, Pulawy, Poland).

Entwistle, P.C., Hulugalle, N.R., and Finlay, L.A. (1997). Measuring dispersion with an electronic sediment density meter. In "Moving Towards Precision with Soil and Plant Analysis", Proc. 2nd National Conference of Australian Soil and Plant Analysis Council, 23-26 November 1997, Launceston, Tasmania, Eds. L.A. Sparrow and A.J. Fist, pp. 140-142. (ASPAC, Launceston, TA, Australia).

Hulugalle, N.R., Entwistle, P.C., Roberts, G., and Finlay, L.A. (1998). Allelopathic behaviour of grain legumes in cotton-based farming systems. In "Agronomy - Growing a Greener Future", Proc. 9th Australian Agronomy Conference, 20-23 July 1998, Wagga Wagga, NSW, Eds. D.L. Michalk and J.E. Pratley, pp. 367-370. (Australian Society of Agronomy, Inc., Wagga Wagga, NSW, Australia).

Freebairn, D.M., Hulugalle, N.R., Tullberg, J., and Connolly, R.D. (1998). Greenhouse gas emission from cropping - the role of alternative tillage systems on clay soils. Paper presented at symposium on "Conservation Tillage: Can it Assist in Mitigating the Greenhouse Gas Problem?", 30 April 1998, University of Queensland, St. Lucia, Qld.

Hulugalle, N.R., Entwistle, P.C., Scott, F., and Kahl, J. (1998). Sustainable cropping systems for irrigated cotton: sowing wheat or grain legumes as rotation crops. Proc. 9th Australian Cotton Conference, 12-14 August 1998, Broadbeach, Qld., pp. 93-100. (Australian Cotton

Grower's Research Association, Wee Waa, NSW, Australia).

Hickman, M., Rochester, I., Tennakoon, S., Hare, C., Hulugalle, N., Charles, G., Allen, S., Nehl, D., Scott, F., Cooper, J., and Conteh, A. (1998). Rotation crops: What is the impact on an irrigated farming system. Proc. 9th Australian Cotton Conference, 12-14 August 1998, Broadbeach, Qld., pp. 49-59. (Australian Cotton Grower's Research Association, Wee Waa, NSW, Australia).

Tennakoon, S.B., Milroy, S.P., and Hulugalle, N.R. (1998). Comparison of crop water use efficiency with rotation and continuous cropping in an irrigated Vertisol. Proc. 9th Australian Cotton Conference, 12-14 August 1998, Broadbeach, Qld., pp. 537-540. (Australian Cotton Grower's Research Association, Wee Waa, NSW, Australia).

Hulugalle, N. R., Entwistle, P.C., Scott, F., and Kahl, J. (1999). Sowing wheat or grain legumes as rotation crops after cotton in an irrigated Vertisol. Paper accepted for presentation at GCTE Focus 3, 1999 Conference and Workshop, Reading, September 20-24 1999, UK.

Nkem, J.N., Lobry de Bruyn, L.A., Grant, C.D., and Hulugalle, N.R. (1999). The potential of soil macrofauna activities in reducing soil degradation: the case of mound-building activities of ants (*Iridomymex greensladei*). Paper accepted for presentation at GCTE Focus 3, 1999 Conference and Workshop, Reading, September 20-24 1999, UK.

Hulugalle, N.R. (1996). Rotations and soil structure. Proc. Cotton Soil and Agronomy Systems Co-ordination Meeting 3-4 December 1996, Narrabri, (eds. I. Rochester and K. Larsen), p. 10. (CRDC, Narrabri, NSW).

Hulugalle, N.R. (1998). Cotton rotations and soil quality. Proc. Cropping Systems Forum, 2-3 December 1998, Narrabri, NSW, (Eds. I. Rochester and H. Dugdale). (CRDC and CRC for Sustainable Cotton Production, Narrabri, Australia).

Hulugalle, N.R. (1998). Sustainability of cotton soils. Proc. Cotton and Grains Farming Systems Seminar, 4-5 August 1998, Dalby, Qld., P. 46. (CRDC/GRDC, Narrabri, NSW, Australia).

Nkem, J.N., Lobry de Bruyn, L.A., Grant, C.D., and Hulugalle, N.R. (1998). Response pattern of soil macrofauna to a cotton-based rotation under wheat cropping at two N levels. Proc. Cropping Systems Forum, 2-3 December 1998, Narrabri, NSW, (Eds. I. Rochester and H. Dugdale). (CRDC and CRC for Sustainable Cotton Production, Narrabri, Australia).

Oral Presentations:

Hulugalle, N.R., and Cooper, J.L. (1997). Soil structure in cotton-based rotation systems at Field 13, Auscott-Warren. Presentation at Macquarie Valley Cotton Field Day, Warren, NSW, 13 March 1997.

Hulugalle, N.R. (1997). Managing rotation crops in cotton-based farming systems. Presentations at Upper Namoi Valley Sustainable Farming Systems Tour, Narrabri, Wee Waa and Merah North, NSW, 24 March 1997.

Hulugalle, N.R. (1997). Sustainability of cotton soils. Presentation at Annual Review of CRC for Sustainable Cotton Production, 25 June 1997.

Cooper, J.L., Hulugalle, N.R., and Scott, F. (1997). Updates on Field 13 Experiment. Cottongrower Meeting at Warren Golf Club, 5 November 1997, Warren, NSW.

Hulugalle, N.R. (1997). Soil properties at CRC rotation trial at "Beechworth", Merah North. Field presentation to Cotton CRC External review Panel, 24 January 1997.

Hulugalle, N.R. (1998). Sustainable cotton systems for irrigated cotton: Wheat or grain legumes as rotation crops. Presentation to Cotton Industry Extension Officers Annual Workshop, 19 May 1998, Narrabri, NSW.

N'Kem, J.N. (1998). The influence of cotton-based rotational systems on soil macrofauna activities. Seminar presented at the Division of Ecosystem Management, University of New England Armidale, NSW 2351, on 21 October 1998.

Other:

Short summaries of the Farming Systems trials were included in the Lower Namoi and Macquarie valley field day handbooks from 1996 to 1999.

10. Links to Other Projects

1. Diseases of Cotton - IV (CRDC DAN 121C)
2. Black root rot and slow early season growth of cotton (CRDC DAN 122C)
3. Cotton industry development officer (CRDC DAN 109C)

4. Operational costs for cotton experiments - II (DAN 127C)
5. Overseas Travel to Attend 14th Conference of International Soil Tillage Research Organization held at Pulawy, Poland, and Post-conference Study Tour Entitled 'Agricultural Landscapes of Poland' (CRC NSWA 491)
6. Farming systems experiments Namoi & Macquarie valleys (CRC NSWA 511) and Darling Downs (CRC DPIQ 512)
7. Improving the N nutrition of cotton using rotation crops (CRC 1C/CRC CSIRO 532)
8. Assessing water use efficiency on eastern Australian cotton farms (CSP 93C)
9. ACRI Plant breeding fibre quality laboratory (CSP 77C)
10. Assessment of winter crop rotation phases for salinity prevention in cotton-based rotation systems (DAN 99C)
11. UNE/World Bank Fellow (Mr. J.N. N'Kem) - Soil invertebrate distribution in cotton-wheat rotation systems and their effects on soil physical and chemical properties
12. Extension technical officer, Dalby (CRC DPIQ 411)
13. Controlled traffic & crop rotations for dryland cotton including control of erosion & chemical movement (CRC DPIQ 513)
14. Sustainable cotton weed management systems (CRC NSWA 242). Mr. Graham Charles has been conducting weed surveys on all on-farm experimental sites at regular intervals.

11. Acknowledgements

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

12. Appendix I - Budget

BUDGET ($)

Item	1996-97	1997-98	1998-99
A. STAFFING			
Technical officer:			
Salaries	33111	35363	35153
Leave loading	497	531	527
Payroll tax	2318	2582	2566
Workers comp.	993	1061	1055
Super contributions	1987	2122	2461
Temporary labour:			
Salaries	7557	7784	9020
Leave loading	680	646	858
Payroll tax	529	533	631
Workers comp.	227	195	180
Super contributions	453	467	631
TOTAL STAFFING	**48352**	**51089**	**53082**
B. TRAVEL			
Sustenance country	3723	4095	4162
Cotton conference	2214	-	1579
TOTAL TRAVEL	**5937**	**4095**	**5741**
C. OPERATING			
Lab equipment	3400	500	550
Lab expenses	6800	1000	7140
Soil and plant tissue chemical analyses	13880	2520	17820
Vehicle expenses	5940	5940	5940
Field expenses	4000	4000	3000
Crop husbandry	5000	10000	1000
Computer for project	3500	0	0
Computer supplies	1200	500	300
Recruitment expenses	1500	0	0
Library services support	1356	734	1073
TOTAL OPERATING	**46576**	**25194**	**36823**
D. CAPITAL	**0**	**0**	**0**
TOTAL REQUESTED	**100865**	**80378**	**95646**

Estimated income from project: nil
Total funds requested (1993-1996): **276,889 $**