Final Report

Assessment of Winter Crop Rotation Phases for Salinity Prevention in Cotton Based rotation Systems

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Plain English Summary.

Deep drainage of cotton based rotation systems were estimated on two soils in the Macquarie Valley: on a heavy cracking clay at "Auscott", Warren and on a hard setting red soil on the Twynam property "Elengerah", near Trangie. Analysis of soil chloride profiles at the beginning and end of the 18 month rotations showed that none of the systems were maintaining chloride levels at a steady state (ie. The mass of the solute applied to the soil profile was not equal to the mass of the solute leaving the profile). Water entry into the soil profiles decreased markedly after the first irrigation in the hard setting red soil. Estimations of deep percolation were made on all rotations. In both soils, the treatments not including a winter crop had a substantially higher calculated deep percolation. The calculated deep percolation was much higher on the cracking grey clay than the hard setting red soil.

Background to the Proposal.

Pilai and McGarry (1994) and Hulme (1991) have pointed out the benefit of rotation crops such as wheat, for improving soil structure due to soil drying and cracking. One aim of project Dan 83C: Maximising benefits of rotation crops, is to develop crop rotations to overcome soil structural degradation. The drying effect of these crops also needs to be assessed to determine their ability to minimise deep drainage, by utilising stored soil water and winter rainfall.

McKenzie *et al.* (1990), found that significant deep drainage occurred due to cotton irrigation in a Macquarie Valley clay profile. This may lead to an accumulation of soil water in the subsoil and consequently contribute to groundwater recharge. Measurements taken in the Macquarie Valley, after the 1992/1993 cotton season showed that soil water content was higher below the root zone (1m) following crop harvest. Bland and Dugas (1989) found that cotton in a swelling silty clay loam failed to extract all avaliable soil water in a growing season and appreciable quantities of water were left behind at crop maturity. As a result of this, shallow watertables develop on some soils in the Macquarie Valley during the cotton season and persist after harvest. Rainfall may also contribute to deep drainage, especially during periods of fallow or low evapotranspiration. The benefit of a winter cropping phase to deplete excess soil water and minimise deep drainage needs to be assessed. Salinity prevention could be an additional benefit of rotation crops in cotton systems. This concept has been supported by local growers and consultants.

The Objectives and the Extent to Which they have been Achieved.

The objectives of the project were:

1. Establish experimental sites on two soil types; a hardsetting red soil and a heavy clay soil incorporating three treatments on a paddock scale:

- A continuous cotton treatment utilizing no winter crop in the rotation
- A cotton/wheat treatment utilizing wheat sown after cotton in the rotation
- A cotton/grain legume treatment utilizing a grain legume sown after cotton

The experimental site on the hardsetting red soil was meant to start in the 1995/1996 season. However, due to water shortages, the project was delayed for one year. In the 1996/1997 season, the three treatments were utilised on the CRC Systems experiment at the "Auscott" Warren site. An experimental site was established on a hardsetting red soil at "Elengerah", a Twynam property near Trangie in September 1997. Unfortunately, this site was inadvertently sprayed out in September 1998. The site was restarted in the 1998/1999 season and progressed without any further problems.

1. Complete salt balances to determine level and stability of salt profiles for treatments on both soil types.

Salt balances were determined for both sites.

2. Estimate deep drainage for treatments on both soil types.

Deep drainage was estimated by mass balance modelling of chloride for treatments on both soil types.

Methodology and justification for the methodology used.

Method of estimating deep drainage

Deep drainage is difficult to assess because of the difficulty in capturing all of the water that escapes through a profile. Direct methods of measuring water utilization and drainage, such as the use of lysimeters are prohibitively expensive and are not practical on a field scale. Willis (1995) compared three methods of estimating groundwater recharge:

- Using a water balance model and estimating groundwater recharge through changes in stored soil water
- Using tensiometry and permeameters to determine matric potential, hydraulic potential gradient, hydraulic conductivity an drainage flux, and
- Using solute mass balance modelling to estimate groundwater recharge.

Of these three methods, the solute mass balance modelling gave more accurate and repeatable results. The work done by Willis (1995) justified using solute mass balance modelling as the principal method for determining deep drainage in this project.

Selection of sites

Two sites were selected as representative of the two major soil types that cotton is sown into in the Macquarie Valley; a grey cracking heavy clay and a hardsetting red soil. The grey cracking heavy clay site was located at "Auscott" Warren on the CRC systems experimental site. The hardsetting red soil site was located at the Twynam property "Elengerah" near Trangie.

Large scale plots were used in this experiment. In the cotton CRC site at "Auscott", each plot was 40 rows wide (relating to five passes of 8 metre sowing machinery) and in the red soil site at "Elengerah", each plot was 36 rows wide (relating to three passes of 12 metre sowing machinery). This gave the experiment practical significance, as deep drainage cannot practically be assessed on a small scale due to the possibility of lateral water movement.

Treatments

There were three treatments at each experimental site:

- A continuous cotton treatment utilizing no winter crop in the rotation
- A cotton/wheat treatment utilizing wheat sown after cotton in the rotation
- A cotton/grain legume treatment utilizing a grain legume sown after cotton

Cotton was sown into all plots at the start of the experiment and this was followed either by a winter fallow or a winter crop sown in the months after cotton harvest. Field peas and wheat were the winter crops sown into the grey clay site at "Auscott". Faba beans and wheat were the winter crops sown into the hardsetting red soil site. Each treatment was randomly replicated three times. The CRC systems site that was utilised in the experiment had a total of 7 treatments. Only three of these were used, namely treatment 1 (continuous cotton), treatment 3 (field peas) and treatment 4 (wheat – low input). Trial plans of both trial sites are shown in Figures 1 and 2.

56 buffer rows			56
Plot	**Treatment**	**Description**	**No. of rows**
1	2	Long Fallow	40
[redacted]	[redacted]	[redacted]	[redacted]
3	6	Wheat / Lab Lab	40
[redacted]	[redacted]	[redacted]	[redacted]
5	7	Wheat / Lab Lab / Fert	40
6	5	Wheat – High Input	40
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
10	7	Wheat / Lab Lab / Fert	40
[redacted]	[redacted]	[redacted]	[redacted]
12	6	Wheat / Lab Lab	40
13	2	Long Fallow	32
14	5	Wheat – High Input	40
15	6	Wheat / Lab Lab	40
16	5	Wheat – High Input	40
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
20	2	Long Fallow	40
21	7	Wheat / Lab Lab / Fert	40
32 buffer rows			32

Figure 1: Field Plan, CRC Cotton Rotation Experiment, Field 13, Auscott, Warren.
Highlighted plots are the ones used in this experiment.

Plot	Treatment Description	Rows
Saltbush plantation		
12 Buffer Rows		12
1	Cereal	36
2	Fallow	36
3	Grain Legume	36
4	Fallow	36
5	Cereal	36
6	Grain Legume	36
7	Cereal	36
8	Grain Legume	36
9	Fallow	36
12 Buffer Rows		12

Figure 2: Field Plan, Cotton Rotation Experiment, Field 27, Elengerah, Trangie.

Estimation of water infiltration during irrigation.

3 * 2m access tubes were installed in each plot 50m from the head ditch at the start of the cotton growing season. Measurements of volumetric water content were taken before and after irrigation on each plot at depths of 20, 30, 40, 50, 60, 80, 100, 120, 140, 160 and 180 cm. The differences in water content before and after irrigation events was calculated by subtracting the amount of water in the soil profile after each irrigation from the amount of water in the soil profile before each irrigation.

A total of seven irrigations were conducted during the cotton season at Auscott and eight irrigations were conducted at Elengerah. The dates for each irrigation are detailed in Figure 3:

Irrigation Number	Auscott	Elengerah
1	10/10/1996	5/12/1998
2	5/12/1996	19/12/1998
3	29/12/1996	30/12/1998
4	18/1/1997	8/1/1999
5	7/2/1997	18/1/1999
6	1/3/1997	29/1/1999
7	12/3/1997	10/2/1999
8		2/3/1999

Figure 3: Irrigation dates for cotton irrigation at each site.

This method is not recommended for estimation of groundwater recharge. Instead, this method was used to ascertain whether there were appreciable differences in water infiltration between irrigations.

Estimation of salt balances on each treatment.

Chloride profiles were determined prior to sowing cotton, after cotton harvest and after the harvest of winter crops. Six soil samples were collected from each plot at each time at 15cm depth increments between 0 and 195cm. Soils were dried and ground to pass through a 2mm seive. A saturated paste was made for each sample using a blotting paper tension table (Beatty and Loveday, 1974). The saturated paste extract was obtained by centrifuging 35g of paste at 7000 rpm for 10 minutes and decanting the supernatant. Chloride concentrations were obtained by titrating the supernatant through a Buchler chloridimeter. Comparisons were made between times of sampling for each soil type, rotation system and depth.

Electrical conductivity of these soil extracts were also measured to determine is the EC levels were limiting.

Estimation of deep percolation using solute mass balance modelling.

Gravimetric water content was determined in subsamples of the soils collected at the sampling times in the above section. It was not possible to sample for bulk density at either site because of the disruption soil pits made to the operation of the farm. Instead, bulk densities previously calculated from a cracking clay at Auscott were used for the grey clay, and bulk densities from a similar soil type in the same landform were used for the hardsetting red soil. Chloride concentrations from the saturated paste extracts obtained for the estimations of salt balances were also used.

From these measurements, soil chloride (S_z) and soil water chloride (C_z) were obtained from the following equations:

$$\mathbf{S_z = 0.814\, C_{SP}\, \theta_{SP}\, \sigma_s}$$

$$\mathbf{C_z = C_{SP}\, \theta_{SP}/\theta_g}$$

Where:

C_{SP} = Chloride concentration of saturated paste extract (mol m^{-3})

θ_{SP} = Gravimetric Water content of saturated paste (kg kg^{-1})

σ_s = Soil bulk density (Mg m^{-3})

θ_g = Gravimetric water content of soil sample at time of sampling (kg kg^{-1})

0.814 = factor accounting for anion exclusion in the saturated paste

From these, average soil chloride contents ($S_{(0-z)}$) at depths below the root zone were calculated.

Mean irrigation over the length of the cotton season was calculated from the number of irrigations, and the length of the cotton season. Amount of water per irrigation was taken to be 100mm per irrigation.

Choride concentration of the irrigation water (C_i) was taken from Department of Land and Water conservation water chloride concentration averages. While it would have been possible to sample irrigation water during irrigation, the variability in the irrigation water over time meant that unless sampling was conducted at every irrigation, a more representative value could be obtained from DLWC sampling. Calculations were conducted with the assumption that C_i had a value of 1.25 mol m^{-3} for Auscott and 0.93 mol m^{-3} for Elengerah.

Deep percolation was calculated using the following equation (Willis, 1995):

$$\mathbf{L = [(I\ Ci) - (S_{(0-z)t1} - S_{(0-z)t2})] / C_z}$$

Where: L = deep percolation (mm yr-1)

I = Irrigation over the cotton season (mm)

C_i = Chloride concentration of irrigation water (0.96 mol m^{-3})

t_1 and t_2 are initial and final sampling times.

Results.

Water infiltration during irrigation.

There were no differences between treatments in infiltration at any particular irrigation event. There was a distinct difference in infiltration of later irrigations in the hard setting red soil compared to the initial irrigation. This was because of the hardsetting nature of the soil. The red soil tended to slump on the first irrigation, reducing the capacity of that soil to let water in on subsequent irrigation events. Figure 4 shows the amount of water infiltrated in the first and second irrigations.

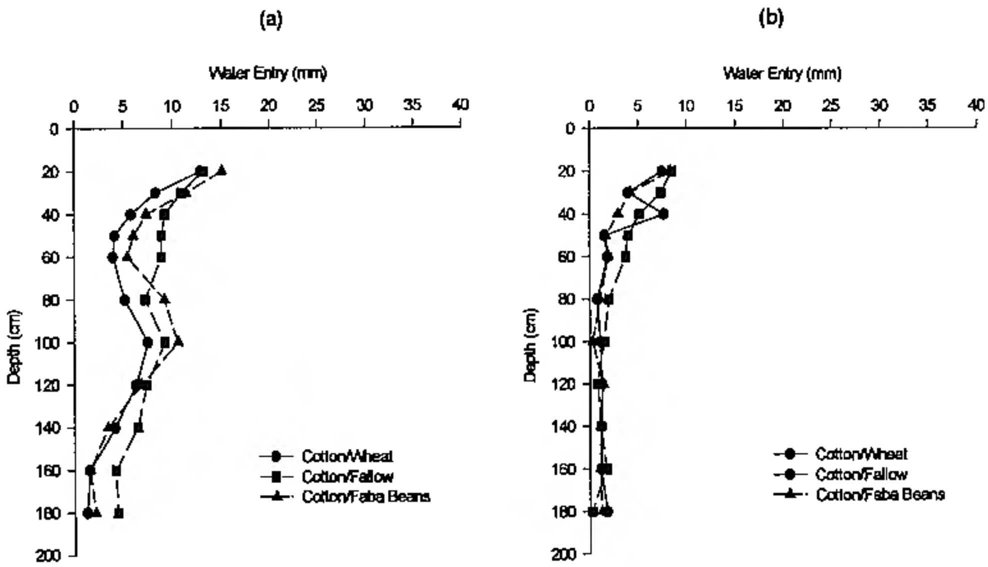

Figure 4: Water entry into red soil (a) after first irrigation and (b) after second irrigation.

Irrigations on the grey clay tended to allow similar amounts of water into the soil profile. The grey clay had the ability to crack and infiltration into this soil was dominated by preferential flow into the cracks. Infiltration into the grey clay was high initially and tended to follow rooting depth. Figure 5 shows water entry after the second and fifth irrigations as examples. The second irrigation is the first irrigation after cotton was planted and so is comparable to the first irrigation in the red soil.

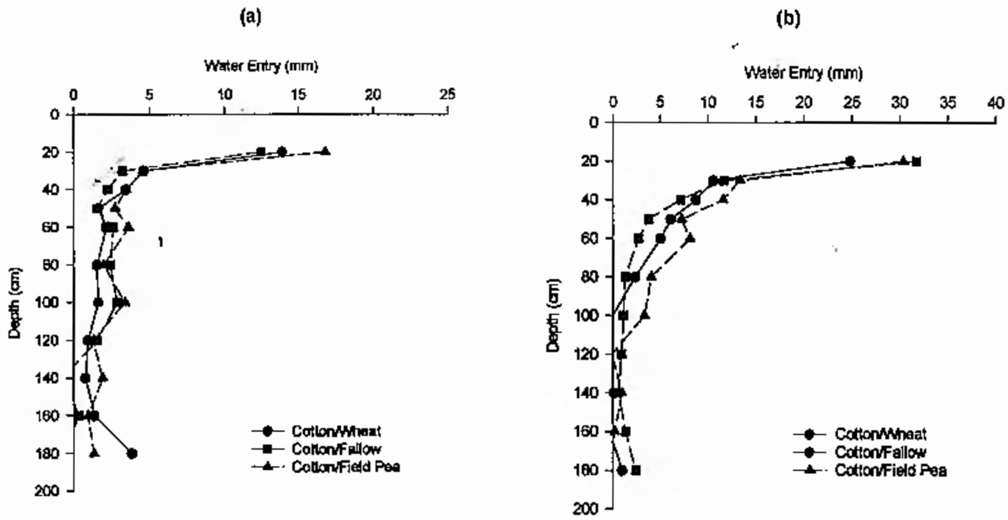

Figure 5: Water entry after irrigation on grey clay (a) after second irrigation and (b) after fifth irrigation.

<u>Estimation of salt balances</u>

Estimation of soil chloride levels before cotton was sown and after the winter crops were harvested showed that chloride levels were different between treatments at certain depths and that chloride levels were changing with time. Figure 6 shows mean stored soil chloride levels of the hardsetting red soil and Figure 7 shows mean stored soil chloride levels of the grey clay.

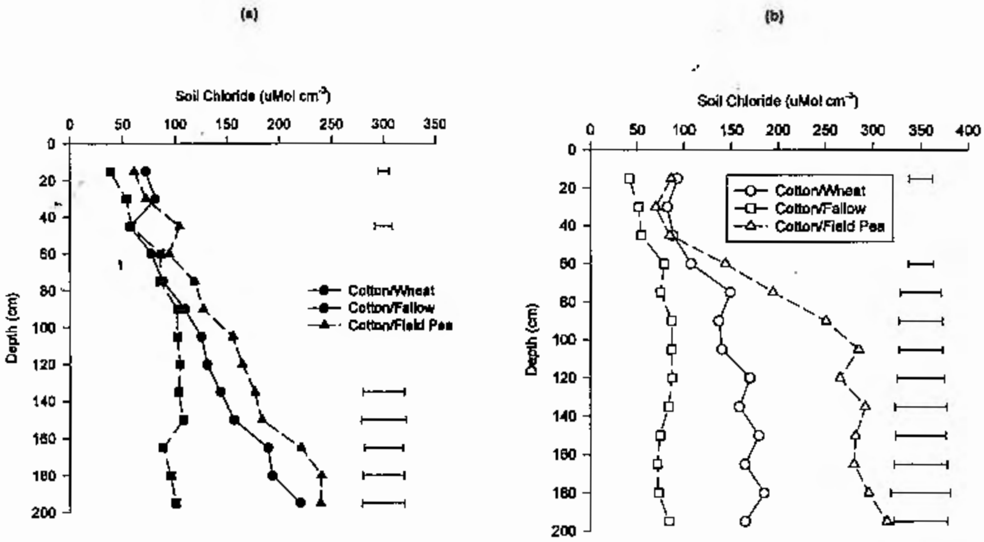

Figure 6: Mean stored chloride content on the red soil site (a) before sowing cotton and (b) after harvesting the winter crop.

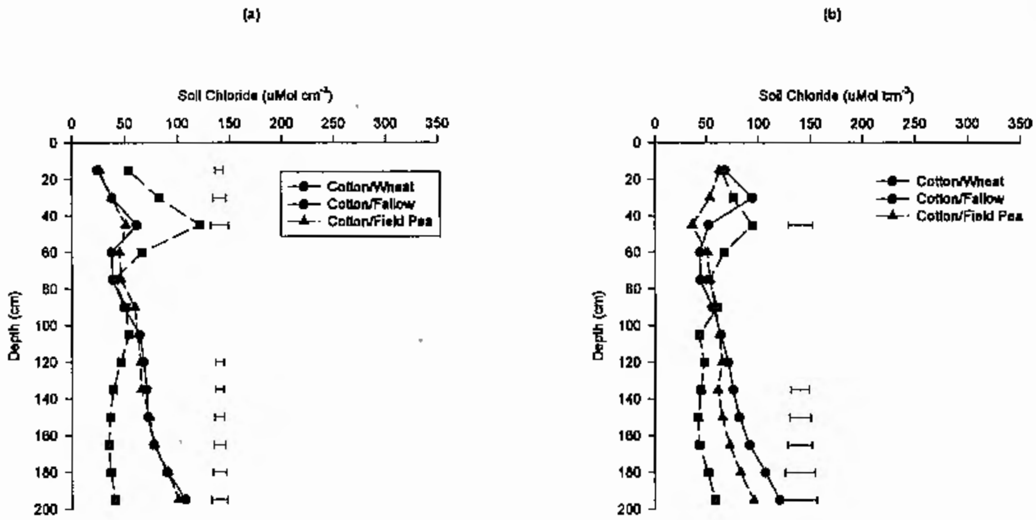

Figure 7: Mean stored chloride content on the grey soil site (a) before sowing cotton and (b) after harvesting the winter crop.

Electrical conductivity levels measured in the soil extract remained low for all treatments. At both sites, EC was very variable, and there were no distinct treatment effects. EC did tend to increase at both sites with depth. Figure 8 shows EC levels for both sites at the beginning and end of the project. Although EC tended to increase, when compared to the EC value limiting growth by 10% (7.7 dS m^{-1}), EC did not appear to be a growth limiting factor at either site for any depth.

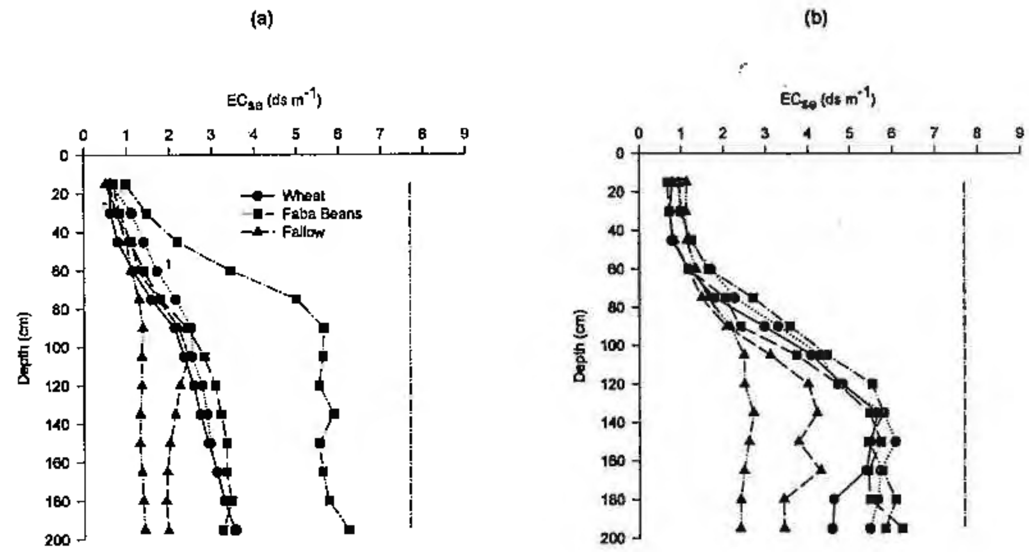

Figure 8: EC_{se} levels at (a) the red soil site and (b) the grey clay site. Symbols followed by solid lines represent EC levels prior to sowing cotton, symbols followed by dotted lines represent EC levels after the harvest of the winter crop. The dashed line at 7.7 dS m^{-1} represents EC_{se} levels where a 10 percent yield penalty is expected.

Estimation of deep percolation.

Deep percolation estimates are shown in Figure 9. On the hardsetting red soil (Figure 9(a)) The cotton / faba bean treatment had the lowest deep percolation rate at 63mm. The cotton / wheat treatment was significantly higher at 103mm and the cotton / fallow treatment was substantially higher with an estimated deep percolation rate of 193 mm over the course of the experiment.

On the cracking clay soil, estimated deep percolation rates were substantially higher than on the hardsetting red soil for all treatments (Figure 9b). The winter crop treatments of cotton / wheat and cotton / field pea had similar levels of deep percolation at 306 and 348mm respectively. The estimated deep percolation for the cotton / fallow treatment was much higher at 578mm.

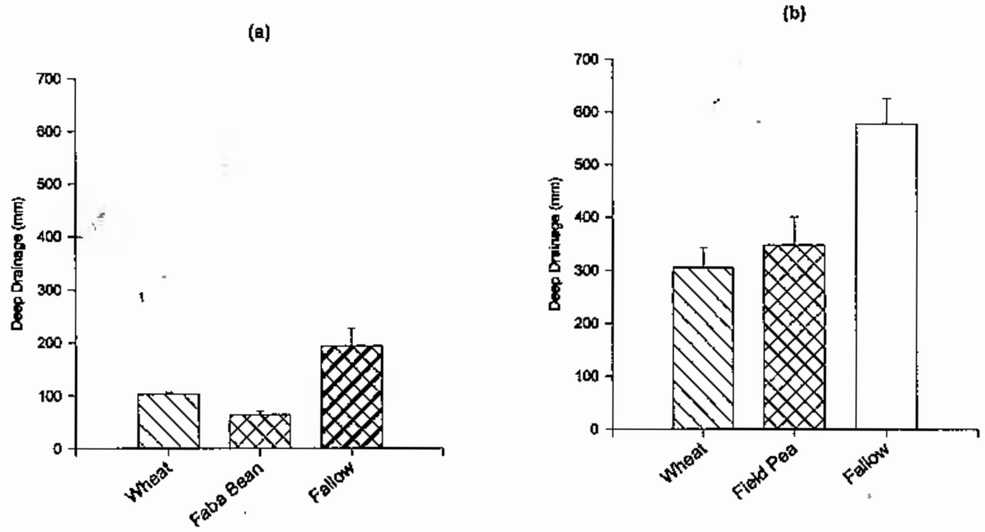

Figure 9: Estimated deep percolation rates for three rotations (cotton/wheat, cotton/grain legume and cotton/long fallow) on (a) a hardsetting red soil and (b) a cracking clay.

Discussion

Water infiltration during irrigation.

There are large differences in water infiltration patterns between the two soils (figures 4 and 5). The different characteristics of the two soils account for this. The heavy clay is a cracking soil and therefore flow of irrigation water is dominated by preferential flow down cracks. As the soil dries out it shrinks, providing large pathways (cracks) for the water to flow down. Because furrow irrigation inundates the surface with water, irrigation of these soils has the potential to fill the soil profile from the bottom up.

Conversely, the red soil infiltration pattern is dominated by its hardsetting nature. The first irrigation provides a large amount of water infiltrating deep into the soil profile. Significant amounts of water in the first irrigation have infiltrated past 160cm and it is clear that water has escaped past 180cm. This first irrigation causes the soil to slump and subsequent irrigations allow much less water into the profile. This reduced amount of water allowed into the profile reduces the potential for deep percolation of irrigation water.

Estimation of salt balances.

Mean stored chloride content was significantly different between treatments in the surface and at depth for both soils at both times (figures 6 and 7). While both sites started the experiment with cotton, both had been subjected to different treatments prior to the start of this experiment. The grey soil site had undergone one complete rotation of cotton and winter crops. The red soil site had undergone most of a rotation, having been sprayed out prior to sowing the cotton crop in this rotation. This would account for the differences in initial chloride contents.

In both soils at both sampling times, the mean chloride content was significantly lower at depth for the cotton treatment. A noticeable buildup in chloride content was apparent in the red soil and not in the grey soil. Examination of the profiles in the grey soil reveals that the profiles for all three treatments appear to be approaching steady state. That is, the amount of chloride in the profiles is similar at the two different times, suggesting that the mass of the chloride applied to the profile is roughly equal to the mass of the chloride leaving the profile. There is a noticeable buildup of chloride in the winter crop treatments in the red soil. It is clear that these winter crop treatments have not reached a steady state. EC_{SE} levels increase with depth but at this stage would not be considered detrimental to plant growth. EC_{SE} levels in the root zone are still well under the limits that will restrict plant growth (Figure 8). It is important to monitor these EC levels until the system reaches a steady state, as increases in EC levels have the potential to affect yield in the future.

Estimation of deep percolation.

Deep percolation rates are substantially higher in the grey clay than in the red soil figure 9). This is evident in the results from the previous sections where the water entry after irrigation is higher in the grey clay than the red soil (figures 4 and 5) and where the chloride buildup is greater in the red soil than in the grey clay (figures 6 and 7). For the cotton/fallow treatment, estimates of 578 mm for the grey clay over the summer and winter cropping period appear to be very high. Willis et al (1997) published potential groundwater rises of 465mm for the 1992/1993 cotton growing season and that recharge was highly dependant on weather conditions prevailing during the season. The figure of 578 mm is well within the boundaries of potential groundwater rise as this figure also incorporates a period of a six month fallow.

Willis et al (1997 found that potential recharge was considerably lower for a red brown earth, with a potential groundwater rise of 267mm over the cotton growing season. This compares with an estimation of 193mm found in this experiment. It is probable that the degree of hardsetting in these soils will play a major role in determining the extent of water entry and hence deep percolation into these soils.

There is a potential for error on these calculations. Chloride levels in the irrigation water were taken from averages of river water chloride levels provided by the Department of Land and Water Conservation. The concentration of chloride can vary considerably over the cotton season and there is a potential for this to affect the estimation of chloride applied to the soil.

The estimation of irrigation water applied also is a source of potential error. For these calculations, an average figure of 100mm applied per irrigation was used. In the red soil, it is clear that the amount of water decreased markedly after the first irrigation. More accurate estimates of irrigation water applied would lead to mare accurate estimates of deep drainage.

Even though there are potentials for error, this method does give a useful comparison between treatments and it is clear that for both soil types, the incorporation of a winter crop into a rotation has the potential to substantially reduce the amount of deep percolation. Further reductions would be expected over a longer time frame because the number of years that irrigated cotton is on any one field is reduced because of the winter crop rotation.

Likely impacts and conclusions.

Continuous irrigated cotton has the potential to contribute significant quantities of water to the watertable, particularly in cracking clays, probably due to the ease in which water can access the lower parts of the root zone. The incorporation of a winter crop has the potential to significantly reduce the level of deep percolation. When considering the benefits of rotation crops, the effects they have on reducing watertable accessions may make them a more attractive alternative.

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Project Technology

No patents or licences have been applied for or granted.

Technical summary of other information

More accurate estimates of determining the amount of chloride entering the system would provide a more accurate method. More detailed analysis of irrigation water applied, detailing both amounts of water applied and chloride concentration would have given a more accurate estimate of deep drainage.

Recommendations on activities or other steps that may be taken to further develop, disseminate, or to exploit the project technology.

The chloride levels in the soil are not in steady state. It would have been useful to gather information over a longer period of time. Of particular interest would have been the effects of a subsequent cotton crop. It is possible that the chloride buildup (particularly in the red soil) would reduce due to leaching with the following cotton crop. If this does not happen, then it would be useful to know how much a winter crop rotation would increase the chloride levels and whether this level would be limiting to crop growth.

List of publications

Friend J.J. (1998.). Winter crop rotations to reduce chloride buildup in irrigated cotton in the Macquarie Valley. Proceedings, 5th National Conference of Productive Use and Rehabilitation of Saline Land. Tamworth, 9th – 13th March, 1998.