

MEASURING DEEP DRAINAGE UNDER IRRIGATED COTTON WITH THE A.C.R.I. LYSIMETER

Anthony Ringrose-Voase¹, Tony Nadelko²

1. CSIRO Land and Water, Canberra, ACT, anthony.ringrose-voase@csiro.au

2. CSIRO Land and Water, Narrabri, NSW, anthony.nadelko@csiro.au

SUMMARY

Deep drainage below irrigated crops wastes a scarce resource and can potentially lead to rising water tables and salinity. The lysimeter facility at the Australian Cotton Research Institute (ACRI) was used to measure deep drainage at 2.1 m depth under a furrow irrigated cotton-wheat rotation

Drainage accounted for 11% of the irrigation. Two distinct types of drainage were observed – matrix and bypass. Bypass drainage was much faster and occurred immediately after irrigation. It accounted for most of the drainage. Drainage could arrive at the watertable at 16 m depth within 15 - 30 days.

Bypass drainage was inefficient at leaching accumulated salt, but removed about 6% of the applied nitrogen.

INTRODUCTION

For much of the history of the Australian cotton industry deep drainage under furrow irrigated cotton was thought to be insignificant because the heavy clay soils on which cotton is grown have low permeability. During the 1990s, studies on heavy clay soils in northern NSW showed there could be appreciable amounts of drainage even under dryland systems (e.g. Ringrose-Voase *et al.* 2003). This raised concerns about the amount of drainage under cotton. Drainage was seen as a waste of an increasingly scarce resource and having the potential to cause rising watertables and salinity. In 2004 the ACRI lysimeter was commissioned to investigate drainage in detail at one location. The work is part of a multi-faceted approach to investigate deep drainage that also uses other, less expensive methods at many locations (Gunawardena *et al.* 2011, Silburn *et al.* 2011).

METHODS

The ACRI lysimeter facility near Narrabri in northern NSW is under a furrow irrigated cotton-wheat rotation using minimum tillage with stubble retention and permanent beds (Ringrose-Voase and Nadelko, 2011). Cotton is fully irrigated, but wheat only receives supplementary irrigation. Alternate furrows are used for traffic and irrigation.

The soil is a Self-mulching, Grey Vertosol (Isbell, 1996), with 60% clay (<2 µm), 14% silt (2-20 µm) and 25% sand (20-2000 µm) above 1.2 m depth.

Below 1.2 m, the clay content decreases to 50% by 2 m depth with corresponding increases in silt and sand to 20% and 30% respectively. Exchangeable sodium increases down the profile from <1% at the surface to 6.5% at 2 m depth.

The ACRI facility is a 'variable tension lysimeter' modified from a design by Brye *et al.* (1999) and Pegler *et al.* (2003). It consists of six collection trays that cover an area of 1.6 square metres. They were installed by tunnelling horizontally from an access shaft so that the overlying soil is undisturbed. The trays are stainless steel boxes whose upper surfaces are made of porous, sintered stainless steel, 1 mm thick with a nominal pore size of 0.0002 mm. Once saturated with water it can hold water against a suction of 28 kPa (equivalent to 2.8 m of water). The floor of each tray slopes to a drain in one corner, and each tray is connected to a vacuum. The applied vacuum is continuously adjusted to match the suction of the soil at tray depth measured using tensiometers. This ensures water moves into the trays at the same rate as if they were not there.

The drain from each tray is connected to its own collection tank in the access shaft that is automatically weighed every 15 minutes. Four neutron probe access tubes are installed to 3 m depth around the lysimeter to allow measurement of soil water content at frequent intervals during the irrigation season. They were also used to determine the amount of irrigation water that infiltrated into the soil by using measurements made immediately before and after irrigation.

Two piezometers are located 5 and 10 m from the lysimeter, screened at 20 and 34 m below ground surface, respectively. They are used to monitor the groundwater head in the two top aquifers on an hourly basis. The watertable is about 16 m below ground surface.

RESULTS AND DISCUSSION

Drainage was measured over three cotton seasons (2006-7, 2008-09, 2010-11) as well as one wheat season (2009) and subsequent fallow (2009-10). The amount of drainage between each irrigation and its electrical conductivity (EC), which is a measure of salinity, are shown in Table 1 for the three cotton seasons. During the first two seasons drainage was equivalent to about 11% of the irrigation water that infiltrated into the soil. Drainage

represented 8.7% and 5.5% of the total rainfall plus irrigation in 2006-07 and 2008-09, respectively. The small quantities of drainage during the 2010/11 season may have been due to soil compaction above the lysimeter, which has since been rectified by deep cultivation.

During the wheat crop, which received two irrigations, there was only 1.4 mm of drainage, and during the following, year long fallow there was 21.6 mm. The results demonstrate that drainage between seasons and between individual irrigations is highly variable.

The lysimeter detected two types of drainage – matrix and bypass. Matrix drainage is the ‘normal’ type of drainage under dryland or irrigated land uses on most soil types. It occurs when the infiltration of rainfall over an extended period exceeds evapotranspiration until the water holding capacity of the root zone is filled. Matrix drainage is illustrated by a drainage event during the 2009-10 fallow (Figure 1B). The event occurred after 9 months of fallow following a wheat crop. The crop had created a soil water deficit of 200 mm. During the 9 months there was 640 mm of rain, which gradually filled up the soil profile from the top down (Figure 2B). The wetting front reached 2.1 m depth on 5 September 2010 and generated 14 mm of drainage over the next 35 days. The event was characterised by a gradual increase in the drainage rate over 10 days until it reached a plateau of 0.5 mm/day for about 20 days. After this it slowly declined back to zero. The drainage had a fairly high EC of 6.6 dS/m. Both the pattern of downward movement, wetting up successive layers, and the EC of the drainage indicate the water moved through the soil matrix.

The pattern of drainage during the cotton seasons was quite different to matrix drainage as illustrated by the 2008-09 cotton season (Figure 1A). After most irrigations, especially those early in the season, there was a rapid increase in the drainage rate, typically starting about 6 hours after the irrigation front passed the lysimeter. The rate peaked after 25 hours and then declined exponentially. The peak drainage rate was 3.2 mm/day after the first irrigation (data not shown) but declined after successive irrigations (Figure 1A). Irrigation generally filled the upper 0.5 m of soil, but frequently did not fill the layers below this (Figure 2A). Layers below 1 m depth rarely showed any sudden increase in water content. This shows that drainage was occurring without wetting the subsoil. In addition, the EC of the drainage was generally low, indicating that it was moving relatively little of the salt accumulated in the subsoil by evapotranspiration of irrigation water. The speed with which drainage was generated after irrigation, the absence of wetting of the subsoil and the low EC all suggest that some irrigation water bypassed

most of the subsoil and very quickly became drainage. This is referred to as ‘bypass drainage’.

Bypass drainage occurs in relatively few situations. It happens when water is ponded on the surface of a soil with an extensive network of large pores – as when furrow irrigation is used on a cracking clay soil. Rainfall, unless it is heavy and prolonged, does not usually cause water to pond on the surface and thus cause bypass drainage.

Detailed analysis of the results showed that the quantity of rapid drainage (that occurring within 48 hours of an irrigation) increases with increasing soil water deficit in the top 0.5 m – i.e. the drier the soil the greater the amount of drainage. This is probably because the cracks are wider and more extensive in dry soil resulting in water travelling rapidly to the subsoil. Conversely, the analysis also showed that rapid drainage decreased with the soil water deficit at 0.5 – 1.0 m depth, although the relationship is statistically weak. If confirmed with more measurement this would imply that the dryness of the layer at 0.5 – 1.0 m mitigates against drainage. The soil water deficit at 1.0 – 2.0 m depth had no effect on drainage.

The analysis helps to explain why drainage was greater during the 2006-07 cotton season than in the 2008-09 season (Table 1). In 2006-07, the subsoil was relatively wet when cotton was sown, with a deficit of only 9 mm in the 0.5 – 1.0 m layer. However, there was little rain during the season so that the first irrigation was immediately after sowing. The early irrigations, in particular, caused large quantities of drainage because the subsoil was already wet. In contrast, the deficit at 0.5 – 1.0 m depth at the start of the 2008-09 season was about 20 mm, and early rainfall meant that irrigation was not required until late December. By this stage the crop had developed sufficiently to create a substantial subsoil deficit between irrigations.

The piezometer results were used to estimate the relative recharge rate into the top aquifer. Comparison of this rate at 16 m depth with the drainage rate from the lysimeter at 2.1 m depth showed that seasonal drainage peaks could be arriving at the watertable within 15 to 30 days.

As discussed above, measurements of the EC of the drainage showed that bypass drainage generally had a relatively low EC (Table 1) compared to matrix drainage. One result of this is that bypass drainage is relatively inefficient at leaching accumulated salt from the profile. Consequently, more drainage may be required as a leaching fraction to prevent a build up of salt than calculated by conventional methods (e.g Richards, 1954).

The concentration of nitrate in the drainage was measured during the 2008/09 cotton season. Over

the season 9.5 kg N/ha were removed from the soil, mainly after the first four irrigations. This represents 6% of the N applied as fertilizer. Unfortunately, nitrogen (unlike salt) mainly occurs in the top soil where it can be efficiently mobilised by irrigation water and lost through bypass drainage.

CONCLUSIONS

- Up to 11% of irrigation was lost as deep drainage.
- Drainage removed significant amounts of nitrogen fertiliser.
- Seasonal drainage arrived at the watertable at 16 m below ground surface within 15 to 30 days.
- Drainage occurred either as matrix or bypass drainage, of which bypass accounts for most of the drainage under furrow irrigation on cracking clay soil.
- Bypass drainage was greater when early irrigation was necessary and the subsoil from 0.5 – 1.0 m depth was already wet.

REFERENCES

- Brye KR, Norman JM, Bundy LG, Gower ST (1999) An equilibrium tension lysimeter for measuring drainage through soil. *Soil Sci. Soc. Am J.* 63: 536-543.
- Gunawardena TA, McGarry D, Robinson JB, Silburn DM (2011) Deep drainage through Vertosols in irrigated fields measured with drainage lysimeters. *Soil Res.* 49: 343-354.
- Isbell RF (1996) *The Australian Soil Classification*. CSIRO Publishing: Melbourne.
- Pegler D, Foley J, Silburn DM (2003) Design and construction of an equilibrium tension lysimeter for use in swelling clay soils. In 'International Soil Tillage Research Organisation 16th triennial conference. Brisbane, Queensland'. pp. 891-896. University of Queensland: Brisbane.
- Richards LA (Ed) (1954) *Diagnosis and Improvement of Saline and Alkaline Soils*. USDA Agriculture Handbook 60. USDA: Washington DC.
- Ringrose-Voase AJ, Nadelko AJ (2011) Quantifying deep drainage in an irrigated cotton landscape. Final report for Cotton Research and Development Corporation Project CRC125/Cotton Catchment Communities Cooperative Research Centre Project 1.02.12 and Cotton Research and Development Corporation Project CLW1102. Cotton Research and Development Corporation, Narrabri, NSW. http://www.cottoncrc.org.au/general/Research/Projects/1_02_12
- Ringrose-Voase AJ, Young RR, Paydar Z, Huth NI, Bernardi AL, Cresswell HP, Keating BA, Scott JF, Stauffacher M, Banks RG, Holland JF, Johnston RM, Green TW, Gregory LJ, Daniells I, Farquharson R, Drinkwater RJ, Heidenreich S, Donaldson S (2003). Deep drainage under different land uses in the Liverpool Plains catchment. NSW Agriculture, Agricultural Resource Management Report No. 3. http://www.clw.csiro.au/publications/consultancy/2003/Deep_Drainage_in_Liverpool_Plains.pdf
- Silburn DM, Tolmie PE, Biggs AJW, Whish JPM, French V (2011) Deep drainage rates of Grey Vertosols depend on land use in semi-arid subtropical regions of Queensland, Australia. *Soil Res.* 49: 424-438.

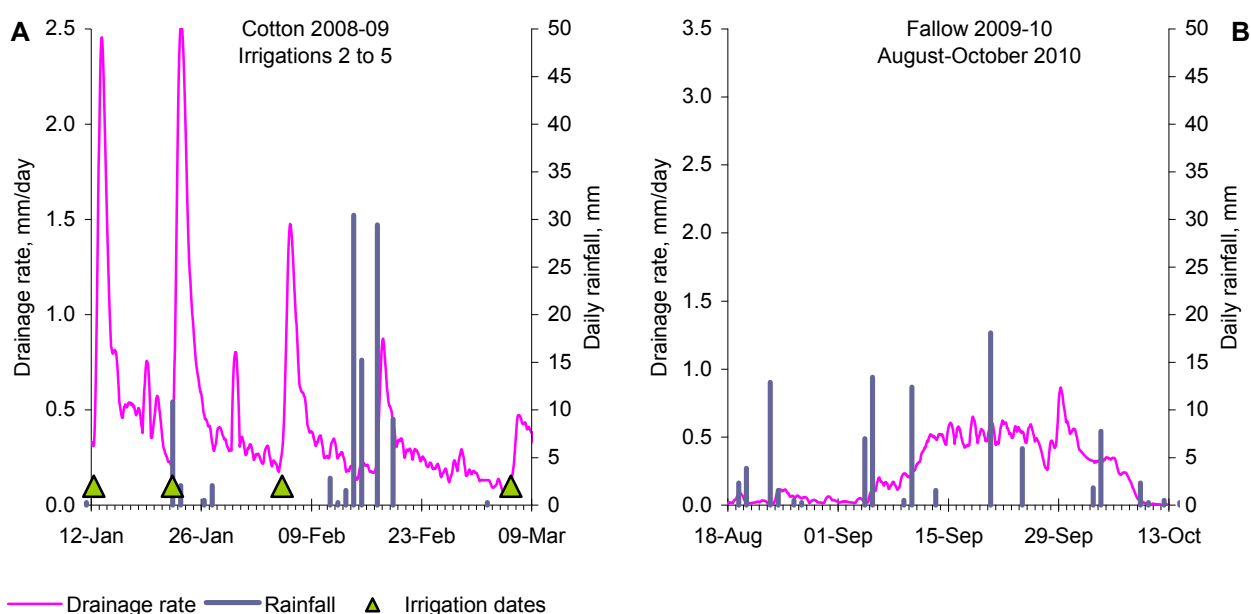


Figure 1. Drainage rate at 2.1 m depth measured by the lysimeter (left vertical axes) and daily rainfall (right vertical axes) over 8 week periods during A) the 2008-09 cotton crop and B) the 2009-10 fallow.

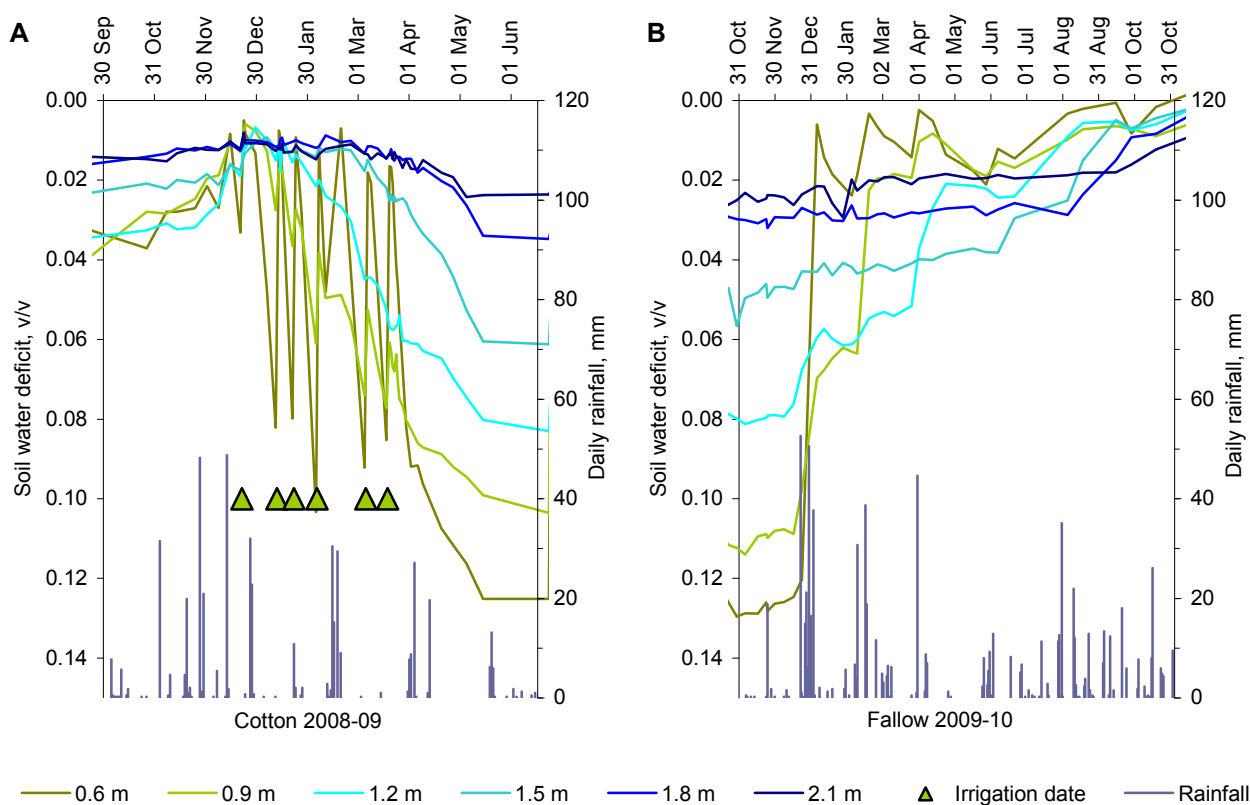


Figure 2. Soil water deficit (relative to drained upper limit) of subsoil layers from 0.6 – 2.1 m depth during A) the 2008-09 cotton crop and B) the 2009/10 fallow measured by neutron moisture meter.

Table 1. Drainage and its electrical conductivity after each irrigation during the 2006/07 2008/09 and 2010/11 cotton seasons as measured by the ACRI lysimeter. Amounts shown are from the date of the event until the date of the next event shown on the next row. “↓” indicates there was too little drainage for collection and analysis, so drainage was accumulated over several events.

Event	2006/07			2008/09			20010/11		
	Date	Drainage mm	EC dS/m	Date	Drainage mm	EC, dS/m	Date	Drainage mm	EC dS/m
Sowing	19-Oct	0.0		09-Oct	5.5	3.4	04-Nov	0.4	↓
Irrigation 1	24-Oct	8.8	3.1	22-Dec	13.3	3.8	20-Jan	0.1	↓
Irrigation 2	22-Nov	22.0	2.2	12-Jan	7.3	2.9	02-Feb	0.1	4.9
Irrigation 3	12-Dec	34.7	2.1	22-Jan	8.6	2.6	17-Feb	0.1	↓
Irrigation 4	03-Jan	3.6	2.1	05-Feb	9.3	3.6	01-Mar	0.1	↓
Irrigation 5	16-Jan	0.2	2.2	06-Mar	2.5	5.5	16-Mar	0.1	3.7
Irrigation 6	30-Jan	0.5	2.5	19-Mar	7.4	8.1			
Irrigation 7	14-Feb	2.1	2.6						
Irrigation 8	28-Feb	2.3	3.2						
End	18-May			23-Jun			24-Jun		
Season total		74.2		53.9			0.7		