CHAPTER 8

CROP GROWTH AND SOIL PHYSICAL CONDITIONS 1985 TO 1986/87 COTTON SEASON

8.1 INTRODUCTION

Small differences in soil properties and plant growth between tillage treatments which were observed during the 1984/85 season, as described in Chapter 6, showed that the use of permanent beds did not involve a loss of productivity, at least over a period of two years. The 1984/85 results suggested more favourable conditions in the ripped soil. Questions arose regarding the suitability of current methods for detecting tillage treatment differences. Evaluation of experimental methods between the 1984/85 and 1986/87 seasons, outlined in Chapter 7, indicated some deficiencies in methods previously used. Improved techniques such as measurement of aeration status using oxygen flux density measurement, tensiometers, and core measurement of air filled porosity (ε_a), in combination with previously used techniques such as neutron moisture meter and penetrometer, were used during the 1986/87 season to improve the sensitivity in detecting tillage treatment differences.

Continued monitoring of the experiment in the 1986/87 season should provide information on the effective lifetime of the permanent bed system under direct listing and on the need for deep tillage. Favourable conditions for root growth would be maintained in the absence of deep tillage if the ameliorative process of cracking during soil shrinkage (Section 2.4.1) was able to overcome degradation caused by continued wheel passage, irrigation and tillage (Section 2.2). As outlined in Section 2.4.2, maintenance of soil conditions suitable for root growth in the absence of tillage is aided by separation of the rootbed from wheel traffic areas afforded by the rowcrop farming system. While roots grow throughout the soil the rootbed, in which optimal conditions for root growth are desired, is beneath the hills, and the wheel traffic areas are in the furrows. This separation means that structural degradation beneath wheeled areas, measured in Section 7.2, should not reduce plant growth unless roots are 'boxed in' by degraded soil (Trouse, 1983).

This chapter is mainly concerned with soil conditions and cotton growth during the 1986/87 cotton season. In between the cotton crops of 1984/85 and 1986/87 two other crops were grown on the experimental site. These were: (i) wheat to reduce buildup of Verticillium wilt; (ii) maize grown in an attempt to dry the soil in part of the experimental site when rain during wheat maturation and after harvest had left the soil wet to at least 1 m.

8.2 WHEAT CROP : 1985

8.2.1 Introduction

An infection of Verticillium wilt, a fungal disease caused by *Verticillium* sp., was observed in the experimental field during growth of the 1984/85 cotton crop. Further buildup of the disease was considered likely, due to infection levels as high as 75% of plants occurring in some fields on the Auscott Warren farm (Allen, 1984). As rotation of the cotton crop with small grains reduces losses from Verticillium in subsequent cotton crops (Presley and Bird, 1968), wheat was grown after harvest of the 1984/85 cotton crop.

Little effort was devoted to monitoring soil conditions and crop response during the wheat crop as porosity changes resulting from deep tillage are believed to be transient (Section 2.4.1), and no porosity changes due to tillage were detected in the preceding cotton crop (Chapter 6). Consequently, the small differences in physical properties found in the 1984/85 cotton season would be expected to diminish as a result of the uniform cultivation treatment applied across all plots after imposition of the tillage treatments.

8.2.2 Materials and methods

Wheat cv. 'Banks' was planted on 23/5/85 at 30 kg ha^{-1} at a depth of 0·02 m below the soil surface into cotton hills, which had received no preparatory cultivation. The planter had rigid planting tines spaced at 0·25 m, but no other tines. A starter fertilizer was applied at the time of planting. Cotton stalks were slashed above ground level in early July, after wheat emergence.

The water regime under which the wheat crop grew severely limited growth. Soil water content was low at the harvest of the cotton crop preceding the wheat crop. Gravimetric water content (θ_g) at this time was 0·19 kg kg^{-1} or lower to a depth of 0·45 m (Table 7.2), and the soil strength much too high to use a penetrometer (penetration resistance > 4 MPa), indicating that the soil was too strong for root growth. Water supply to the wheat crop was thus restricted to rainfall after cotton picking and possible soil water reserves at depths greater than 0·45 m until an irrigation was applied 17 weeks after planting. Rainfall of 144 mm from planting until the end of September (Table 8.1) was adequate to keep the wheat alive, but not growing vigorously. The crop was irrigated on 25/9/85, but water deficit stress suffered prior to this limited final crop yield.

Two sets of measurements were taken during growth of the wheat crop. Plant density was estimated 34 days after planting by counting the number of emerged seedlings in 2 m of a row at each of 10 locations in a transect from the head ditch to the tail drain in each of the 9 tillage plots. At each location, counts were taken in plant lines 0·13, 0·28, 0·63, and 0·88 m from the centre of the six row set (Appendix 2), giving two counts each side of a hill adjacent to a furrow wheeled during rowcrop tillage.

Grain yield, estimated by the grain harvested with a wheat header from a 24 m wide strip running from the head ditch to the tail drain in the centre of each plot, was also measured. Subsamples of the grain harvested from each plot were collected to determine water content, and grain weight.

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

	Year	
Month	1985	1986
January		52·5
February		12·0
March		0·0
April		0·0
May	21·5	25·5
June	34·0	2·5
July	4·0	0·0
August	68·8	69·0
September	15·5	25·3
October	59·0	
November	69·5	
December	57·0	

8.2.3 Results

Analysis of variance showed that no treatment differences in emergence, yield, and grain weight were statistically significant. Wheat plant density 34 days after planting was 719 000 plants ha^{-1}, the average grain yield was low at 1380 kg ha^{-1}, as was the average grain weight of 29.8 mg (Table 8.2).

Table 8.2 Wheat grain yield (kg ha^{-1}) and grain weight (mg) in response to tillage treatments harvested from Field 30, Auscott, Warren, November, 1985.

Treatment	Grain yield	Grain weight
Direct list	1435	30·2
Rip	1424	30·1
Chisel	1286	28·7
5% l.s.d.	302	2·8

8.2.4 Discussion

The lack of treatment differences in wheat yields in this experiment were not unexpected in view of the transient nature of changes brought about by deep tillage (Loveday *et al.*, 1970; Soane *et al.*, 1986). The grain yield of 1380 kg ha^{-1} was low compared to an average 3000 kg ha^{-1} for irrigated wheat crops in the central west region of NSW, which includes the study site, (Powell *et al.*, 1985).

The poor wheat yield seemed likely to be due to water deficit and nitrogen deficiency stress. In the absence of measurements of nitrogen status during growth of the wheat crop, evidence of nitrogen stress is only circumstantial. However, in a vertisol at Narrabri, Hearn (1986) showed that grain yield of wheat grown in rotation with cotton increased with increasing application rates from 0 to 120 kg N ha^{-1}. Therefore, the 7 kg N ha^{-1} applied to the wheat crop in this experiment was in all probability well below that required for maximum wheat grain yield. Partitioning the low grain yield between nitrogen and water stress in this experiment is impossible in the absence of comparative treatments and of measured plant water and nitrogen status. The measured grain weight also sheds little light on the cause of the poor grain yield, as Whitfield and Gyles (1986) have shown that both nitrogen and water stress can reduce grain weight to the levels measured in this experiment.

The established wheat density of 719 000 plants ha^{-1} is lower than the 1 700 000 plants ha^{-1} recommended by Stapper (1986) for high yielding wheat crops in southern NSW. However, Fawcett (1964) has shown that low plant densities, similar to those measured in this experiment, give optimal grain yields when water supply is restricted. Other cultural practices, such as planting and harvesting dates, and weed control, were in accordance with recommendations for irrigated wheat growing in the region.

8.2.5 Conclusions

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.

Although the low plant density established was below that recommended for maximum biological yield, it was consistent with cotton growers' aim of using limited inputs of irrigation water and nitrogen fertilizer when growing crops in rotation with cotton. This low density would restrict potential yield if application of irrigation water and nitrogen fertilizer were increased.

8.3 COTTON CROP : 1986/87

8.3.1 Introduction

The high water content following harvest of the 1985 wheat crop, when θ_g was 0·26 kg kg^{-1} or higher at 0·35 to 0·45 m depths (Section 7.2.3.2), increased further when 127 mm of rain fell in the month following wheat harvest in mid-November. The soil surface at this time was too wet to carry crawler tractors. In the absence of actively transpiring plants on the field, it was felt that it was unlikely that the soil would dry to the lower plastic limit of 0·23 kg kg^{-1} prior to imposition of tillage treatments planned in January, and would thus be susceptible to structural degradation (McGarry, 1987). In addition, soil structural degradation caused by the wheat header (Section 7.2) reduced the suitability of the soil for root growth, and would test the effectiveness of the tillage treatments in ameliorating structural degradation. A set of circumstances existed to superimpose treatments of wet and dry soil conditions during the imposition of tillage treatments over the main experiment. In January, 1986 maize was planted on half of each tillage plot in an attempt to create two moisture regimes during reimposition of tillage treatments.

Both the temporal and spatial sampling strategies used in the 1986/87 cotton crop differed from those used previously as a result of knowledge gained during the first cotton crop (Chapter 6), and from the testing of experimental methods in the intervening period described in Chapter 7. Samples would be taken from a small zone in each plot rather than over the whole plot, aeration status soon after irrigation would be closely monitored, and measurement of penetration resistance in the four days before irrigation maintained.

8.3.2 Materials and methods

The overall design of the trial, and the cultural practices used in managing the experimental crops, are described in Section 4.3. Description in this section is limited to aspects specific to the 1986/87 cotton season. All measurements were confined to the measurement strip indicated in Figure 4.4.

Imposition of maize and tillage treatments

A seedbed was prepared for the maize crop by pulling loose soil to the top of cotton hills with go devils (Appendix 2). At this time the surface soil had dried to the extent that no structural damage was apparent during maize seedbed preparation. The soil loosened by the go devils was compacted and broken down with a cultipacker, then 12·7 kg ha^{-1} maize, cv. 'Colonel', was planted 0·02 m deep into dry soil, which was irrigated on 8/1/86 to initiate growth. No fertilizer was applied to the crop, but inter-row cultivation occurred on 30/1/86, and the maize was irrigated on 12/2/86. Maize grain was not harvested, but the crop was slashed on 2/4/86, shortly before reimposition of the tillage treatments. Little rain fell between planting and harvest of the maize.

Water depletion under the maize crop was estimated from neutron moisture meter readings in three access tubes in one plot. Maize dry matter production was estimated by harvesting five, 1 m row lengths along a diagonal of the measurement zone of Figure 4.4. Samples were dried to constant weight at 80°C.

Tillage treatments, described in Section 4.2, were reimposed on 2nd and 3rd April, 1986.

Gravimetric soil water content was measured at five locations within the measurement zone in all 18 plots. Gravimetric, rather than volumetric, soil water content was measured at this time as it was far cheaper to use gravimetry than the neutron moisture meter for one moisture determination. Samples were taken from 0·1, 0·2, 0·3, 0·4, 0·5, 0·6, and 0·8 m depths in holes below the centre of a cotton hill, transported to the laboratory for determining θ_g.

Management summary

The 1986/87 season was less favourable for cotton growth than the 1984/85 season, yields on the farm surrounding the experimental site being 30% lower than in the 1984/85 season (Figure 1.2). The 1986/87 season was wetter, had a longer period of minimum temperatures below 10°C at the start of the season, and more frequent minima above 20°C and maxima above 35°C than in the 1984/85 season (Figures 6.1 and 8.1), all of which are detrimental to vigorous cotton growth (Thomson, 1979).

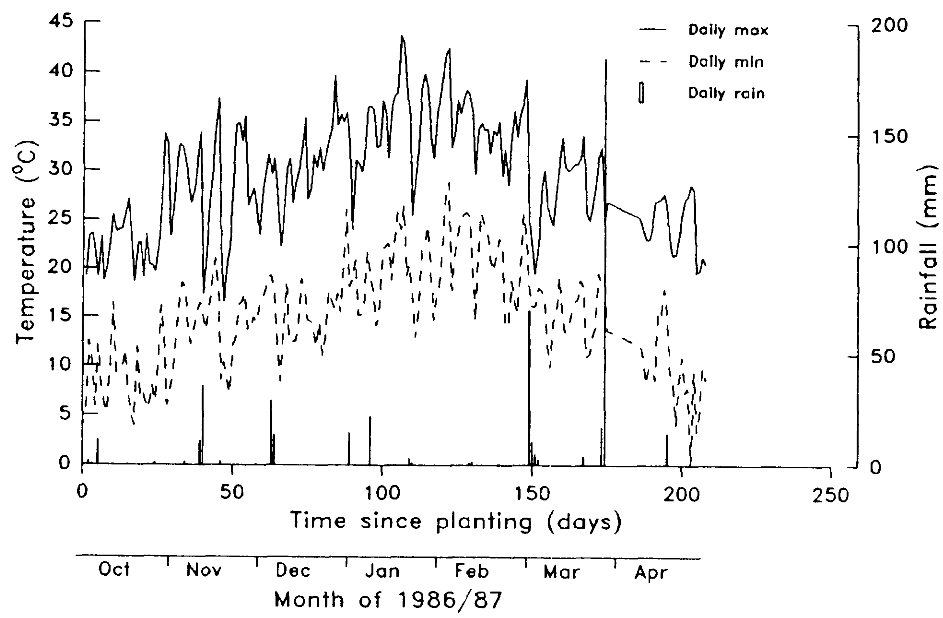


Figure 8.1 Climatic conditions at Field 30, Auscott, Warren for the 1986/87 season.

The experimental crop was planted on 5/10/86, and irrigated to initiate germination on 7/10/86. Three passes of wheeled machinery were made over the field between planting and picking, one for insecticide application, and two interrow cultivations. The field received 12 insecticide applications, and five furrow irrigations during the growing season (Table 8.3).

To determine the rate of nitrogen fertilizer application, five samples from 0 to 0·3 m depth were collected from each plot and then bulked. A subsample was extracted with water and nitrate determined colorimetrically. The mean nitrate nitrogen level was 6·2 ppm and no significant treatment

Table 8.3 Cultural operations and pesticide application during 1986/87 cotton crop, Field 30, Auscott Warren (Ground and Aerial refer to chemical application methods).

Date	Operation	Chemical	Rate
1986			
2-7/4 Tillage treatments imposed			
3/6	Cultivator	Trifluralin	4·3 l ha^{-1}
23/7	Cultivator		
4/9	Cultivator	Diuron	0·6 kg ha^{-1}
		Fluometuron	0·6 kg ha^{-1}
5/10	Lilliston		
5/10	Planting	Fluometuron	1·8 l ha^{-1}
7/10	Irrigation		
28/10	Aerial insecticide	Endosulfan	2·5 l ha^{-1}
7/11	Cultivator		
28/11	Ground insecticide	Endosulfan	2·1 l ha^{-1}
		Methomyl	0·5 l ha^{-1}
4/12	Aerial insecticide	Endosulfan	3·0 l ha^{-1}
		Methomyl	0·5 l ha^{-1}
12/12	Aerial insecticide	Thiodocarb	2·1 l ha^{-1}
18/12	Aerial insecticide	Endosulfan	3·0 l ha^{-1}
	First crop irrigation		
29/12	Aerial insecticide	Endosulfan	3·0 l ha^{-1}
1987			
2/1	Cultivator		
3/1	Second crop irrigation		
8/1	Aerial insecticide	Endosulfan	3·0 l ha^{-1}
		Methomyl	0·5 l ha^{-1}
21/1	Aerial insecticide	Profenofos	3·0 l ha^{-1}
	Third crop irrigation		
26/1	Aerial insecticide	Cyhalothrin	3·0 l ha^{-1}
5/2	Fourth crop irrigation		
6/2	Aerial insecticide	Profenofos	1·5 l ha^{-1}
11/2	Aerial insecticide	Profenofos	1·5 l ha^{-1}
19/2	Fifth crop irrigation		
7/3	Aerial insecticide	Profenofos	1·0 l ha^{-1}
15/4	Aerial conditioner	Def	1·0 l ha^{-1}
24/4	Aerial desiccant	$NaClO_3$	15 l ha^{-1}
30/4	Cotton picking		

differences existed. This value, combined with the cropping history of the field, from the criteria developed by Hearn (1986) for nitrogen fertilizer requirement for irrigated cotton confirmed that the 80 kg N ha^{-1} applied to the field in July, 1986 was optimal for cotton production.

Water content

Aluminium access tubes, 50 mm in diameter, were installed one month after planting of the cotton crop in hills adjacent to furrows which had been wheeled since 1983 (Figure 4.4). This location was selected as the soil beneath these hills was expected to contain the largest range of physical conditions between ripped and direct listed treatments. Soil water content was determined at 0·2, 0·4, 0·6, 0·8, 1·0, and 1·2 m depths below the centre of cotton hills in seven locations in each of the 18 plots by taking single 15 s readings with the Campbell Pacific Nuclear 503 neutron moisture meter described in Section 5.3 and using the calibration described in Section 5.3. Three access tubes were placed 26 m apart, a separation determined after geostatistical analysis (Section 6.3), in two hills in each plot (Figure 8.2). The distance between hills monitored ranged from 14 to 24 m, and was determined by the need for hills to be adjacent to furrows wheeled by both 6 and 8 row machinery (Figure 4.4; Section 4.3). The remaining access tube, installed to sample short range lateral variation in volumetric water content (θ_v), was placed 1 m from the easternmost access tube in the more northern of the 2 rows sampled in each plot.

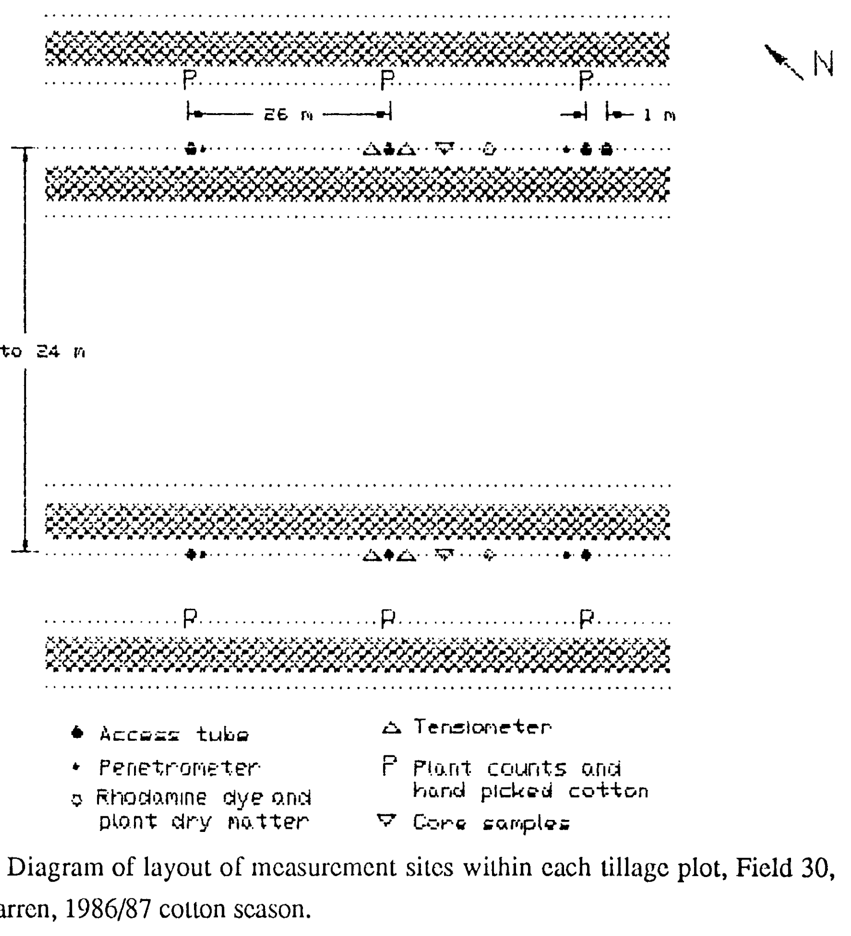


Figure 8.2 Diagram of layout of measurement sites within each tillage plot, Field 30, Auscott Warren, 1986/87 cotton season.

Neutron moisture meter readings were taken at fortnightly intervals from access tube installation until the first crop irrigation. At least three sets of readings were then taken between each crop irrigation, the first as soon as the soil was trafficable after irrigation, the second a week later, and the third one day before crop irrigation. In addition, daily readings were taken between irrigations on 5/2/87 and 19/2/87. Following the final crop irrigation on 19/2/87, readings were taken at fortnightly intervals until desiccant was applied to the crop on 24/4/87.

Water potential

Pairs of tensiometers were installed with their 17·5 mm diameter cups 0·2 and 0·3 m below the centre of cotton hills, and 0·2 m from the central neutron moisture meter access tube in both rows sampled in all three replicates of the ripped minus maize, and direct list minus maize treatments (Figure 8.2). These tensiometers were installed in conjunction with the swelling gauges described in Section 5.2.2, and their location is shown in Figure 5.2.1. Additional tensiometers were installed with their cups 1·2 m below the centre of the hill adjacent to 6 of the 12 neutron moisture meter access tubes instrumented with tensiometers and swelling gauges. Pressure potential (ψ_p) in all tensiometers was recorded daily between irrigations on 5/2/87 and 19/2/87. Concurrent moisture measurement was obtained with the neutron moisture meter.

In addition to the computations described in Section 7.3.2, hydraulic gradient (H) between the tensiometers was calculated as:

$$H = (\psi_{p_a} - \psi_{p_b} + z) / z \qquad 8.3.1$$

where ψ_{p_a} and ψ_{p_b} are ψ_p for the shallow and deep tensiometers respectively, and z is the vertical distance between tensiometers.

Oxygen flux density and core measurement of solid, air and water relations

Core samples were taken according to the method of McIntyre and Barrow (1972), using thin walled sampling tubes with an internal diameter of 75 mm. Two adjacent cores were taken 0·2 m below the centre of the hill within 5 m of the two central neutron moisture meter access tubes in each plot of the direct list minus maize, and ripped minus maize treatments (Figure 8.2), 4, 7, 11 and 13 days after the irrigation on 5/2/87. In addition, a total of two cores were sampled at 0·3 m on each sampling date. The cores were sealed in plastic bags for transport to the laboratory.

Oxygen flux density (OFD) was measured on each core using the method of Hodgson (1986), adapted from Taylor (1949). Following OFD measurement, the cores were weighed, weight loss being negligible during the 10 minute OFD measurement period, dried to constant weight at 105^{o}C, and reweighed for determination of solid, air, and water ratios.

Dye infiltration

The dye infiltration technique described in Section 7.3 was used at two locations in one plot of both the ripped minus maize and direct list minus maize treatments on 9/2/87 after the soil had been wet up by irrigation on 5/2/87 (Figure 8.2). Measurement was abandoned after these two plots when no obvious treatment differences were observed between these plots.

Penetration resistance

A 'Rimik' recording penetrometer, described in Section 6.2, was used to measure penetration resistance at 15 mm intervals to a depth of 0·45 m. Three insertions per access tube site, all on hills within 3 m of access tubes, were averaged to provide a strength profile adjacent to four of the access tubes in each plot (Figure 8.2) 6, 10 and 12 days after irrigation on 5/2/87. A series of measurements at a range of water contents was attempted before the first crop irrigation, but only one complete set of measurements was recorded as the penetrometer repeatedly malfunctioned.

Gravimetric water content was recorded concurrently with penetration resistance. Soil samples were collected from 0·03 and 0·1 m depths, and placed in airtight jars for determination of θ_g in the laboratory. Gravimetric water content was determined at 0·2, 0·3 and 0·4 m depths with the neutron moisture meter, and using calibration equations presented in Table 5.3.3.

Plant growth and yield

Counts of emerged seedlings were taken within the measurement zone of each plot on 27/10/86, from 6, 5 m long sections of row adjacent to wheeled furrows and one row away from neutron moisture meter access tubes (Figure 8.2), as it was expected that treatment differences between direct list and ripped treatments would be greatest adjacent wheeled furrows. Measurement of numbers of fruiting structures was made at approximately fortnightly intervals from 2/12/86 until leaf fall was induced by a chemical conditioner on 15/4/87. Fruit counts were taken from six, 0·75 m long sections of row within the area from which seedling counts had been taken. Each set of fruit counts was taken from the same plants. The height of these plants was measured simultaneously until 27/2/87. Plant height and the stage of fruit development were determined according to procedures outlined in Section 6.2.

Dry matter production of each plot was estimated by harvesting plants from 1 m of row midway between the two easternmost neutron moisture meter access tubes in both rows in which access tubes were placed (Figure 8.2) at peak flowering on 5/2/87. Plant samples were dried to constant weight at 80^{o}C before being weighed. After weighing, the samples were ground to pass through a 2 mm screen before nitrogen content was determined using infra red spectroscopy (Hymowitz *et al.*, 1974).

Plant yields were measured in two ways. Seed cotton (lint and cotton seed) was hand picked four days prior to machine harvest from 12, 0·75 m lengths of row in each plot. The samples were taken from the row length from which fruit counts had been taken throughout the season, and an adjacent length of the same row. This yield comparison of adjacent sections of the same row was undertaken to test whether the damage to cotton plants whilst taking fruit counts had affected cotton yield. Machine-picked seed cotton from the whole of each plot was also measured. Lint yield and gin turnout (ratio of lint to seed cotton) of the machine harvested sample were measured. Each cotton bale was classified commercially by Auscott Ltd. in terms of grade, colour, and micronaire of the lint (for definition of terms see Appendix 2).

Statistical analyses

The statistical significance of differences in treatment means was determined using analysis of variance (ANOVA) and a split plot design, with tillage treatments as main plots in a randomized complete block design, and maize as the split plot. Covariate analysis of penetration resistance with θ_g

was conducted when ANOVA showed statistically significant treatment differences in θ_g.

Linear regression was used to model the relationship between penetration resistance and θ_g for data collected in the interval between irrigations on 5/2/87 and 19/2/87. A linear rather than a curvilinear model was used as a scatter plot of penetration resistance and θ_g showed only a linear relationship over the range sampled. Linear regression and a logarithmic model was used to describe relations between water potential and water content, further details of which are given in Section 7.3. A 2-stage linear regression model was fitted to the relationship between OFD and ε_a.

8.3.3 Results

Maize crop and imposition of tillage treatments

The maize crop extracted at least 0·075 m^3 m^{-3} water at each measured depth from 0·2 to 0·8 m (Figure 8.3). Water extraction was markedly less below 0·8 m, being less than 0·01 m^3 m^{-3} at 1·0 and 1·2 m. However, substantial water was also lost from the plots with no maize. Water loss from the plots without maize, and the addition water to the maize plots by irrigation led to a lower water content of the plots without maize at 0·1 to 0·3 m compared with the maize treated plots at the time of the imposition of tillage treatments in April, 1986 (Figure 8.4). The soil in all treatments was drier than the plastic limit of 0·23 kg kg^{-1} to 0·5 m, the greatest depth of tillage. Average dry matter production of maize was low at 2610 kg ha^{-1}, with no significant treatment differences recorded.

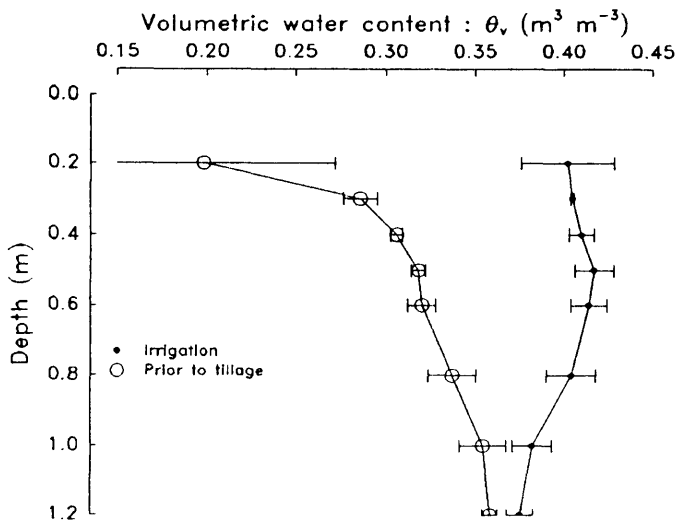


Figure 8.3 Soil water extraction by maize as indicated by volumetric water content profiles soon after irrigation, and before maize was ploughed in. Data were obtained from three neutron moisture meter access tubes in one plot, Field 30, Auscott, Warren (Bars are twice s.d.).

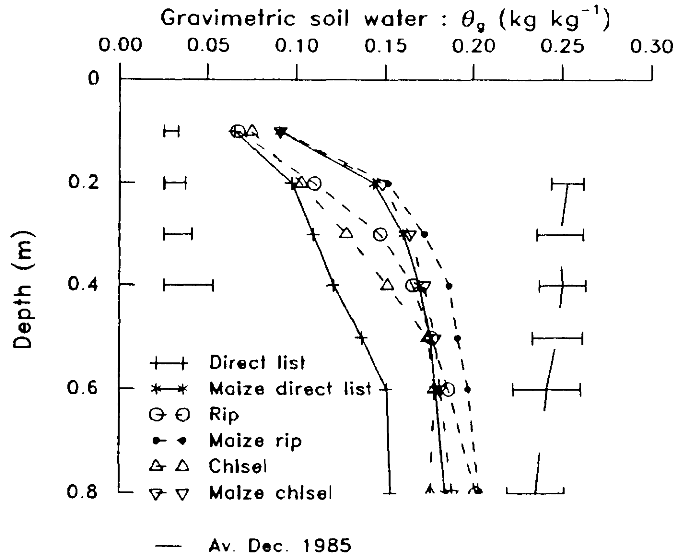


Figure 8.4 Gravimetric water content at imposition of tillage treatments, Field 30 Auscott, Warren, March, 1986.

Water content

Many differences in θ_v were statistically significant, although no treatment differences were measured at 0·2 m. Tillage treatment differences at 0·4, 0·6, 0·8, 1·0, and 1·2 m were all similar (Figures 8.5 and 8.6). Although not all differences were significant, the ripped soil was wetter than chiselled soil which was wetter than the direct listed soil (Figures 8.5 and 8.6) for all reading times at these five depths.

Maize treatment differences at 0·8, 1·0, and 1·2 m were less clear cut than tillage treatment differences, while maize differences at 0·2, 0·4 and 0·6 m were not significant during the period for which data is presented. Significant maize effects were often associated with a significant interaction, with θ_v being higher in maize treated areas than non maize areas of the direct listed and chiselled, but not ripped plots (Figure 8.6).

Rapid water depletion (> 0·03 m^3 m^{-3} day^{-1}) was measured at 0·2 m from the first reading time on 6/11/86. Water depletion at this rate did not occur at 0·4 m until after the first irrigation on 19/12/87, at 0·6 m until after the second irrigation on 4/1/87, at 0·8 m until after the third irrigation on 22/1/87, and at no time at 1·0, and 1·2 m.

Water potential

Models fitted to the *in situ* water retention curves differed between the two depths (0·2 and 0·3 m), and the two tillage treatments studied (Table 8.4). The air entry potential (ψ_e) of the direct listed treatments was lower than ψ_e of the ripped treatments, while the second curve fitting parameter, b, was greater at 0·3 than 0·2 m (Table 8.4).

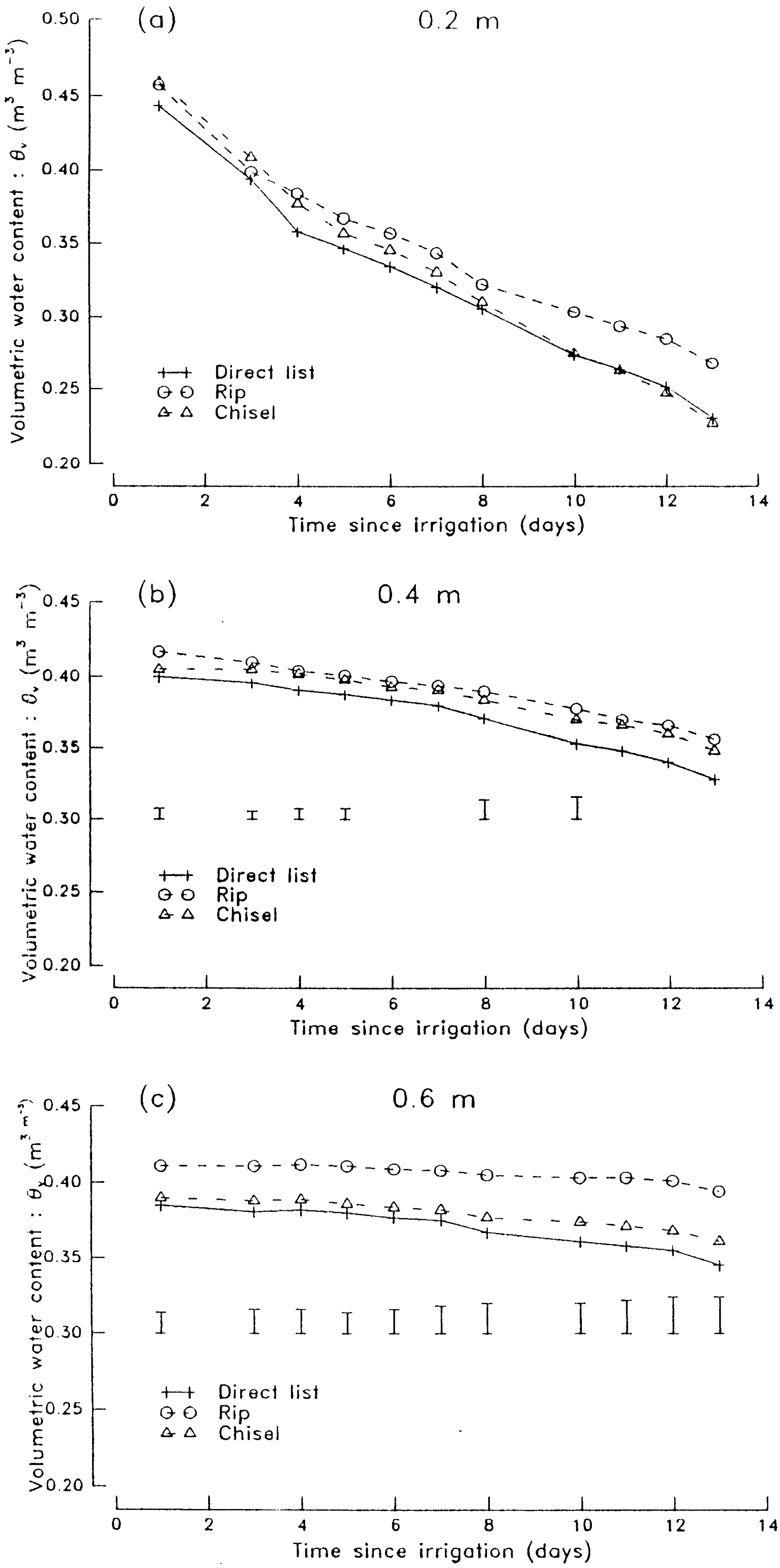
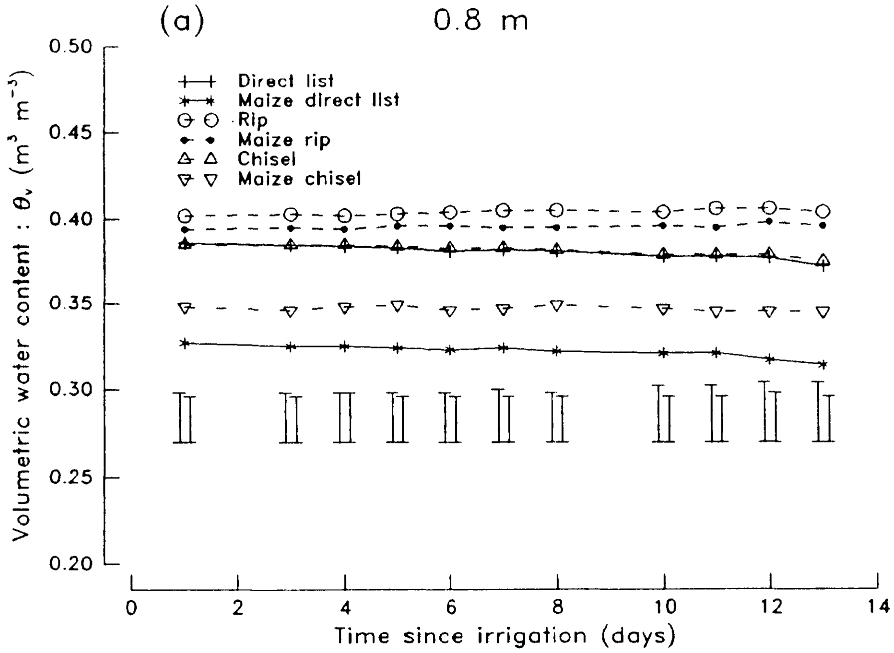


Figure 8.5 Effect of tillage treatments on volumetric water content at a) 0·2 m, b) 0·4 m and c) 0·6 m beneath a cotton crop irrigated on 5/2/87.

Bars are 5% l.s.d. for differences between tillage treatments, and are presented only if treatments were significantly different.



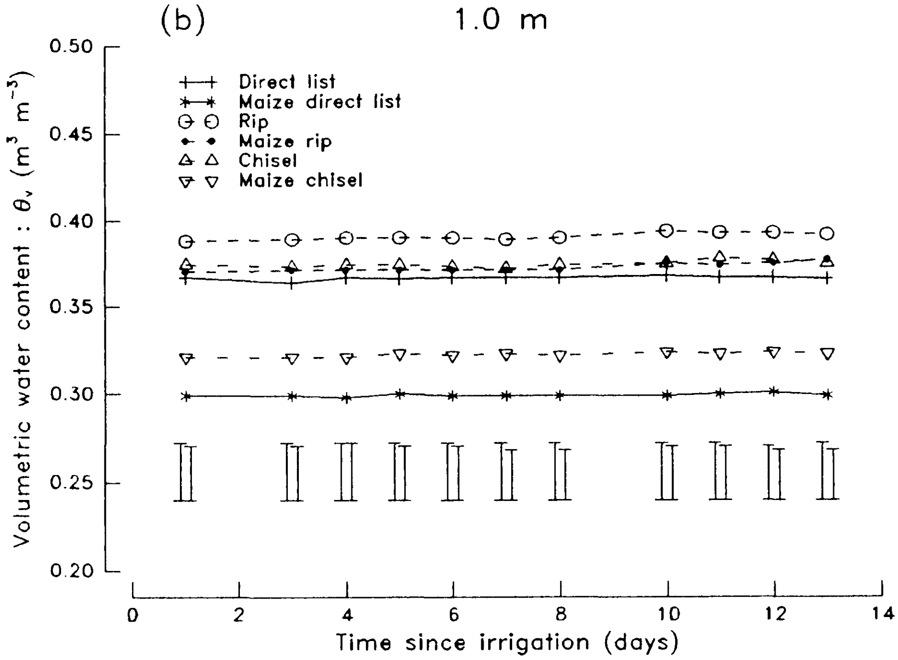


Figure 8.6 Effect of tillage treatments on volumetric water content at a) 0·8 m, and b) 1·0 m beneath a cotton crop irrigated on 5/2/87.
Bars are 5% l.s.d. for interaction between tillage and maize treatments. Right hand bar is for comparisons between tillage treatments, and left hand bar is for all other comparisons.

Table 8.4 Effect of tillage treatment and depth of sampling on retentivity parameters fitted to field pressure potential values (ψ_p; kPa) from four tensiometers per tillage treatment at two depths, Field 30 , Auscott, Warren. The model fitted is:
$\psi_p = \psi_e(\theta_v / \theta_{vs})^{-b}$, where ψ_e, and b are curve fitting parameters, and θ_{vs} is saturated volumetric soil water content ($m^3\ m^{-3}$); DL is Direct list; Tillage and Depth are effects in analysis of variance.

Parameter	Depth (m)				5% l.s.d.	
	0·2		0·3			
	DL	Rip	DL	Rip	Tillage	Depth
ψ_e	1·49	2·27	1·51	2·95	0·93	
b	7·90	8·01	26·0	18·1		6·1

Combination of the *in situ* water retention curve with shrinkage measured with swelling pins and Saran coated clods can give indications of the relative volume of interaggregate and intraaggregate pores. Volume measured by Saran coating includes intraaggregate, but not interaggregate pores; the volume measured by swelling pins contains both interaggregate and intraaggregate pores, while the water retention curve indicates the volume of water filled pores. Thus the area between the lines indicating porosity measured by swelling pins and Saran coated clods in Figure 8.7 represents interaggregate ε_a; the area between the lines indicating porosity measured by the Saran coated clods and the water retention curve represents intraaggregate ε_a. For a given ψ_p, the soil at 0·3 m depth had both lower interaggregate and intraaggregate ε_a than the soil at 0·2 m depth (Figure 8.7). In addition, the soil at 0·3 m depth had a lower proportion of its total porosity as intraaggregate pores than the soil at 0·2 m depth. Although intraaggregate ε_a was a large proportion of the total ε_a at small ψ_p, the majority of the increase in ε_a as the soil dried between irrigations was interaggregate ε_a. This indicates that few intraaggregate pores drained over the range of ψ_p studied.

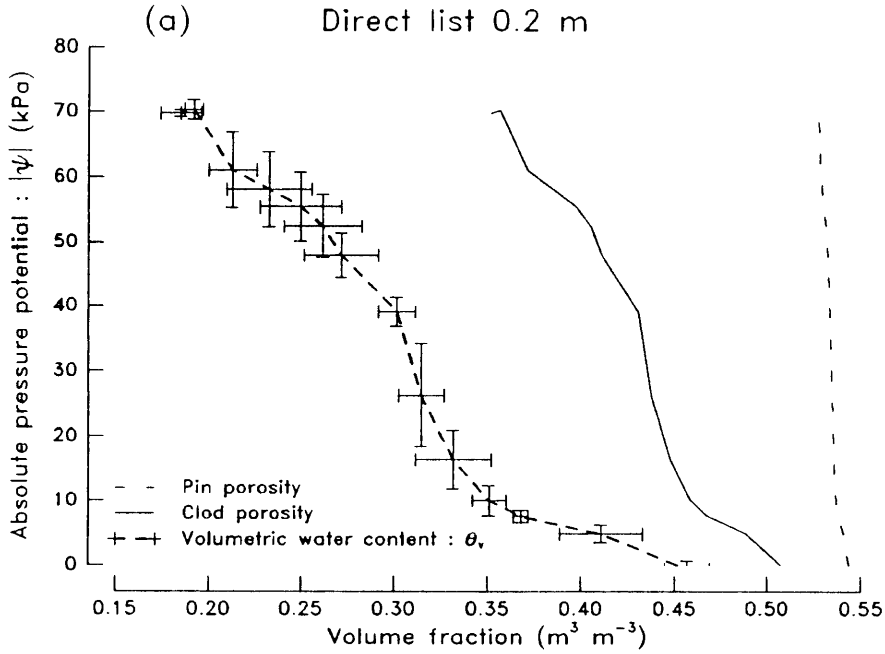
ψ_p at 1·2 m changed very little over the θ_v range studied, indicating that the soil was wetter than ψ_e (Figures 8.7e and 8.7f).

A small positive pressure gradient of less than 2 kPa m^{-1} was present between 0·2 and 0·3 m depths shortly after irrigation (Table 8.5). This gradient reversed as the profile dried to become steeper than -50 kPa m^{-1} at 9 DAI. The gradients between 0·3 and 1·2 m varied less than for the shallower soil. A positive gradient of less than 1·5 kPa m^{-1} was maintained for 4 DAI, changing to a negative gradient as the soil dried and decreasing to -30 kPa m^{-1} 13 DAI.

Oxygen flux density and core measurement of solid, air and water relations

The model fitted to the relationship between measured ε_a ($m^3\ m^{-3}$) and measured OFD (g O_2 $m^{-2}\ day^{-1}$) at 0·2 m depth was:

$$OFD = 766((\varepsilon_a - 0{\cdot}128) + |\varepsilon_a - 0{\cdot}128|) \quad 8.3.2$$



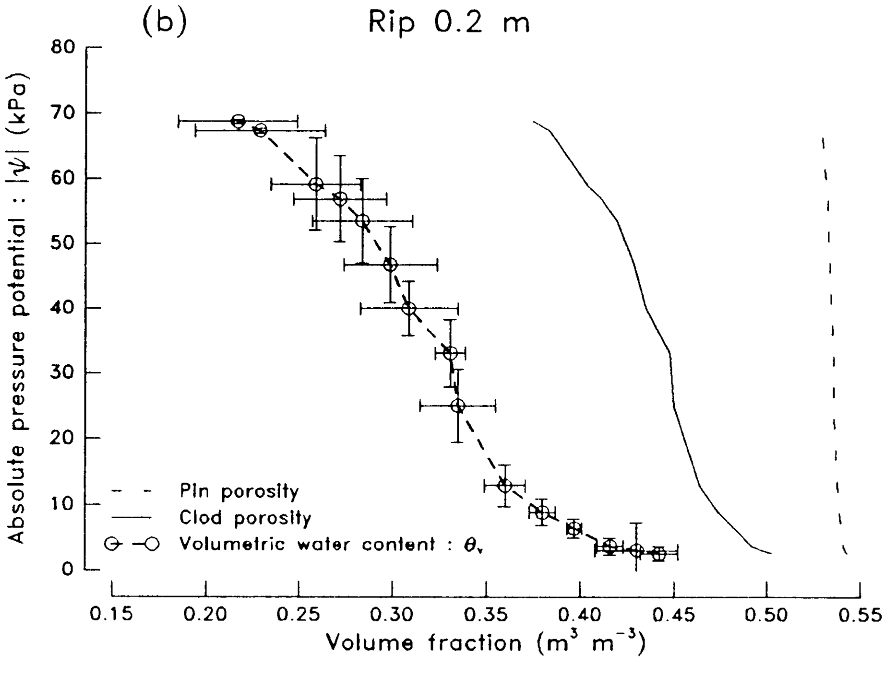
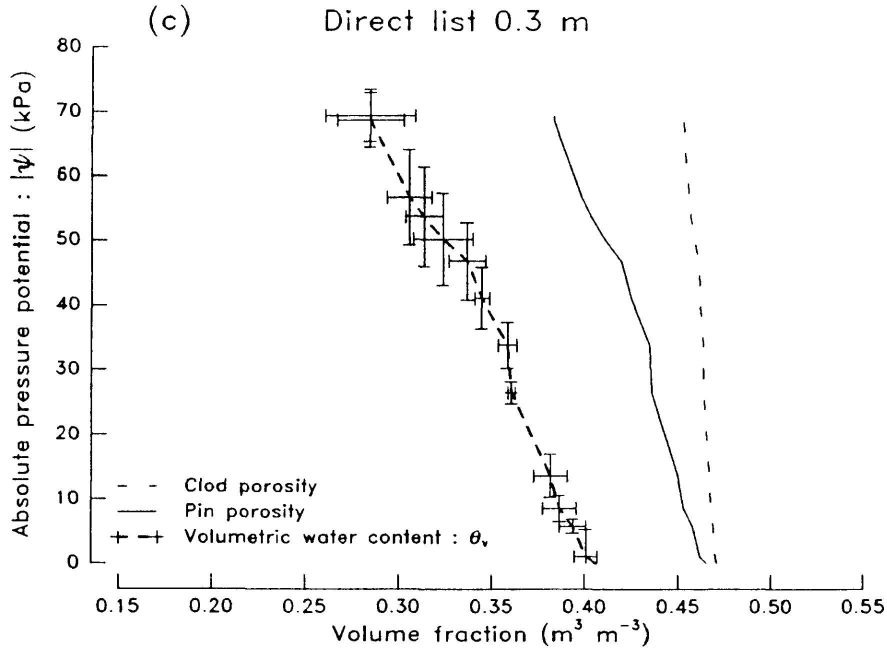


Figure 8.7 Field water retention curves established in the drying cycle following irrigation on 5/2/87. The water retention curves are for: a) direct list at 0·2 m, b) rip at 0·2 m, c) direct list 0·3 m, d) rip at 0·3 m, e) direct list 1·2 m and f) rip at 1·2 m
Bars are twice s.d.



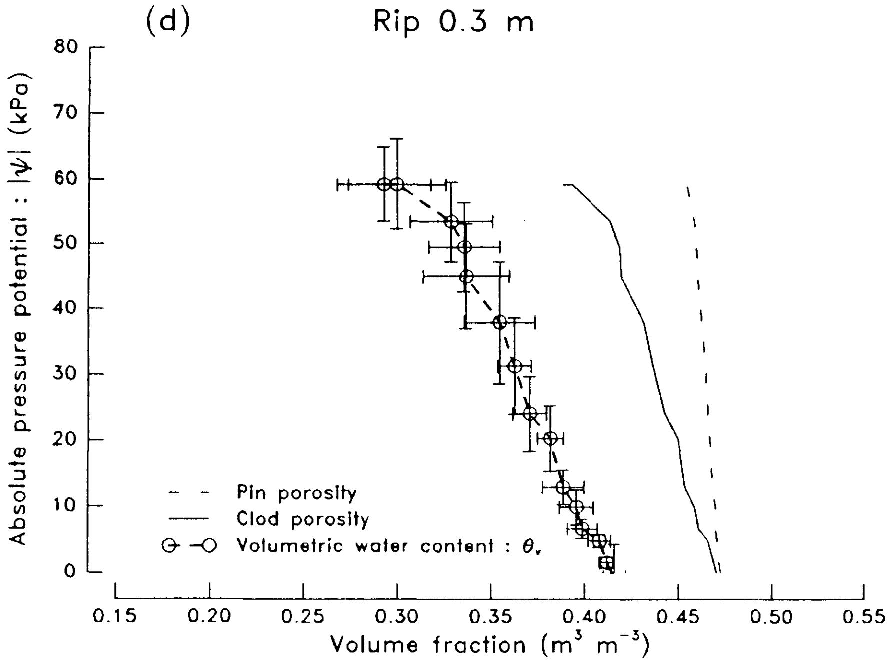


Figure 8.7 (continued) Field water retention curves established in the drying cycle following irrigation on 5/2/87.

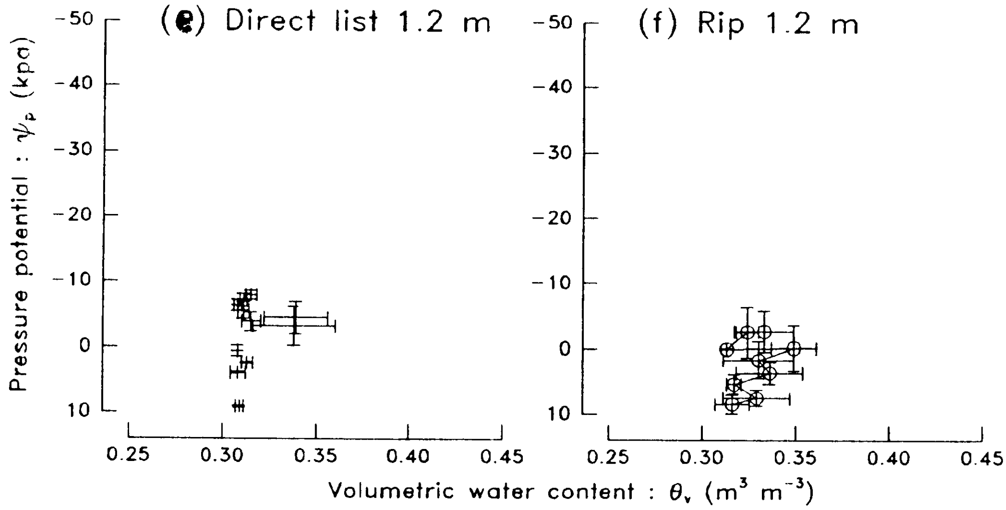


Figure 8.7 (continued) Field water retention curves established in the drying cycle following irrigation on 5/2/87.

Table 8.5 Change in hydraulic gradient (H; kPa m^{-1}) with time for two depth intervals, following furrow irrigation of ripped and direct listed treatments, Field 30, Auscott Warren, February 1986 (DAI is time since irrigation, days; s.d. is standard deviation of G).

DAI	0·2 to 0·3 m		0·3 to 1·2 m	
	H	s.d.	H	s.d.
1	-3·2	5·3	0·4	0·8
2	1·6	13.3	0·1	1·3
3	-3·1	7·0	1·4	1·2
4	-8·6	13·5	0·8	1·3
5	-7·0	9·9	-0·6	2·1
6	-10·4	13·1	-3·5	2·6
7	-21·2	15·5	-11·7	2·2
8	-35·2	27·0	-6·5	0·2
9	-49·9	77·8	-16·5	4·6
10	-62·0	40·5	-19·9	5·2
11	-74·4	52·1	-23·4	5·5
12	-69·0	54·2	-29·0	1·7
13	-64.2	47·5	-32·3	1.1
14	-53·8	46·5		
15	-48·3	50·4		
16	-59·0	62·8		

The critical ε_a below which the model predicts zero OFD was 0·128 m^3 m^{-3} which is lower than the critical ε_a of 0·145 m^3 m^{-3} predicted for a similar soil by Hodgson (1986). Two measures of the precision of the model fitting were calculated: the coefficient of determination of the model (r^2) was 0·85, and $se_{y.x}$ 28 g O_2 m^{-2} day^{-1}. Despite the prediction of the model that no oxygen flow occurred for ε_a less than 0·128 m^3 m^{-3}, many measurements at ε_a lower than 0·128 m^3 m^{-3} had measurable OFD, indicating that the relationship between ε_a and OFD varied from core to core (Figure 8.8).

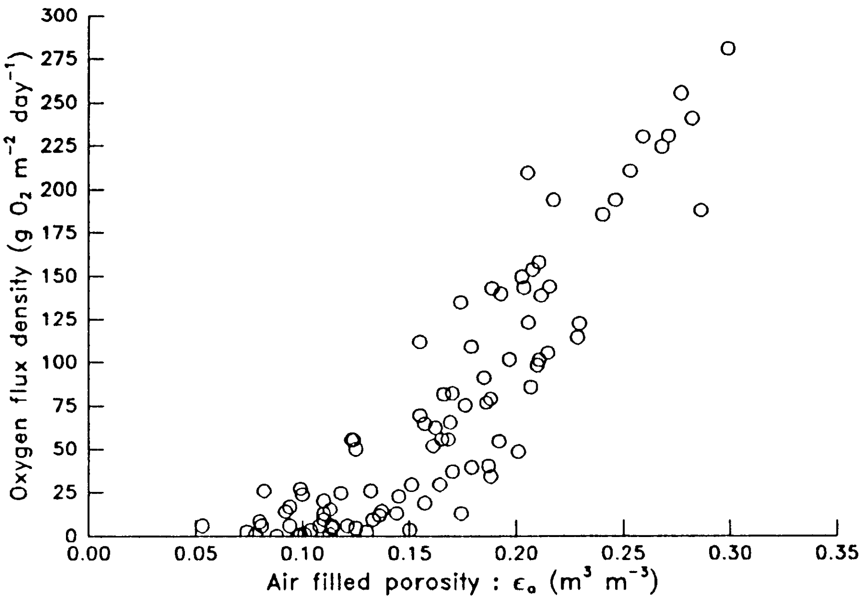


Figure 8.8 Scatter plot of oxygen flux density against air filled porosity at 0·2 m below the centre of cotton hills, Field 30, Auscott, Warren.

For six samples from 0·3 m depth with ε_a greater than 0·128 m^3 m^{-3}, OFD was 40 g O_2 m^{-2} day^{-1} (s.d. 14 g O_2 m^{-2} day^{-1}) higher than that predicted by the model derived from data collected at 0·2 m depth. Insufficient OFD determinations were made at 0·3 m to develop a separate model for this depth.

Air filled porosity measured in core samples at 0·2 m at 4 DAI was similar to the critical ε_a for OFD (0·128 m^3 m^{-3}) in both ripped and direct listed treatments (Table 8.6). Air filled porosity increased in the direct listed plots and decreased in the ripped plots at 7 DAI, and was greater in the direct listed than ripped plots at that time. At both 11 and 13 DAI, ε_a was substantially greater than the critical ε_a for OFD, and ε_a was greater in the ripped than direct listed plots. Interpretation of changes in ε_a and bulk density (ρ_b) measured in core samples is complicated by anomalous trends in the ripped plots where, in contrast to the density increase expected as soils dry and shrink, measured ρ_b decreased between 7 and 15 DAI despite a decrease in measured θ_g (Table 8.6). This anomaly could be due to unrepresentative sampling of cracks, with a smaller proportion of cracks sampled 7 DAI than at other sampling times. Cracking would be expected at the water contents sampled, as θ_g in both tillage treatments at 11 and 13 DAI was less than the swelling limit of 0·22. kg kg^{-1} (Section 7.2.3)

Table 8.6 Air filled porosity (ε_a; $m^3\ m^{-3}$), bulk density (ρ_b; $Mg\ m^{-3}$) and gravimetric water content (θ_g; $kg\ kg^{-1}$) measured at 0·2 m below the centre of cotton hills, Field 30, Auscott Warren (DAI is time since irrigation, days).

DAI	Treatment		5% l.s.d.
	Direct List	Rip	
ε_a			
4	0·127	0·131	0·050
7	0·135	0·105	0·022
11	0·183	0·204	0·017
13	0·220	0·243	0·006
ρ_b			
4	1·44	1·34	0·15
7	1·47	1·45	0·10
11	1·49	1·39	0·08
13	1·47	1·32	0·09
θ_g			
4	0·239	0·278	0·038
7	0·219	0·249	0·026
11	0·179	0·204	0·032
13	0·170	0·203	0·024

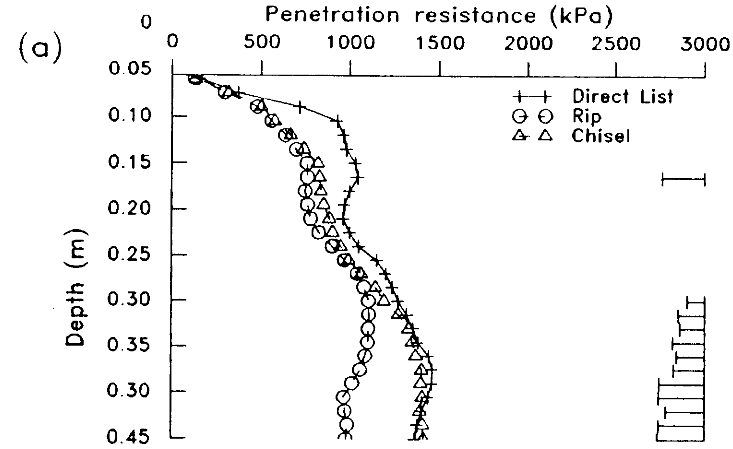
Bulk density measured in core samples at 0·2 m increased between 4 and 7 DAI, after which ρ_b decreased in the ripped but not direct listed treatment (Table 8.6). Bulk density was significantly higher in the direct listed than ripped soil at 11 and 13 DAI, but differences were not statistically different for the two measurement times soon after irrigation.

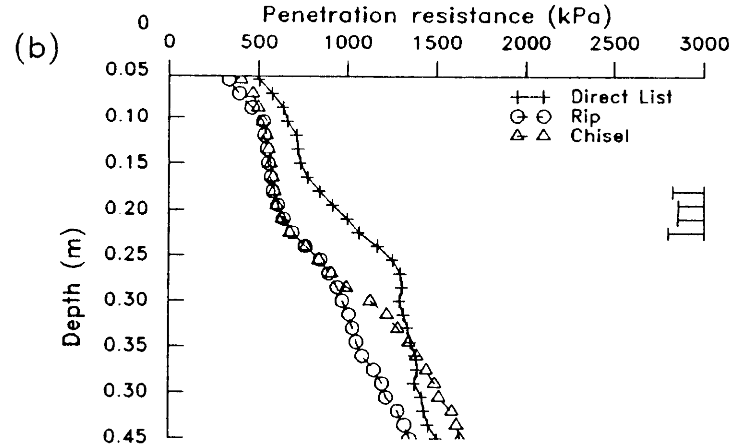
Penetration resistance

No differences in penetration resistance were measured in response to maize treatments, consequently all penetration resistance profiles are averaged over maize treatments.

Penetration resistance profiles recorded on 10/11/86 reflected the depth of tillage, with the direct listed soil having a higher penetration resistance than the ripped soil at 0·165 m depth, and both the chiselled and direct listed soils having higher penetration resistance than the ripped soil from 0·315 to 0·450 m depths (Figure 8.9). No treatment differences in θ_g were observed at any depth on this day (Table 8.7).

The direct listed soil was drier than the ripped soil at 0·10 m depth at 4, 10 and 12 DAI, with this trend being significant at 0·03 m only at 10 DAI. No treatment differences in θ_g for depths greater than 0·1 m were significant (Table 8.7).





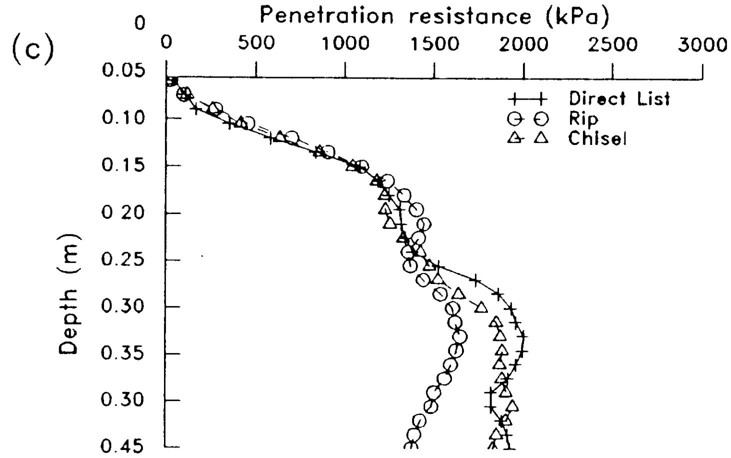


Figure 8.9 Penetration resistance profiles corrected for gravimetric water content on a)10/11/86, b)11/2/87 (six days after irrigation) and c)17/2/87 (12 days after irrigation), Field 30, Auscott Warren. Bars are 5% l.s.d.

Table 8.7 Gravimetric water content (kg kg^{-1}) measured concurrently with penetration resistance, Field 30, Auscott, Warren.

Depth (m)	Treatment Direct list	Rip	Chisel	l.s.d. 5%
10/11/86				
0·03	0·047	0·055	0·051	0·006
0·10	0·211	0·243	0·239	0·033
0·20	0·217	0·225	0·221	0·025
0·30	0·247	0·238	0·252	0·022
0·40	0·254	0·254	0·262	0·015
10/2/87				
0·03	0·246	0·272	0·253	0·019
0·10	0·242	0·272	0·252	0·014
0·20	0·263	0·273	0·268	0·023
0·30	0·257	0·261	0·266	0·013
0·40	0·255	0·265	0·264	0·010
15/2/87				
0·03	0·160	0·173	0·169	0·021
0·10	0·191	0·214	0·205	0·016
0·20	0·177	0·196	0·175	0·032
0·30	0·212	0·220	0·218	0·026
0·40	0·227	0·245	0·241	0·016
17/2/87				
0·03	0·101	0·133	0·132	0·030
0·10	0·178	0·199	0·190	0·014
0·20	0·159	0·179	0·153	0·032
0·30	0·202	0·216	0·207	0·028
0·40	0·217	0·237	0·234	0·024

Regression of penetration resistance on θ_g for data collected between 4 and 12 DAI on 5/2/87 showed that penetration resistance at 0·03 to 0·12 m depths was poorly correlated with θ_g (Table 8.8). At greater depths penetration resistance was more strongly correlated with θ_g in the direct listed than chiselled plots, which were more strongly correlated than the ripped plots (Table 8.8). These differences in correlation were associated with a trend of higher penetration resistance in the direct listed than ripped or chiselled plots at 12 DAI, with all treatment means being less than 2400 kPa, below which Taylor *et al.* (1966) observed no cotton root growth (Figure 8.9).

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 (a and b are constant and slope values fitted by regression with standard error se; n is the number of samples at each depth; $se_{y.x}$ is the standard error of the estimate of y for fixed x).

Depth (m)	Tillage treatment	a	se	b	se	r^2	$se_{y.x}$	n
0·1	all	363	85	644	390	0·013	193	212
0·2	all	2221	76	-5522	364	0·524	277	212
0·3	Direct list	4844	353	-13788	1561	0·527	422	72
0·3	Rip	2305	322	-4387	1374	0·127	360	72
0·3	Chisel	3429	358	-8304	1559	0·301	361	72
0·4	Direct list	5632	452	-16424	1927	0·509	391	72
0·4	Rip	1832	506	-2274	2022	0·018	404	72
0·4	Chisel	3782	540	-8520	2200	0·185	301	72

Plant growth and yield

Although some plant response to tillage treatments was recorded, no differences in plant emergence, numbers of fruiting structures, plant height, dry matter production, or yield in response to maize treatments were statistically significant. Consequently, all plant measures presented are averaged over maize treatments.

Plant emergence was similar for all plots at 150 000 plants ha^{-1}. The number of open bolls was greater in the direct listed than in both chiselled and ripped plots for the last three sets of fruit counts on 14/3/87, 31/3/87 and 17/4/87 (Figure 8.10). These differences followed a consistent trend of higher fruit numbers in the direct listed than chiselled and ripped plots throughout the season. A greater increase in fruit (square, flower and boll) numbers between counts on 12/1/87, and 30/1/87 in the direct listed plots preceded treatment differences in open boll numbers.

Average plant height increased by 7 mm day^{-1} from 0·10 m to 0·24 m between 2/12/86 and 24/12/86. Thereafter, the rate of height increase was 10 mm day^{-1} until 12/1/87, when plants were 0·43 m high, then declined to 6 mm day^{-1} until 30/1/87 when plants were 0·54 m high. Plant height then declined to 0·52 m on 27/2/87, as the stems bent under the increasing boll weight they were supporting, when height measurement was discontinued. Average plant height was similar for all treatments at each measurement time.

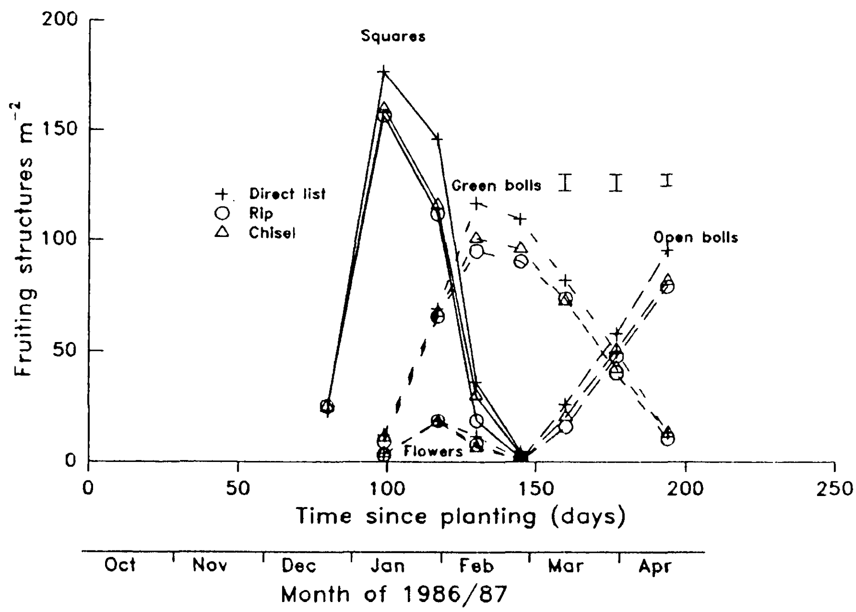


Figure 8.10 Effect of three tillage treatments on production of fruiting structures. Field 30 Auscott Warren, 1986/87 season.
Bars 5% l.s.d for open bolls.

Plant dry matter production of 3910 kg ha^{-1} was similar for all treatments, as was nitrogen uptake of 70 kg N ha^{-1}. There was a strong trend of higher nitrogen content of the direct listed (0·0185 kg N kg^{-1}) than the ripped (0·0166 kg N kg^{-1}) plots, with the chiselled plots intermediate (0·0179 kg N kg^{-1}), and the 5% l.s.d. being 0·0023 kg N kg^{-1}.

Both hand and machine picking showed a trend of higher cotton lint yields in the direct listed than ripped treatments, but this difference was significant only for hand picking (Figure 8.11). Hand picked estimates tended to be higher than machine picked estimates. The cotton yield of plants from which counts had been taken throughout the season was not statistically different from neighbouring plants on which no counts were taken.

Classing results showed no treatment differences. Fibre length of 26 mm was constant for all plots, micronaire varied from 3·8 to 4·9, and grade varied from middling to strict low middling plus (defined in Appendix 2).

Verticillium wilt was found in 3·7% of plants checked. No treatment differences were recorded

8.3.4 Discussion

Cotton lint yield of the direct list treatment showed that maintaining beds in the same place for 4 years and cultivating only the surface soil and a narrow zone 0·2 m deep immediately beneath the plant row during NH_3 injection did not lead to yield penalty when compared to treatments cultivated to 0·25 and 0·5 m depths and subsequently subjected to the same cultural treatments. The overall yield of the

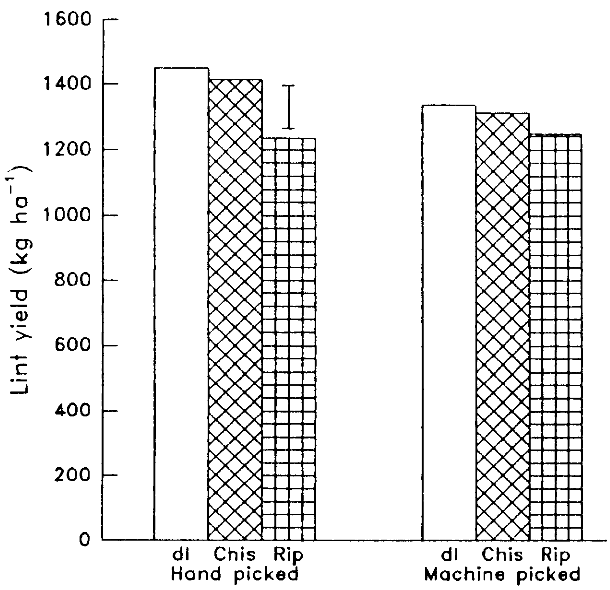


Figure 8.11 Hand and machine picked cotton lint yield estimates of tillage treatments. Field 30, Auscott, Warren, April, 1987.
Bars 5% l.s.d., DL is direct list, Rip is ripped Chis is chisel.

experimental site was 11% higher than the average yield on the surrounding farm, indicating that the yield of the direct listed treatments compared favourably with commercial tillage practices. Similar infections of verticillium wilt in all tillage treatments indicated that, in contrast to fears held by plant pathologists (S. Allen, personal communication), the less intensive tillage of the direct listed plots did not affect verticillium wilt suppression by tillage.

Drying of plots on which no maize was grown by weeds (mainly *Euphorbia drumondi*, caustic weed) and evaporation, combined with low rainfall in the three months preceding tillage, thwarted attempts to create contrasting moisture regimes during the imposition of tillage treatments. These conditions dried the soil more thoroughly than the maize treatment, which was irrigated before being subjected to water deficit stress to dry the soil. In addition, the presence of shrinkage cracks in all plots at this time would have led to amelioration of structural damage in the experiment caused by the wheat header (McGowan *et al.*, 1983). Consequently, maize treatments had little effect on soil physical properties or cotton growth, apart from a higher θ_v at 0·6 m and deeper in the maize treatment for the chiselled and direct listed plots.

No measurements indicated when these differences in soil water content developed, but the ranking in terms of tillage treatment of soil water contents at 0·6 m and deeper was the same during imposition of tillage treatments (Figure 8.4) as during growth of the cotton crop nearly 10 months later (Figures 8.5 and 8.6). This implies that the higher soil water content of the maize treated plots was due irrigation of the maize crop, rather than improvements in soil structure by the maize.

There were few indications of poorer soil physical fertility in the direct listed plots than the more disruptive tillage treatments. Observation of backhoe pits dug near the measurement strip of the central plot of the direct listed minus maize, ripped minus maize, and chiselled minus maize treatments after harvest of the 1986/87 cotton crop showed no differences between treatments in crack pattern or root morphology. Regressions of penetration resistance on θ_g at 0·3 and 0·4 m depths (Table 8.8) indicated that high penetration resistance would be more likely to limit root growth in the direct listed than ripped or chiselled soils. However, regressions for the direct listed soil were similar to those derived from data collected in the 1984/85 season (Table 6.3), indicating that little change in the relationships between penetration resistance and θ_g occurred between the 1984/85 and 1986/87 seasons.

The higher ψ_e of the ripped than direct listed soils (Table 8.4) provides evidence of larger pores in the direct listed than ripped soil as ψ_e is inversely proportional to the largest pore sampled (Hutson, 1983). Pores present at such small values of ψ_e would probably be interaggregate pores (Hamblin, 1985) and be stable to swelling.

The greatest difference between physical properties of the tillage treatments was θ_v being higher in the ripped plots than chiselled plots, with the direct listed plots being the driest. This order of treatment differences in θ_v was measured at 0·2 to 0·4 m depths during the imposition of tillage treatments, and was maintained at 0·6 to 1·2 m depths throughout the 1986/87 season.

The pattern of water depletion measured in this experiment provides no evidence of poor soil physical conditions limiting plant water uptake. The water depletion pattern was consistent with observations that the majority of the root system of cotton grown under high moisture conditions is within 0·6 m of the soil surface (Bloodworth *et al.*, 1958), and that rapid depletion of water near the soil surface occurs before any depletion at 0·6 m and deeper (Rose and Stern, 1968). Also, Hillel *et al.* (1975) have shown that the pattern of water extraction shown in Figures 8.5 and 8.6 would be expected from energy and root resistance considerations alone

The non-limiting water range (NLWR), which is the optimum range of water contents for plant growth (Letey, 1985), was developed from the relationships between OFD and ε_a, and penetration resistance and θ_g, derived at the experimental site. This NLWR shows that soil conditions were much more favourable for root growth at 0·2 than 0·3 m (Figure 8.12). The model reinforces the observation that, for a given water content ε_a is higher at 0·2 than 0·3 m. The model also predicts that poor aeration would restrict root growth at 0·3 m for most of the growing season. For example, θ_g at 0·3 m in the ripped treatment did not fall below the critical value of 0·22 kg kg^{-1} until more than 10 DAI (Table 8.7).

The poor rooting conditions predicted by the NLWR provide an explanation of why roots in vertisols often grow between aggregates (Hasegawa and Sato, 1987) where conditions are more favourable for root growth than inside aggregates. Interaggregate pores have lower penetration resistance than the aggregates (O'Sullivan *et al.*, 1987) as cracks are planes of weakness and, because they are larger, drain sooner than interaggregate pores creating a zone of higher aeration along cracks. The importance of interaggregate pores in soil aeration is shown in the water retention curves, where most of the increase in ε_a during a drying cycle came from an increase in interaggregate ε_a (Figure 8.8). The apparent improvement in soil conditions for root growth in Figure 8.12 by including interaggregate pores in ε_a measurement highlight the need to include these pores in correlating ε_a with plant growth. Calculating ε_a using Saran coated clods indicates that, in contrast to field observation, roots should not grow at 0·3 m. Accounting for interaggregate pores in porosity measured by swelling pins gives a more realistic impression that, while root growth can occur at 0·3 m, conditions are suboptimal for extended periods.

The occurrence of OFD greater than the oxygen consumption in the soil of 14·7 g O_2 m^{-2} day^{-1} (Hodgson, 1986) for ε_a less than 0·128 m^3 m^{-3} (Figure 8.7), brings into question the prediction described above of no root growth in soils with ε_a less than this critical level. These values also highlight the importance of taking account of soil variability, such as that introduced by cracks, when modeling plant response to soil physical conditions (Hamblin, 1985).

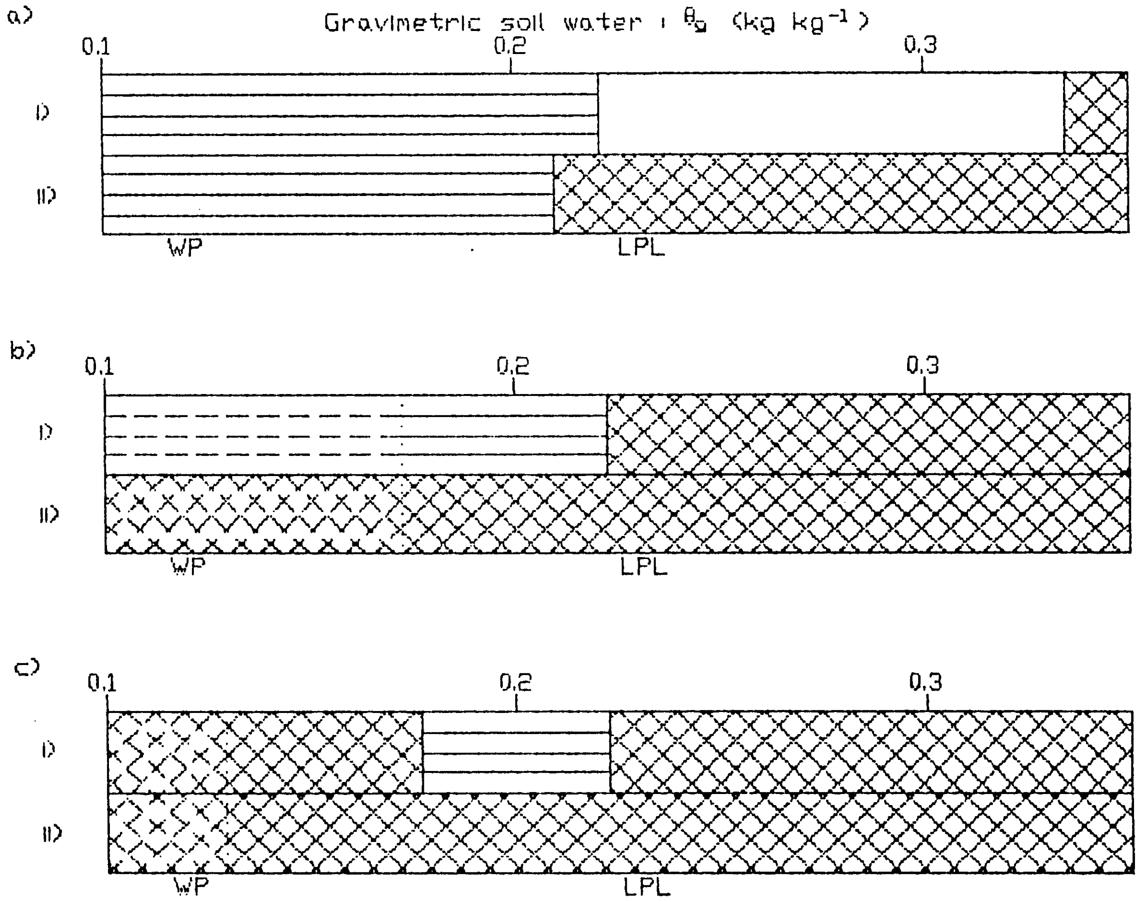


Figure 8.12 Range of non-restrictive (unshaded), partly (lined) and fully (hatched) restrictive water contents at a) 0·2 m for ripped and direct listed tillage treatments. b) 0·3 m for ripped treatment c) 0·3 m for direct listed treatment
Two relationships between ε_a (hence OFD) and θ_g are used in each case. They are: i) ε_a containing both interaggregate and intraaggregate pores, and ii) ε_a containing intraaggregate pores only.
WP is wilting point, LPL is lower plastic limit, dashed shading indicates water contents drier than those used to develop relationship between gravimetric water content and penetration resistance.

The poor soil aeration status outlined above indicates that waterlogging in this soil is an inevitable consequence of surface irrigation or substantial rainfall. The poorer yield in the ripped than direct listed and chiselled plots is attributed to a longer duration of waterlogging in the first treatment. The ε_a of 0·11 m^3 m^{-3} in the ripped plots 7 DAI was lower than both the 0·13 m^3 m^{-3} below which zero OFD is predicted, and 0·14 m^3 m^{-3} in the direct listed soil. The trend of lower nitrogen content of plants also indicates greater waterlogging in the ripped plots (Hodgson, 1986). Similarly, the lower yield of the ripped plots estimated by hand compared to that estimated from machine picking was associated with longer duration of waterlogging in the measurement strip than over the whole field due its flatter slope (Figure 4.3).

Increasing the duration of waterlogging throughout the season is associated with a decrease in cotton lint yield (Hodgson, 1986). Consequently, reduced irrigation frequency should, in the absence of water deficit stress, be associated with increased cotton lint yield. The ripped soil had the potential to have a higher plant available water content (PAWC, Section 2.3.3), thus needing fewer irrigations than the direct listed plots, as indicated by the higher θ_v and shallower water depletion in the ripped than direct listed soil in the 1986/87 season. This higher PAWC was not utilized, as all plots were irrigated when water deficit stress was observed in one plot, usually the direct listed plots. Because of the constraints of working on a commercial farm where irrigation was bound to tight scheduling, it was not practicable to impose different irrigation regimes on different treatments. This timing of irrigation could bias results in favour of plots with lower PAWC (Carter and Colwick, 1971).

Positive values of ψ_p at 1·2 m depth soon after irrigation indicate that the soil was near saturation in both tillage treatments monitored. Higher θ_v beneath the ripped than direct listed soil at this time could reflect structural degradation limiting infiltration of water into the direct listed soil (Hamblin, 1985), or the presence of a larger volume of entrapped air in the direct listed soil (van Bavel *et al.*, 1968). Decreases in ψ_p at 1·2 m with time after irrigation can be partially attributed to decreases in overburden potential (ψ_Ω, Philip, 1969) as the soil dried, combined with reduced ψ_p in shallower soil as it dried. Net flow of water through the root zone would be expected to be low due to the low saturated hydraulic conductivity of grey clays (median 2·3 mm day^{-1}, van der Lelij, 1984). Other factors contributing to the low water flow through the root zone are the likelihood that the soil at 1·2 m contains considerable entrapped air, described above, and the larger magnitude and longer duration of negative than positive hydraulic gradient between 0·3 and 1·2 m in the presence of a constant θ_v at 1·2 m.

8.3.5 Conclusions

Permanent beds established using direct listing were the highest yielding plots in the 1986/87 season. The permanent beds were successful because the soil structure at the start of the experiment was good, and no damage occurred during the experiment to warrant deep tillage. 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, such as poorer aeration in the ripped than direct listed soils, were able to account for the yield differences between tillage treatments. However there was still little difference between the treatments, consequently little can be drawn from the experiments regarding the sensitivity of methods of differentiating between physical conditions in the 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.

CHAPTER 9

ECONOMIC ANALYSIS AND GENERAL DISCUSSION

9.1 ECONOMIC ANALYSIS

9.1.1 Introduction

Improved cotton production on permanent beds formed by direct listing compared to conventional tillage practices, where beds are reformed each season after chiselling to 0·25 m or deep ripping to 0·45 m, was measured in the experiments described in this thesis. Other possible advantages of permanent beds, such as improved trafficability and timeliness (Taylor, 1983), were not assessed in this study. Cotton growers will not, however, adopt permanent beds unless it can be shown that they will profit by doing so.

The economic benefit of tillage treatments tested in this project, along with the comparative returns from maize and wheat crops, were assessed using partial budgets drawn up from data collected during the project.

9.1.2 Materials and methods

Partial budgets for the tillage treatments and graminaceous crops were drawn up using the guidelines of Anderson (1976), and Perrin *et al.* (1976). Tillage treatment differences in cotton yield were included despite the low probability of these differences being significant (1984/85 $P = 0{\cdot}11$, 1986/87 $P = 0{\cdot}06$) as Perrin *et al.* (1976) stated that farmers are willing to accept evidence less persuasive than the $P < 0{\cdot}05$ level of probability normally used in scientific interpretation of results.

Costs of tillage treatments were contract rates current in April, 1987 in the lower Macquarie valley. Contract rates include costs such as machinery ownership and repairs, and labour, and their comprehensiveness simplifies the analysis. Reduced investment in machinery is one of the main economic benefits of using permanent beds compared to more intensive tillage systems (von Mengerson, 1986; Dowling, 1986a, 1986b); consequently, inclusion of ownership costs is important in a comparison of tillage systems.

Machinery costs for maize and wheat seedbed preparation included only variable and not capital costs, as machinery currently essential to cotton growing can be used for all operations apart from wheat planting for which ownership costs are \$3 ha^{-1} (Jones, 1987). Labour cost was estimated as an award rate (wage rate reached after arbitration between farmers and unions) with an allowance for on-costs such as workers' compensation insurance, as most cotton farms employ contract labour. Wheat and maize harvesting costs were contract rates as these operations utilize specialized, high value machinery.

9.1.3 Results and discussion

The economic benefits of permanent beds are greater than the biological benefits. The cost of preparing permanent beds formed by direct listing was one quarter of the cost of preparing beds formed after ripping, and one third of the cost of preparing beds formed after chiselling (Table 9.1). The small yield increase (<10%) from the direct list compared to the ripped treatment led to increased returns from direct listing of \$124 ha^{-1} at cotton prices of \$1.11 kg^{-1}, and \$197 ha^{-1} at cotton prices of \$1.78 kg^{-1}. The net benefit of direct listing compared to ripping, the poorest economic performer, is equivalent to 258 kg ha^{-1} for cotton prices of \$1.11 kg^{-1}, and 202 kg ha^{-1} lint for cotton prices of \$1.78 kg^{-1}

Ripping and chiselling will only be profitable if application of the tillage treatments leads to yield improvement. Yield improvement in response to deep tillage has not been demonstrated in the current project, nor have cotton yield improvements consistently been demonstrated in tillage experiments on structurally degraded vertisols in central and southern NSW (McKenzie *et al.*, 1984b; Muirhead *et al.*, 1970) as the benefits of deep tillage are short lived. There is a need to predict whether tillage responses can be expected in a given situation, a topic addressed in Section 9.2

Both wheat and maize production return little direct profit to cotton growers (Table 9.2), demonstrating that the reluctance of cotton growers to devote costly inputs to crops grown in rotation with cotton (Beale, 1982) is rational.

The poor economic performance of wheat and maize compared to cotton is highlighted by the returns of each with respect to irrigation water, the most limiting physical resource in irrigated farming. Smith (1986) estimated that cotton gross margin per Ml of irrigation water is higher than for any other field crop commonly irrigated in NSW, and three and seven times the gross margin per Ml for wheat and maize respectively. Since the water use of maize is high compared to wheat, the higher returns from wheat than from maize production without irrigation make it more profitable to grow wheat than maize.

9.1.4 Conclusions

Under the management system used for the project, cotton production on permanent beds formed by direct listing was both economically and biologically superior to production on beds formed after deep tillage.

Wheat is preferable to maize as a break crop as it returns greater benefits per unit of water, the most limiting physical resource in irrigation farming. Furthermore, rainfed wheat is more profitable than rainfed maize, reducing the risk of economic loss because of low rainfall in wheat rather than maize growing when both are subjected to low inputs.

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.

		Direct List	Rip	Chisel
Gross production				
Lint 1984/85 (kg ha^{-1})		1493	1466	1417
Lint 1986/87 (kg ha^{-1})		1451	1255	1414
Average lint (kg ha^{-1})		1472	1361	1416
Income		$	$	$
Value of lint @ $1·11 kg^{-1} (A)		1636	1512	1573
$1·78 kg^{-1} (B)		2617	2420	2517
Less storage and transport costs				
Module building and tarpaulins @ $0·013 kg^{-1}		18	17	17
Transport to gin @ $0·014 kg^{-1}		20	19	20
Value net of storage and transport	**A**	1597	1476	1536
	B	2578	2384	2480
Varying cash costs				
Ripping 1·22 hr ha^{-1} @ $110 hr^{-1} *			135	
Chiselling 0·53 hr ha^{-1} @106 hr^{-1} *				56
Discing 0·31 hr ha^{-1} @ $116 hr^{-1} *			36	36
Listing **		47	42	42
Total varying cash costs		47	212	134
Margin between varying cash costs and returns	**A**	1550	1264	1402
	B	2531	2172	2346

* Contract rate, April, 1987 (R. McCutcheon, personal communication).

** Contract rate, April, 1987 (P. Goddard, personal communication).

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. Costs have been obtained from Jones (1986). (machinery and labour are times input (hr ha^{-1}))

	machinery	labour	$
MAIZE			
Gross income			
Forage 2610 kg ha^{-1} @ \$0·04 kg^{-1}			104
Less harvesting costs @ \$0·02 kg^{-1}			52
Value net of harvest costs			52
Varying costs			
Tillage			
Godevil twice	0·87	1·21	
Cultipack	0·22	0·24	
Plant	0·28	0·45	
Cultivate	0·50	0·91	
Total*	1·87	2·81	60
Seed 12·7 kg ha^{-1} @ \$2·50 kg^{-1}			32
Water 5·4 Ml ha^{-1} @ \$6 Ml^{-1}			32
Total varying cash costs			124
Margin between varying cash costs and returns (loss)			(72)
WHEAT			
Gross income			
Grain 1382 kg ha^{-1} @ \$0·11 kg^{-1}			153
Less			
Contract harvesting			
0·18 hr ha^{-1} @ \$200 hr^{-1}			36
Harvest help 0·18 man hr ha^{-1}, 0·06 tractor hr ha^{-1}			3
Transport to silo @ \$0·05 kg^{-1}			8
Value net of harvest costs			106
Varying costs			
Tillage			
Plant	0·42	0·59	
Slash cotton	0·34	0·48	
Total*	0·76	1·07	24
Seed 30 kg ha^{-1} @ \$0·25 kg^{-1}			8
Fertilizer 67 kg Starter 12 ha^{-1}			
(21% P, 12% N) @ \$4·35 kg^{-1}			29
Water 2·5 Ml ha^{-1} @ \$6 Ml^{-1}			15
Total varying cash costs			76
Margin between varying cash costs and returns		31	

* Tractor cost \$14·77 hr^{-1}, labour \$11·60 hr^{-1}

9.2 GENERAL DISCUSSION

This discussion combines the findings of this and other related projects which are relevant to the management of vertisols for irrigated cotton growing It also deals with topics, such as selection of indicators of structural degradation and management of tillage experiments, which are of more interest to scientists studying the effect of the physical properties of vertisols on cotton growth. Although the interests of cotton growers and researchers overlap, the point of view from which they see the topic is different, hence the artificial division in this discussion.

Experimental factors

Selection of indicators of structural degradation in vertisols is a difficult task, as most physical properties, including density and porosity, vary with soil water content. Methods used to differentiate between physical properties of tillage treatments in the 1986/87 cotton season were much more sensitive than methods used in the 1984/85 season, largely as a result of more intensive sampling soon after irrigation in the second season.

The physical measures best correlated with plant growth were indicators of waterlogging soon after irrigation. As the effect of waterlogging on plant growth is mediated largely through restrictions to oxygen supply to plant roots (Letey, 1985), the air filled porosity (ε_a) was correlated with a measure of oxygen supply to plant roots (OFD). Correlation of OFD measured in core samples with root function highlighted the influence of sample size on volumetric measures (e.g.ε_a Section 8.3.4). Failure to measure interaggregate porosity in Saran coated clods yielded predictions that the soil at 0·2 m depth was waterlogged for 10 days after irrigation, whereas ε_a predicted from density measured in the volume enclosed by swelling gauges showed that the soil at 0·2 m depth was waterlogged for only 2 to 3 days after irrigation, and ε_a measured in 75 mm cores indicated that the soil was waterlogged for four days after irrigation. Other indicators of pore size and continuity, including tensiometry, and measurement of dye infiltration were useful adjuncts to core measurements of porosity, but were more time consuming.

Although bulk density measurement is commonly used as an indicator of structural degradation (Boone, 1986; Letey, 1985), it was found to be a poor indicator of structural degradation in this study. Interpretation of density measurement is complicated by the large influence of soil water content on density in swelling soils, the influence of structural degradation on moisture/density relationships (Smith, 1959), combined with the influence of sample volume on measured density (Chan, 1982).

The study of soil swelling showed that ignoring swelling would lead to large errors only in the measurement of ε_a. This occurs because the error introduced by inaccurate crack sampling affects a larger proportion of ε_a than θ_v. Ignoring swelling in neutron moisture meter calibration leads to a small loss in precision (Section 5.3). As aggregates near the soil surface are considerably smaller than the 75 mm diameter sampling rings used for volumetric measurement, interaggregate pores are adequately sampled by these rings, and no corrections for swelling are necessary to accurately represent volumetric relationships of the bulk soil. At depths greater than 0·4 m, where aggregates are much larger than the sampling rings, changes in soil water content throughout the cotton growing season are small, hence errors in measurements due to swelling/shrinkage at these depths are not important.

Current theories of correcting thickness of profile layers for soil shrinkage, which assume that all interaggregate pores formed during shrinkage are aligned vertically (Section 3.2), were shown to be incorrect when interaggregate pores aligned in planes other than the vertical caused vertical shrinkage to be less than predicted (Section 5.2). Shrinkage theories satisfactorily explained height changes for depths greater than 0·3 m because of increases in aggregate size with depth, hence the effect of the orientation of pores is smaller, but changes in soil water and the importance of shrinkage corrections at this depth were small.

Areal distribution of soil water content had very little spatial structure, apart from a tendency of lower soil water content near the tail drain of the field (Section 6.3). Statistical techniques assuming independence between measurement locations can thus be applied with confidence for soils similar to that of the experiment Conversely, soil water content at one depth was strongly correlated with soil water contents of the depths above and below. Statistical analyses which compare soil water contents between depths must take this correlation into account.

Penetration resistance was successfully used in this project to differentiate between soil conditions created by tillage treatments (Sections 6.3 and 8.3), and show the extent of structural degradation after machinery wheeling (Section 7.2). Due to the precise depth definition of the penetrometer, differences in penetration resistance profiles also showed the extent of structural degradation beneath the disced treatment more clearly than measures of porosity (Section 7.3). Soil water content has a large influence on penetration resistance, and consequently must be taken into account when interpreting penetration resistance profiles. These profiles are a quick, simple means of estimating the forces roots must exert to grow through the soil and, despite the poor correlations with other measures of soil strength, are likely to be used for a long time to come (Dexter, 1987). Care must be taken when relating root growth to penetration resistance in swelling soils as variability in soil strength introduced by small cracks in these soils is not detected by the penetrometer which reacts to penetration resistance of clods and large cracks. Thus roots can grow through small cracks in a soil where high penetration resistance measurements indicate that the soil is too strong to allow root growth through clods. Differences in penetration resistance profiles were not reflected by differences in plant growth in this project despite the restriction of root growth by soil strength as indicated by penetration resistance at water contents higher than wilting point (Section 8.3.4), as waterlogging rather than penetration resistance was the main limitation to plant growth.

The practice adopted in this project of irrigating all tillage treatments at the same time apparently favoured treatments with a low plant available water content (PAWC). The ripped soil had consistently higher water content and lower penetration resistance toward the end of drying cycles than both the chiselled and direct listed soils. Dowling (1986a, 1986b) reported that permanent beds frequently require one more irrigation during the cotton season than cotton grown on similar soils which have been deep tilled. Improved conditions in the ripped soil were not utilized when all treatments were irrigated whenever the first signs of plant stress were observed in the other treatments.

Cultural factors

The absence of a measured decline in soil physical fertility of the permanent beds during the project, combined with the greater cotton production of the permanent beds than of the deep tilled systems, has shown that permanent beds are a viable means of cotton production. However, in view of the structural degradation that has limited cotton production in regularly deep tilled soils (McGarry and Chan, 1984: McKenzie *et al.*, 1984a), care must be taken to avoid structural degradation if the productivity of permanent beds is to be maintained.

The most important factor in avoiding structural degradation is to avoid unnecessary traffic on wet soil. Structural degradation in response to picker and header traffic over wet soil has been documented in this thesis (Section 7.2), while Kirby (1987) has shown that shear rather than density increase is the main mechanism of structural degradation in similar clay soils.

Reducing traffic on wet soil involves much more than a day to day decision of whether the soil is too wet to be trafficked. Rather, irrigated cotton growing has to be planned to reduce the need to drive on wet soil. Because of the decline in cotton quality with delay in harvesting, cotton picking is the trafficking operation least likely to be delayed to accommodate the aim of maintaining good soil structure. Although the cotton grower has no control over rainfall and evaporation, advantage can be taken of seasonal trends to reduce the likelihood of soil damage. As evaporation declines at the end of the cotton season (Table 4.2), the likelihood of wet soil at picking can be minimized by managing the crop so that it yields well, yet matures as early as possible, and timing the final crop irrigation so that the cotton crop can dry the soil before it is defoliated. Successful weed control using available cultural and chemical tools to their best advantage reduces the need to carry out interrow cultivation when the soil is wet. Similarly, adoption of a permanent bed tillage system reduces the number of passes over cotton fields by heavy machinery, and reduces the need to traffic wet soil during seedbed preparation when growing sequential cotton crops (Dowling, 1986b).

Formation of shrinkage cracks in the soil when it is dried by plants can ameliorate structural damage in clay soils (McGowan *et al.*, 1983), and improve the effectiveness of subsequent deep tillage. Stress suffered by plants in penetrating degraded soil precludes the use of high value crops to ameliorate structural degradation. This has led to the use of wheat and safflower in the Macquarie valley to dry and crack the soil, combined with deep tillage to further loosen the soil (Beale, 1982).

Although deep tillage can also be used to ameliorate structural degradation, it does not invariably increase cotton production of irrigated vertisols. McKenzie *et al.* (1984b) reported an increase in cotton yield in response to initial deep ripping of a degraded sodic vertisol, but reripping the same field 2 years later led to yield depression. El-Araby *et al.* (1987), and Muirhead *et al.* (1970) observed no cotton yield improvement in response to deep tillage of vertisols. The challenge now is to identify soil and management conditions which will be lead to positive yield responses to deep ripping.

Evidence from the current study and other experiments indicates that several conditions need to be satisfied for deep ripping of vertisols to lead to yield improvement. First, the soil must contain a barrier to air, water, and root permeability which is shallower than tillage depth (Trouse, 1983). Tillage should be just deep enough to penetrate the impermeable barrier, as the cost of tillage increases rapidly with tillage depth. Deep tillage will be more beneficial if soil below this barrier is suitable for root growth than if it is unsuitable (Trouse, 1983). Evaluation of the state of degradation of the soil is thus important in the rational application of deep tillage. If the subsoil is sodic, the longevity of deep tillage effects can be increased by addition of gypsum (Loveday *et al.*, 1970; McKenzie *et al.*, 1984c), but gypsum application to ameliorate subsoil sodicity is often unprofitable.

Second, deep tillage should be carried out at optimum soil water contents. McGarry (1987) has shown structural degradation, while Daniells (1984), and McGarry (1987) have demonstrated that deep tilling a soil wetter than the lower plastic limit (LPL) depressed cotton yield in comparison to deep tillage when the soil was drier than the LPL. Spoor (1975) states that tillage is most effective when the soil is slightly drier than the LPL, as the bulk shear strength of the soil exceeds the clod shear strength, allowing clods to be broken naturally along their weakest cleavage planes. Soil consistency, for which LPL is one of the critical limits, can be determined in the field with no equipment, so can be used by cotton growers to provide an indication of whether or not deep tillage will cause structural damage. The critical depth of tillage, above which soil moves forward, sideways, and upwards when tilled, causing decompaction, and below which the soil only flows forward and sideways, causing compaction, is also affected by soil water content (Spoor and Godwin, 1978). Critical depths become shallower as the soil becomes more plastic or when surface layers are exceptionally dry and cemented, with moist layers below.

Third, recompaction of the soil by passage of machinery over deep tilled soil should be avoided. One wheel pass over deep tilled soil can cause substantial recompaction (Soane *et al.*, 1986).

Fourth, crops grown after deep tillage need to be managed to utilize the improved porosity created by deep tillage (Carter and Colwick, 1971). This is important when soil conditions are suboptimal for root growth for extended periods (Boone, 1986), exemplified by the waterlogging measured in ripped plots in this experiment in the 1986/87 season.

Penetrometer measurements showed that soil strength was high enough to limit root growth only on the last day before irrigation (Section 6.3). It is thus concluded, on the basis of Hodgson's (1986) findings in the Namoi valley that waterlogging was the main physical limitation to cotton growth measured in this study. Means of alleviating waterlogging and its effects include foliar application of N if soil N status is low, irrigating fields as quickly as possible, and selecting sites for irrigation with steep slopes (Hodgson, 1986). Other methods of reducing waterlogging in vertisols have been less successful. Constable and Hodgson (1984) have shown that trickle irrigation does little to improve cotton production when compared to a well managed furrow irrigation system, and hence reduces the effect of waterlogging only slightly. D. Anthony (personal communication) measured little outflow from plastic drains fed by mole drains, and deduced that subsurface drainage was unsuccessful in reducing waterlogging.

Suggestions for further work

The most immediate need is to extend guidelines for management of irrigated vertisols to cotton growers. Lack of a rational system for soil management leads to mostly *ad hoc* tillage decisions as many growers do not know how much deep tillage their soil needs. This has led to pressure from growers and advisers for a system to aid tillage decision making. It is planned to incorporate the guidelines outlined above and other information in a soil management system tentatively termed 'Compuclod'. The system is to be used as a decision support system for cotton growers, and a guide in planning future research into soil physical limitations to cotton production in irrigated vertisols.

Further research into permanent beds is needed to ascertain how long cotton production can be maintained in the absence of deep tillage. This study has shown that cotton production did not suffer after four years without deep tillage, however, continued monitoring of the present site will show how long permanent beds can be maintained without loss of production, and what factors cause the failure of permanent beds. As soil conditions at harvest have been favourable during the study, we need to examine the effect of wet soil during cotton picking on the permanent beds.

In the light of doubts introduced by the presence of soil cracks regarding the validity of indicators used to delimit the non-limiting water range (NLWR) tested in Section 8.3.4, further research is needed to adequately describe the root environment in cracking clays. One possible technique is the use of carefully placed platinum electrodes to measure the aeration status of small zones in the soil. Another approach is direct root observation throughout the growth of the crop using techniques such as minirhizotrons (Arkin and Taylor, 1981) and careful examination of root distribution in soil profiles exposed by excavation which can be combined with measurements of physical properties to improve the NLWR model for cracking soils.

The differences in treatment PAWC alluded to in Chapters 6 and 8 need to be quantified, to assess whether PAWC differences between rip and direct list are real or perceived. If real differences in PAWC are measured, some economic benefits such as reduced irrigation costs and higher water use efficiency, which were not assessed in this study would accrue to the ripped treatments, thus reducing the relative profitability of permanent beds compared to deep tillage.