An Evaluation of Seedbed Preparation Methods
for Growing Irrigated Cotton in Grey Clays

by

Patrick Joseph Hulme

A thesis submitted for the degree
of Doctor of Philosophy

University of New England
Armidale, N.S.W.
Australia

December, 1987
Preface

I certify that the substance of this thesis has not already been submitted for any degree and is not currently being submitted for any other degree.

I certify that any help received in preparing this thesis, and all sources used, have been acknowledged in this thesis.

Patrick Joseph Hulme
I would like to gratefully acknowledge the assistance I have receive from many people and organizations over the past three years.

Firstly, I wish to thank Dr. Donald MacLeod, a supervisor, for his guidance throughout the project and for his critical appraisal of the thesis. I respect his knowledge, and rue the occasions when I did not follow his advice. Dr. Alfred Cass provided technical guidance with soil physics aspects of the project, particularly with respect to soil swelling and tensiometry. Alf also gave valuable comments on parts of an early draft of the thesis.

Mr. Dave McKenzie, my second supervisor, of the N.S.W. Department of Agriculture, Trangie, generously gave his time and shared his knowledge on soil physics and cotton production. Dave provided the Rhodamine dye infiltration and penetrometer data in Section 7.3, and gave valuable comments on an early draft of the thesis.

Mr. Dave Anthony, former farm manager, Auscott Ltd., Warren, established the field experiment which is the basis of this thesis. Dave's wide knowledge of both practical and scientific aspects of cotton production started the project on a firm basis. Dave's successor, Mr. Chris Hogendyk has maintained the interest and cooperation of Auscott management in the project.

The project would have been impossible without the help of many organizations. It was funded by the Cotton Research Council who paid me a scholarship and provided funds to meet traveling, laboratory and casual assistance expenses. The field experiment was conducted on land owned by the Russ family, and farmed by Auscott Ltd. The carrying out of all cultural operations by Auscott staff allowed me to concentrate on scientific rather cultural aspects of the project. I sincerely hope that the knowledge gained from the project improves the profitability of Auscott's cotton growing operations.

The N.S.W. Department of Agriculture freely provided laboratory, office and computing facilities. Having seen the difficulties others have when monitoring field experiments from afar, I appreciate the use of these services, and the use of their sampling equipment.

The University of New England provided the environment in which to undertake the academic aspects of the project, such as by providing office, library and computing services.

Many people have helped me with specific aspects of the project. Kate Hucker (N.S.W. Department of Agriculture, Trangie) provided willing assistance with field sampling, and laboratory analyses. Other N.S.W. Department of Agriculture, Trangie staff who helped with sampling included Ian Toole, Dave Hall and Julia Harris. Dr. Terry Abbott (N.S.W. Department of Agriculture, Rydalmere) allowed me to use his experimental site for the evaluation of experimental methods in Chapter 7.2. Dr. Ross Higgison and Mark Hanley assisted with sampling in this experiment. Dr. Greg Constable (N.S.W. Department of Agriculture, Myall Vale) guided me in sampling for the soil nitrate determination and analysed the samples. Karen Rose of the same centre conducted the nitrogen content measurement of the 1986/87 cotton plant samples.

Others have assisted me with field sampling, generally under hot conditions which are better suited for cotton growth than tasks such as digging holes to collect soil samples. These people include Al Barrett, John Harvey, Neil Robertson, Mark McArae, Steve Buster, Anthony Freer, Deborah Wilde, Margaret Murphy and Julie Hall.
Frances Hulme, whose knowledge of soil management and cotton production is limited, bravely undertook to read an early draft of the thesis in order to ensure that non-specialists can understand most of it. Her comments were appreciated.

Neil McKenzie, fellow postgraduate, described the profile presented in Appendix 3, undertook the analyses presented in Table 4.3, and guided my initial reading on geostatistics.

Assistance with data analysis was also provided by many people. Dr. Alec McBratney, pedometrician, (CSIRO Division of Soils, Brisbane), guided me in the geostatistical analysis in Chapter 6. Dr. Vic Bofinger, (UNE) with his vast knowledge of analysis of agronomic experiments, provided invaluable guidance in analysis of data collected in the 1984/85 season. Dr. John Evans (N.S.W. Department of Agriculture, Sydney) undertook the two-way repeated measures analysis presented in Chapter 7. Peter Baker (N.S.W. Department of Agriculture, Trangie) assisted with the design of the picker compaction experiment presented in Chapter 7, while Dr. Ian Davies (UNE) guided me in analysis of that experiment.

I have learnt much from discussions with other scientists on many aspects of soil physics and crop growth. Dr. Paul Blackwell (CSIRO Division of Soils, Canberra) assisted in the design of the swelling pins described in Chapter 5, and encouraged me to persist with analysis of that data when I was initially disheartened by the limited swelling measured. Paul also commented on an early draft of the description of the field measurement. I enjoyed challenging discussions with Dr. Arthur Hodgson (N.S.W. Department of Agriculture, Myall Vale), and also wish to thank him for use of the oxygen flux density measurement equipment. Dr. Des McGarry (CSIRO Division of Soils, Brisbane) shared his knowledge of soil swelling and its relationship to field sampling, and commented on a draft of the review on swelling. Dr. Mac Kirby (CSIRO Division of Soils, Canberra) kindled my interest in soil mechanics.

Last, but far from least, I wish to thank many people whose company I have enjoyed in work and leisure over the last three years. I wish to thank my family, who provide a stable base, which keeps me to steady despite my nomadic lifestyle. I have shared accommodation with a different group of people in each of the four periods I have spent in Armidale, and enjoyed the experience each group has provided with their distinct lifestyles. I stayed at quarters provided by N.S.W. Department of Agriculture, Trangie during all of the 18 months I spent there. Among the many people whose company I have enjoyed there I particularly wish to thank the cook at the quarters, Carole Bourchier, who does her best to make the quarters a home to many people.

As I have typed the thesis, drawn the sketches, plotted the graphs and set out the tables I accept full responsibility for the imperfections in it. However I wish to thank Phil Jones for providing me with the computer and software on which much of the thesis was typed, and Richard Luck for loaning me his computer so the final version could be printed on a high quality printer.
## CONTENTS

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preface</td>
<td></td>
<td>i</td>
</tr>
<tr>
<td>ii</td>
<td></td>
<td></td>
</tr>
<tr>
<td>iii</td>
<td></td>
<td></td>
</tr>
<tr>
<td>iv</td>
<td></td>
<td></td>
</tr>
<tr>
<td>v</td>
<td></td>
<td></td>
</tr>
<tr>
<td>vi</td>
<td></td>
<td></td>
</tr>
<tr>
<td>vii</td>
<td></td>
<td></td>
</tr>
<tr>
<td>viii</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ix</td>
<td></td>
<td></td>
</tr>
<tr>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>xii</td>
<td></td>
<td></td>
</tr>
<tr>
<td>xiii</td>
<td></td>
<td></td>
</tr>
<tr>
<td>xiv</td>
<td></td>
<td></td>
</tr>
<tr>
<td>xv</td>
<td></td>
<td></td>
</tr>
<tr>
<td>xvi</td>
<td></td>
<td></td>
</tr>
<tr>
<td>xvii</td>
<td></td>
<td></td>
</tr>
<tr>
<td>xix</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### PART I

## REVIEW OF LITERATURE

<table>
<thead>
<tr>
<th>Chapter 2</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Introduction</td>
<td>1</td>
</tr>
</tbody>
</table>

### 2.1 Introduction

2.2 Structural degradation

2.2.1 Influence of soil water content on structural

2.2.2 Wheel passage

2.2.3 Tillage

2.2.4 Irrigation

2.3 Effect of soil physical properties on cotton growth

2.3.1 Bulk density

2.3.2 Porosity

2.3,3 Plant available water content

2.3.4 Soil strength

2.4 Management to minimize the effect of structural degradation in vertisols

2.4.1 Amelioration of structural degradation

2.4.2 The development of tillage management systems

2.4.1.1 Tillage

2.4.1.2 Crops

2.4.1.3 Gypsum

2.4.3 The development of tillage management systems
Chapter 3 Measurement of soil properties in vertisols 28
3.1 Introduction 28
3.2 Soil swelling and measurement of soil properties 28
   3.2.1 Mechanism of swelling and its relationship to sampling 28
   3.2.2 Accounting for swelling in measurement of soil properties 30
3.3 Statistical methods used in description of soil physical properties 35
   3.3.1 Methods assuming spatial independence 35
   3.3.2 Geostatistics 37
   3.3.3 Estimation of sample size 41
   3.3.4 Conclusions 42

PART II EXPERIMENTAL METHODS
Chapter 4 General description of experiments 44
   4.1 Introduction 44
   4.2 Experiment design 44
   4.3 Cultural practices 51
   4.4 Climate 53
   4.5 Soil description 54
Chapter 5 Soil swelling, and neutron moisture meter and gamma density meter calibrations 57
   5.1 Introduction 57
   5.2 Field measurement of soil swelling 57
      5.2.1 Introduction 57
      5.2.2 Materials and methods 58
      5.2.3 Results 61
      5.2.4 Discussion 64
   5.3 Neutron moisture meter and gamma density meter calibrations 69
      5.3.1 Introduction 69
      5.3.2 Materials and methods 70
      5.3.3 Results 73
      5.3.3 Discussion 79
### List of Tables

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Soil consistency and basic cultivation operations.</td>
<td>21</td>
</tr>
<tr>
<td>3.1</td>
<td>Examples of simple authorized functions used to describe semivariograms.</td>
<td>39</td>
</tr>
<tr>
<td>4.1</td>
<td>Cropping, fertilizer, and seedbed preparation histories of experimental site, Field 30, Auscott, Warren.</td>
<td>46</td>
</tr>
<tr>
<td>4.2</td>
<td>Climatic means for Trangie, 1948 to 1985.</td>
<td>54</td>
</tr>
<tr>
<td>4.3</td>
<td>Laboratory analyses of soil collected from pit near south-western corner of Field 30, Auscott, Warren.</td>
<td>55</td>
</tr>
<tr>
<td>4.4</td>
<td>Exchangeable cation concentrations determined on 18 samples each bulked from 15 subsamples from 0 to 0.3 m. Field 30, Auscott, Warren.</td>
<td>55</td>
</tr>
<tr>
<td>5.1</td>
<td>Vertical and horizontal movement of swelling pins over a drying cycle between irrigations, and their separation Field 30, Auscott, Warren, February, 1987.</td>
<td>62</td>
</tr>
<tr>
<td>5.2</td>
<td>Slope and intercept of regressions fitted to shrinkage curves estimated by swelling pins between 1 and 12 days after irrigation, Field 30, Auscott Warren, February, 1987.</td>
<td>62</td>
</tr>
<tr>
<td>5.3</td>
<td>Coefficients fitted by three stage linear regression to shrinkage in the laboratory of clods collected from 0.2 and 0.3 m.</td>
<td>63</td>
</tr>
<tr>
<td>5.4</td>
<td>Gravimetric water content, and specific volume of cores collected during installation of swelling pins, and clods collected during removal of swelling pins. Field 30, Auscott, Warren, 1987.</td>
<td>64</td>
</tr>
<tr>
<td>5.5</td>
<td>Models fitted by linear regression to change in specific volume with change in gravimetric water content of samples collected at a range of water contents during installation and removal of swelling pins, Field 30, Auscott, Warren, 1987.</td>
<td>64</td>
</tr>
<tr>
<td>5.6</td>
<td>Corrected changes in cumulative profile water capacity measured with neutron moisture meter from 1 to 12 DAI compared with uncorrected changes.</td>
<td>67</td>
</tr>
<tr>
<td>5.7</td>
<td>The effect of changes in volume of soil prism measured by swelling pins between 1 and 12 days after irrigation on measured air filled porosity calculated from changes in volumetric water content within the prism measured with neutron moisture meter</td>
<td>67</td>
</tr>
<tr>
<td>5.8</td>
<td>Ranges and means of measured gravimetric water content and volumetric water content ($\theta_w$), and $\theta_v$ corrected for undimensional and 3-dimensional shrinkage of samples collected during calibration of a CPN 503 neutron moisture meter. Field 30, Auscott, Warren, 1985.</td>
<td>73</td>
</tr>
</tbody>
</table>
List of tables

Table 5.9  Ranges and means of measured air filled porosity, and calculated air filled porosity corrected for 3-dimensional shrinkage of samples collected during calibration of a CPN 503 neutron moisture meter. Field 30, Auscott, Warren, 1985.  
Table 5.10  Ranges and means of measured bulk density, calculated bulk density corrected for 3-dimensional shrinkage and water content of samples collected during calibration of a CPN 503 neutron moisture meter and a CPN 501 gamma density meter. Field 30, Auscott, Warren, 1985.  
Table 5.11  Regression coefficients, and two measures of precision of calibration, for CPN 503 neutron moisture meter calibrations of count rate ratio, or count rate ratio corrected for bulk density on measured volumetric water content ($\theta_v$), $\theta_v$ corrected for 3-dimensional shrinkage, and gravimetric water content. Field 30, Auscott, Warren, 1985.  
Table 5.12  Regression coefficients, and two measures of precision of calibration, for CPN 503 neutron moisture meter calibration of count rate ratio corrected for bulk density on air filled porosity corrected for 3-dimensional shrinkage. Field 30. Auscott, Warren, 1985.  
Table 5.13  Regression coefficients, and two measures of precision of calibration for CPN 503 neutron moisture meter count rate ratio corrected for bulk density on bulk density, and CPN 501 gamma density meter count rate ratio on bulk density corrected for water content. Field 30, Auscott, Warren, 1985.  
Table 5.14  Measured values of gravimetric and volumetric ($\theta_v$) water contents, density, and $\theta_v$ and air filled porosity corrected for 3-dimensional shrinkage measured in samples from 24 sites at 0.3 m depth, compared with values predicted by neutron moisture meter calibrations. Field 30, Auscott, Warren, 1985.  
Table 6.1  Cultural operations and pesticide application during 1984/85 cotton crop, Field 30, Auscott, Warren.  
Table 6.2  Gravimetric soil water measured concurrently with penetration resistance at two and zero days before irrigation due on 5/3/85, Field 30, Auscott, Warren.  
Table 6.3  Linear regression of penetration resistance on gravimetric soil water, Field 30, Auscott, Warren, 5/3/85.  
Table 6.5  Root length beneath ripped and direct list treatments determined by core break method on samples taken up to two weeks after picking, Field 30, Auscott Warren.
List of tables

Table 7.1  Depth of water added to wet and moist plots and date of wetting, before passage of cotton picker on 23/4/85, Field 30, Auscott, Warren. 98

Table 7.2  Gravimetric water content of three moisture treatments during passage of pickers, averaged over tillage treatments Field 30, Auscott, Warren, April, 1985. 101

Table 7.3  Change in bulk density corrected to 0.4 kg kg\(^{-1}\) during passage of cotton pickers over two tillage treatments at three moisture contents. 104

Table 7.4  Regressions fitted to shrinkage estimated from specific volume and gravimetric water content from samples collected picker compaction experiment, Field 30, Auscott, Warren. 105

Table 7.5  Regressions fitted to the relationship between air filled porosity and gravimetric water content from samples collected during picker compaction experiment, Field 30, Auscott, Warren. 105

Table 7.6  Maxima, means and minima of air filled porosity and field bulk density of samples collected during picker compaction experiment. Field 30, Auscott, Warren, 1985. 106

Table 7.7  Probability that fitting given term using stepwise regression in two way repeated measures analysis of treatment contrasts to describe changes in profile \(\theta_v\) between two crop irrigations improves model after fitting all preceding terms. Field 34, Auscott, Warren, 1986. 116

Table 7.8  Regression models fitted to the relationship between cumulative profile water capacity from 0 to 1.2 m and time since irrigation during 1 drying cycle (17/2/85 to 28/2/86), Field 34, Auscott, Warren. 116

Table 7.9  Retentivity parameters fitted to field pressure potential values from two tensiometers per plot 0.25 m below the centre of hills, Field 34, Auscott Warren. 117

Table 7.10  Air filled porosity and bulk density measured with 75 mm diameter core samples from 0.25 m below the centre of cotton hills, Field 34, Auscott, Warren. 118

Table 7.11  Air filled porosity and bulk density measured using 75 mm diameter core samples below the centre of cotton hills, 4 days after irrigation, Field 34, Auscott, Warren. 119

Table 8.1  Monthly rainfall at Field 30 Auscott, Warren between harvest of cotton in April, 1985, and planting of the next cotton crop in October, 1986. 127

Table 8.2  Wheat grain yield and grain weight in response to tillage treatments harvested from Field 30, Auscott, Warren, November, 1985. 127
Table 8.3  Cultural operations and pesticide application during 1986/87 cotton crop, Field 30, Auscott, Warren.  

Table 8.4  Effect of tillage treatment and depth of sampling on retentivity parameters fitted to field pressure potential values from four tensiometers per tillage treatment at two depths, Field 30, Auscott, Warren.  

Table 8.5  Change in hydraulic gradient with time for two depth intervals, following furrow irrigation of ripped and direct listed treatments, Field 30, Auscott, Warren, February 1986.  

Table 8.6  Air filled porosity, bulk density and gravimetric water content measured at 0.2 m below the centre of cotton hills, Field 30, Auscott, Warren.  

Table 8.7  Gravimetric water content measured concurrently with penetration resistance, Field 30, Auscott, Warren.  

Table 8.8  Regressions fitted to relationship between penetration resistance and gravimetric water content from samples collected during one drying cycle, Field 30, Auscott, Warren.  

Table 9.1  Per hectare partial budget of tillage treatments based on yields and machinery operation rates for Field 30, Auscott, Warren, 1984 to 1987.  

Table 9.2  Per hectare partial budget for maize and wheat crops based on inputs, yields and machinery operation rates for Field 30, Auscott, Warren, 1985 and 1986.
List of Figures

Figure 1.1 Cotton growing localities of Queensland and New South Wales. 1
Figure 1.2 Average cotton yields, Auscott Ltd., Warren farm. 2
Figure 2.1 Typical moisture-density curve for a medium textured soil, indicating maximum density obtainable with a particular compactive effort. 7
Figure 2.2 Example of pattern of tractor wheel tracks over an area during traditional seedbed preparation. 8
Figure 2.3 Plots of theoretical and exemplar shrinkage lines using the coordinates of specific volume and gravimetric water content. 12
Figure 2.4 Effect of bulk density and soil water suction on penetration resistance of a loam soil. 16
Figure 2.5 The effect of penetrometer resistance on the percentage of cotton tap roots that penetrated through 0.025 m thick cores of four soils. 18
Figure 2.6 Variation in shear strength with moisture content. 20
Figure 2.7 Lint yield of irrigated cotton as a function of a) available water and b) energy input by tillage. 23
Figure 2.8 Custom Prescribed Tillage (CPT). 26
Figure 3.1 The stages of water gain and loss as postulated by Yule and Ritchie (1980a). 29
Figure 3.2 Changes in soil height between wet and dry profiles of Cunnanurra clay, together with soil height adjusted from dry sample to fully swollen height according to the preferred method of Bridge and Ross (1984). 32
Figure 3.3 Idealized semivariograms. 40
Figure 4.1 Field locations and sizes, Auscott Ltd. Warren farm. 45
Figure 4.2 Extent of disturbance for three primary tillage treatments. 49
Figure 4.3 Contour map of Field 30, Auscott, Warren, onto which layout of tillage experiment has been superimposed. 50
Figure 4.4 Wheeling pattern for 6 row machinery (used prior to 1986/87) and 8 row machinery (used in 1986/87). 51
Figure 4.5 Monthly distribution of mean, median and maximum rainfall at Trangie for the period 1886 to 1975. 53
List of figures

**Figure 5.1** Instrumentation on one side of neutron moisture meter access tube during field measurement of soil shrinkage, Field 30, Auscott, Warren, 1987, showing side elevation.

**Figure 5.2** Instrumentation on one side of neutron moisture meter access tube during field measurement of soil shrinkage, Field 30, Auscott, Warren, 1987, showing a) end elevation and b) enlarged detail of the method used to link adjacent horizontal pins using a bicycle brake cable.

**Figure 5.3** Schematic effect of the postulated effect of aggregate surface irregularities resulting in a smaller than expected change in surface height as the soil shrinks.

**Figure 5.4** Diagram of the effect of the location of measurement points within blocks which shrink by 25%, but do not move with respect to one another, on the the change in distance separating the points.

**Figure 5.5** Relationship between gravimetric soil water and specific volume measured at 1·2 m, Field 30, Auscott, Warren, 1985.

**Figure 6.1** Climatic conditions at Field 30, Auscott Warren for 1984/85 season.

**Figure 6.2** Effects fitted by median polish to volumetric water content of nine tillage plots, Field 30 Auscott, Warren.
   a) Depth effect soon after irrigation (30/1/85) and one day prior to irrigation (5/2/85)
   b) Lateral effect 30/1/85

**Figure 6.3** Scatter plot of semivariance of residuals from median polish of θv for each lag along a 520 m long transect in direct list treatment rep 2 on 5/2/85, at seven depths, Field 30 Auscott Warren.

**Figure 6.4** Volumetric soil water measured at two depths, a) 0·4 m and b) 1·0 m before and after irrigation in three tillage treatments. Field 30 Auscott, Warren.

**Figure 6.5** Standard error predicted for neutron moisture meter from data collected at Field 30 Auscott Warren in 1985.

**Figure 6.6** Median elapsed time for water to run from head ditch to tail drain in the central 60 furrows in each plot in second, third, fourth and fifth crop irrigations, Field 30, Auscott Warren.

**Figure 6.7** Resistance to cone penetration in the centre of cotton hills a) two and b) zero days before irrigation due on 5/3/85.

**Figure 6.8** Effect of tillage treatment on production of fruiting structures.

**Figure 7.1** Layout of sampling sites within each 4 m by 4·5 m moisture plot of picker compaction experiment.
List of figures

Figure 7.2 Dimensions of cutting tip of sampling tube used for collection of soil cores in picker compaction experiment.

Figure 7.3 Contours of cone penetration resistance averaged over three insertions at each location beneath a transect across two and a half rows before and after passage of a cotton picker over a vertisol at two soil water contents.

Figure 7.4 Example shrinkage curves obtained during drying in the laboratory of Saran coated cores sampled from 0.35 m.

Figure 7.5 Penetration resistance profiles of soil before and after wheeling by a wheat header at three location, either: a) beneath cotton hills b) furrow wheeled during rowcrop tillage or c) furrow not wheeled during rowcrop tillage.

Figure 7.6 Diagram of location of measurement sites, Field 34, Auscott Warren. 1986.

Figure 7.7 Volumetric soil water as a function of depth and time since irrigation.

Figure 7.8 Models and 95% confidence intervals fitted to treatment contrasts in volumetric soil water content following irrigation by two-way repeated measures analysis.
   a) Crop vs no crop averaged over all depths
   b) Crop vs no crop averaged over all days
   c) Safflower vs wheat averaged over all depths
   d) Safflower vs wheat averaged over all days.

Figure 7.9 Field measured soil water retention curves, with standard deviations, for fallow treatment plot 2, and five other fallow, safflower and wheat plots; measured during a drying cycle between cotton irrigations, Field 34, Auscott, Warren.

Figure 7.10 Observed values and curves fitted by 1-way (depth) repeated measures analysis to
   a) Length of dyed soil per unit length of grid line
   b) Number of intercepts of dyed soil per unit length of grid line.

Figure 7.11 Penetration resistance corrected for gravimetric water content as a function of depth and treatment.

Figure 8.1 Climatic conditions at Field 30, Auscott, Warren for the 1986/87 season.

Figure 8.2 Diagram of layout of measurement sites within each tillage plot, Field 30, Auscott Warren, 1986/87 cotton season.

Figure 8.3 Soil water extraction by maize as indicated by volumetric water content profiles soon after irrigation, and before maize was ploughed in.

Figure 8.4 Gravimetric water content at imposition of tillage treatments, Field 30 Auscott, Warren, March, 1986.
List of figures

**Figure 8.5** Effect of tillage treatments on volumetric water content at a) 0.2 m, b) 0.4 m and c) 0.6 m beneath a cotton crop irrigated on 5/2/87.

**Figure 8.6** Effect of tillage treatments on volumetric water content at a) 0.8 m, and b) 1.0 m beneath a cotton crop irrigated on 5/2/87.

**Figure 8.7** Field water retention curves established in the drying cycle following irrigation on 5/2/87. The water retention curves are for: a) direct list at 0.2 m, b) rip at 0.2 m, c) direct list 0.3 m, d) rip at 0.3 m, e) direct list 1.2 m and f) rip at 1.2 m.

**Figure 8.8** Scatter plot of oxygen flux density against air filled porosity at 0.2 m below the centre of cotton hills, Field 30, Auscott, Warren.

**Figure 8.9** Penetration resistance profiles corrected for gravimetric water content on a) 10/11/86, b) 11/2/87 (six days after irrigation) and c) 17/2/87 (12 days after irrigation), Field 30, Auscott Warren.

**Figure 8.10** Effect of three tillage treatments on production of fruiting structures. Field 30, Auscott Warren, 1986/87 season.

**Figure 8.11** Hand and machine picked cotton lint yield estimates of tillage treatments. Field 30, Auscott, Warren, April, 1987.

**Figure 8.12** Range of non-restrictive, partly and fully restrictive water contents at a) 0.2 m for ripped and direct listed tillage treatments. b) 0.3 m for ripped treatment c) 0.3 m for direct listed treatment.
List of Plates

Plate 4.1 Side view of ripper tine and ripping operation at experimental site. 47
Plate 4.2 Chisel plough tine and chisel plough used to impose experimental treatments. 47
Plate 4.1 Disc plough used after experimental deep tillage. 48
Plate 4.1 Lister forming hill and furrow configuration after deep tillage and disc ploughing. 48
## Abbreviations used

### Greek letters

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Name</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta x$</td>
<td>dry height of layer being sampled</td>
<td></td>
</tr>
<tr>
<td>$\Delta X$</td>
<td>fully swollen height of layer being sampled</td>
<td></td>
</tr>
<tr>
<td>$\varepsilon_a$</td>
<td>air filled porosity</td>
<td></td>
</tr>
<tr>
<td>$\gamma(h)$</td>
<td>semivariance</td>
<td></td>
</tr>
<tr>
<td>$\nu$</td>
<td>specific volume</td>
<td></td>
</tr>
<tr>
<td>$\theta_g$</td>
<td>gravimetric water content</td>
<td></td>
</tr>
<tr>
<td>$\theta_v$</td>
<td>volumetric water content</td>
<td></td>
</tr>
<tr>
<td>$\rho_b$</td>
<td>field bulk density (field volume / oven dry mass)</td>
<td></td>
</tr>
<tr>
<td>$\rho_{ba}$</td>
<td>field bulk density of soil sampled between cracks</td>
<td></td>
</tr>
<tr>
<td>$\rho_{b\text{min}}$</td>
<td>field bulk density of fully swollen soil</td>
<td></td>
</tr>
<tr>
<td>$\rho_s$</td>
<td>particle density</td>
<td></td>
</tr>
<tr>
<td>$\sigma^2$</td>
<td>population variance</td>
<td></td>
</tr>
<tr>
<td>$\psi_e$</td>
<td>soil water air entry potential</td>
<td></td>
</tr>
<tr>
<td>$\psi_m$</td>
<td>soil water matric potential</td>
<td></td>
</tr>
<tr>
<td>$\psi_\Omega$</td>
<td>soil water overburden potential</td>
<td></td>
</tr>
<tr>
<td>$\psi_p$</td>
<td>soil water pressure potential</td>
<td></td>
</tr>
</tbody>
</table>

### Latin letters

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Name</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1D</td>
<td>subscript meaning; corrected for unidimensional shrinkage</td>
<td></td>
</tr>
<tr>
<td>3D</td>
<td>subscript meaning; corrected for three dimensional shrinkage</td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>coefficient from curve fitting</td>
<td></td>
</tr>
<tr>
<td>ANOVA</td>
<td>analysis of variance</td>
<td></td>
</tr>
<tr>
<td>AWC</td>
<td>available water content</td>
<td></td>
</tr>
<tr>
<td>b</td>
<td>coefficient from curve fitting</td>
<td></td>
</tr>
<tr>
<td>c</td>
<td>neutron counts</td>
<td></td>
</tr>
<tr>
<td>CEC</td>
<td>cation exchange capacity</td>
<td></td>
</tr>
<tr>
<td>CNSD</td>
<td>conditional, negative, semidefinite</td>
<td></td>
</tr>
<tr>
<td>DAI</td>
<td>days after irrigation</td>
<td></td>
</tr>
<tr>
<td>e</td>
<td>void ratio</td>
<td></td>
</tr>
<tr>
<td>EC</td>
<td>electrical conductivity</td>
<td></td>
</tr>
<tr>
<td>ESP</td>
<td>exchangeable sodium percentage</td>
<td></td>
</tr>
<tr>
<td>$\text{ET}_0$</td>
<td>evapotranspiration from a reference crop</td>
<td></td>
</tr>
<tr>
<td>$H$</td>
<td>hydraulic gradient</td>
<td></td>
</tr>
<tr>
<td>$K_{\text{sat}}$</td>
<td>saturated hydraulic conductivity</td>
<td></td>
</tr>
<tr>
<td>LPL</td>
<td>lower plastic limit</td>
<td></td>
</tr>
<tr>
<td>m</td>
<td>material coordinate</td>
<td></td>
</tr>
<tr>
<td>MANOVA</td>
<td>multivariate analysis of variance</td>
<td></td>
</tr>
</tbody>
</table>
Abbreviations used

MRE  mean relative error
m_s  mass of solids for each depth interval
M(z)  mass coordinate
n  count rate ratio, also used to indicate the number of samples
NLWR  non-limiting water range
OFD  oxygen flux density
P.  probability
PAWC  plant available water content
PVC  polyvinyl chloride
r  correlation coefficient
r^2  coefficient of determination
SAR  sodium adsorption ratio
s^2  sample variance
s_d  sample standard deviation
s_e_{y|x}  standard error of estimate of Y for fixed X
TSS  total soluble salts
UPL  upper plastic limit
x  conventional scale of physical length
Z  depth
Abstract

Declining cotton yields led to doubts about the long term viability of irrigated cotton growing in the lower Macquarie Valley, N.S.W., only 10 years after the industry was established. Soil limitations to cotton growth were implicated as the main reason for the yield decline in the absence of insect and disease outbreaks. Following unsuccessful screening for soil chemical deficiencies, soil physical conditions were studied. A series of experiments have since shown that poor soil physical conditions in Macquarie Valley vertisols can be improved by using crops to dry the soil, deep tillage and gypsum.

The next step, which this project addresses, is to study soil management systems which minimize degradation of soil physical conditions. Aims of this project were to:

i) Assess the viability of the permanent bed system for irrigated cotton production in which the hills on which cotton is grown are left in the same place for a number of years. This was done by comparing soil physical properties and cotton growth on areas prepared using conventional seedbed preparation in which the hills are knocked down and reformed each year with areas of cotton under permanent beds.

ii) Study cotton growth in response to a range of soil physical conditions created by different tillage systems, and the relationship between cotton growth and some measures of soil physical condition. From these relationships, we should gain a clearer picture of how deep tillage ameliorates poor soil structure, and also how it can cause the yield depression observed in some prior experiments.

iii) Combine information from this project with other, similar, projects, to establish guidelines to predict which soil management practices are best suited to a given situation.

The main part of the project was a field experiment, monitored over two and a half years. Three tillage treatments, ripping to 0.45 m, chisel ploughing to 0.25 m, and a permanent bed system were imposed in a randomized complete block design with three blocks (replicates) at the start of the trial in May, 1984. Cotton, wheat, and maize crops were grown over the next two years, then deep tillage treatments were reimposed prior to a second cotton crop.

Soil swelling, and neutron moisture meter and gamma density meter calibrations

Because of the importance of swelling to the physical behaviour of vertisols and weaknesses in the current methods of accounting for swelling, an experiment was undertaken to examine the nature of swelling in the field, and its relation ship to swelling in the laboratory. Field shrinkage measured at 0.2 and 0.3 m using swelling pins was much less than expected from extrapolation from laboratory results. Field shrinkage measurements indicate that the errors introduced to water content measurement by ignoring swelling are no greater than those introduced by sources such as relocation error in placement of the neutron moisture meter source in the access tube. Consequently, little accuracy (3-5% error only) would be lost at this site by ignoring swelling in neutron moisture meter calibrations. Errors in the measurement of soil water and air filled porosity introduced by swelling increase with depth, especially beyond the depths monitored closely in this experiment. However, the importance of these errors is reduced by the decreasing range of water content measured with increasing depth.

As the neutron moisture meter was widely used in measurement of soil water in the current study, a neutron moisture meter was calibrated at the experimental site. The use of corrections for changes in density did not improve the precision of the neutron moisture meter calibration, and led to
only a small increase in accuracy. The use of shrinkage models was only beneficial when applied to specific situations such as the determination of air filled porosity. It was thus recommended that the calibration of neutron count rate ratio on volumetric water content be used to predict soil water content in preference to calibrations using shrinkage models.

Prediction of air filled porosity was improved by the use of the 3-dimensional shrinkage model. The simplest means of determining air filled porosity corrected for 3-dimensional shrinkage ($\varepsilon_{a3D}$) was from the gravimetric water content calibration rather than a separate $\varepsilon_{a3D}$ calibration, and should be used.

A gamma density meter was also calibrated at the experimental site. The gamma density meter was a poor predictor of soil field bulk density. The neutron moisture meter provided a more precise density calibration, and should be sufficiently accurate if measurements are taken at each field site to check the calibration.

**Crop growth and soil physical conditions in the 1984/85 cotton season**

In the 1984/85 season, no yield penalty was suffered by planting cotton into permanent beds formed by direct listing compared to the two alternative seedbed preparation methods where beds were knocked down and reformed.

The few statistically significant differences between treatments detected in this season differences indicated better soil conditions in the ripped than direct listed plots. However, under the prevailing climatic and management regimes, cotton plants did not appear to exploit the more favourable soil conditions in the ripped plots.

Improvements in methods of evaluating soil conditions over those used in the 1984/85 season were needed to quantify differences between tillage treatments. To estimate the degree and duration of waterlogging, increased emphasis should be given to conditions soon after irrigation.

Effectiveness of sampling techniques used in the first cotton season was tested using geostatistical techniques and classical statistics. The geostatistical analysis showed small variability across the field, which means that neutron moisture meter access tubes need not be any further apart than the separation distance used in the analysis (26 m) while, because of the strong correlation of volumetric water content between depths, readings should be separated by at least 0.2 m depth. Classical statistics showed that only one neutron moisture meter reading need be taken per depth unless very high precision is required. Subject to the constraints imposed by the design of this experiment, the sensitivity of penetration resistance in detecting treatment differences would be increased by making insertions much further than 1 m apart, whilst remaining sufficiently close to access tubes to obtain associated moisture measurements.

**Evaluation of methods for measurement of soil physical properties in vertisols**

The few differences in soil properties detected in the 1984/85 season suggested a need to test whether differences in soil properties affecting cotton growth could be better identified by using additional indicators or better use of current indicators. Two studies, the first of which aimed to assess the effect of wheel passage at different water contents on soil structure, were undertaken between harvest of the 1984/85 cotton crop and planting of the 1986/87 crop. In the first study, penetration resistance, but
not field bulk density, proved to be a useful indicator of structural degradation in response to picker and header wheelings. The small response of bulk density was attributed to aggregate deformation rather than volume change being the main form of structural degradation in vertisols.

The critical subsurface soil water content for structural degradation in response to header or picker wheeling in this soil lies between 0.14 and 0.21 kg kg\(^{-1}\). This is drier than 0.23 kg kg\(^{-1}\), the lower plastic limit of the soil.

In the second study, a number of indicators of soil physical condition were used to monitor changes in soil physical condition over a 12 day period after irrigation of a cotton crop planted to evaluate three rotation practices-safflower and wheat crops, and a bare fallow in which weeds were controlled by disc ploughing. The indicators of soil physical condition used were: measurement of air filled porosity and oxygen flux density in core samples; measurement of an *in situ* water retention curve with tensiometers; assessing pore continuity with a dye infiltration technique; penetration resistance as an indicator of soil strength; and water content.

Apart from water content, all indicators of soil structure used in this study were able to differentiate between fallow, wheat and safflower treatments to a depth of 0.25 m. Of the techniques used, a combination of core sampling to measure air filled porosity together with the penetrometer was best able to define structural conditions relevant to root growth down the profile. This conclusion was supported by the greater sensitivity of penetration resistance than bulk density measurement as an indicator of structural degradation caused by wheel passage. The dye infiltration technique provided consistent data, but was more laborious. Tensiometers provided a useful adjunct to other methods of characterizing soil physical properties, although their value is limited by large demands on time, and sensitivity to installation and maintenance.

Suspicion of extended periods of waterlogging following irrigation in the 1984/85 season were confirmed by the results of this experiment. However, the observed waterlogging did not appear to markedly restrict water uptake.

It was concluded that techniques to measure aeration status described here would be used in the 1986/87 growing season. Tensiometers would also be installed despite their drawbacks, as they would enable the determination of hydraulic gradients, hence give information on the direction of water flow in the soil. Rhodamine dye infiltration has provided information on the effects of structural degradation on water flow, and would be used on a limited scale.

*Crop growth and soil physical conditions 1985 to 1986/87 cotton season*

Selective measurements taken during the wheat crop grown between the two cotton crops. All tillage treatments had similarly low wheat yields, which were attributed to moisture deficit and nitrogen deficiency stress. Due to the lack of data and the absence of comparative treatments, no partitioning of the yield depression between these two factors was possible.

Permanent beds established using direct listing were the highest yielding plots in the 1986/87 season. There is little doubt that this form of permanent beds is viable for at least four years after the beds are established, provided the direct listing is carried out under a favourable moisture regime.

Waterlogging, and not high soil strength, was the main soil physical constraint to cotton growth in this experiment. Yield depression in the ripped areas was attributed to a longer duration of waterlogging compared to chiselled or direct listed areas.
The measures of physical properties used in the 1986/87 season were able to account for the yield differences between tillage treatments. The next step in differentiating the physical properties of vertisols subjected to a range of tillage treatments is to assess the plant available water capacity of these soils. The practice of watering the whole experiment when one plot shows signs of water deficit stress needs to be abandoned in favour of separating the experiment into at least two groups for irrigation scheduling.

Conclusions

The project has shown that permanent beds formed by direct listing are a viable means of cotton production. Other research has shown that good soil structure, essential to the longevity of permanent beds, can be maintained by avoiding traffic on wet soil, and utilizing the ability of plants to ameliorate structural degradation as they crack the soil by drying it.

Deep tillage increases soil porosity and disrupts the continuity of impermeable layers near the soil surface. Deep tillage will improve cotton production if it disrupts these layers, and subsequent management protects the porosity created by deep tillage, and utilizes the improved plant available water content of the deep tilled soil. As no impermeable layers were present near the soil surface in the present experiment, deep tillage did not improve cotton production.

Waterlogging is the main soil physical limitation to cotton production in vertisols. Measurement of soil physical differences between imposed treatments in irrigated vertisols must include an assessment of the degree and duration of waterlogging in the treatments. In addition, the non-limiting water range of treatments should be fully assessed, by measuring the extent to which plants can dry soil before soil strength restricts root extension or water potential reduces water supply to the level where plants suffer water deficit stress.