Deep drainage in a Vertosol under irrigated cotton

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Abstract

Deep drainage below the root zone of irrigated crops is both a waste of a scarce resource and a cause of potential environmental problems such as water logging and salinity. We measured deep drainage under furrow irrigated cotton on a Grey Vertosol using a variable tension lysimeter over two contrasting irrigation seasons. The amount of drainage was dependant on both the antecedent moisture conditions and the amount of early season rainfall. Bypass flow was detected in both seasons.

Key Words

Deep drainage, bypass flow, irrigation, water balance, Vertosol, cotton

Introduction

Over much of the history of the Australian cotton industry, it was believed that losses of water below the root zone – deep drainage – were insignificant because of the heavy clay soils on which cotton is grown. During the 1990s there was increasing concern that greater rates of deep drainage compared to native vegetation in both irrigated and dryland situations could raise watertables, mobilize salt stored in the landscape and cause waterlogging and salinity. Although salinity was not a problem for the cotton industry, it was sufficiently concerned to commission research on drainage, not just because of its potential to cause environmental problems but also because it represents a waste of an increasingly scarce resource. This research found deep drainage to be significant under furrow irrigated cotton, despite the low hydraulic conductivity of the Grey Vertosols on which it is grown, and in excess of what is required to prevent a build up of salinity.

Furrow irrigation is commonly used by the cotton industry in Australia since it can be implemented at relatively low cost over large areas. However, it can cause undesirable rates of drainage for several reasons. It is difficult to control the amount applied, which can lead to over application when the soil water deficit is small. During irrigation, free water is present at the soil surface with the potential of moving rapidly down macropores and bypassing the soil matrix. The project described in this paper aimed to directly measure deep drainage using lysimetry and investigate the mechanisms causing it.

Methods

Lysimeter location

We constructed an equilibrium drainage lysimeter at the Australian Cotton Research Institute near Narrabri in northern New South Wales (30° 11.53' South, 149° 36.31' East) in an experimental plot under a cotton-wheat rotation. Cotton crops are furrow irrigated, but wheat crops only receive supplementary irrigation if there is a risk of crop failure. Minimum tillage is used with stubble retention and permanent beds. Alternate furrows are used for traffic and irrigation. The plot is approximately 200 m long from head to tail ditch.

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

Lysimeter design

Direct measurement of drainage is difficult because most instruments interfere with drainage by altering the hydraulic gradient which is the major driver of water movement. Brye *et al.* (1999) addressed this problem by designing an equilibrium tension drainage lysimeter (or variable tension drainage lysimeter). This consists of a collection tray to which a vacuum is applied that is equal to that in the surrounding soil to make the lysimeter "hydraulically invisible". The design was improved by Pegler *et al.* (2003) by introducing automated regulation of the vacuum. Our design was a modification of those by Brye *et al.* (1999) and Pegler *et al.* (2003). The lysimeter is situated under the root zone at 2.1 m depth, half way between the head and tail ditches. The lysimeter consists of an array of six collection trays (0.91 × 0.29 m area, 0.13 m high) covering a total area of 1.82 × 0.87 m. The trays are essentially stainless steel boxes, whose upper surface is made of porous, sintered stainless steel, 1 mm thick with a nominal pore size of 0.2 µm. Once saturated with water it can hold water up to a potential of -28 kPa. The floor of each tray slopes to a drain in one corner. Each tray also has an internal riser tube in the opposite corner for connection to a vacuum reservoir.

The trays were inserted by excavating horizontally from a cylindrical, concrete access shaft (4 m deep, 2 m diameter) located under neighbouring furrows. Hence the overlying soil is not disturbed. One benefit of having a lysimeter with no walls is that there is no interference with the natural shrink/swell behaviour of the soil. The ceiling of the cavity into which the trays were inserted was prepared by peeling away the soil using polyester resin to ensure a natural surface. A contact material was packed between the ceiling and the trays for hydraulic continuity. The material was manufactured from silica flour, graded to remove particles less than 15 µm. The drain from each tray was connected to a collection tank in the access shaft. Similarly the internal riser tube was connected to a vacuum reservoir kept at approximately -40 kPa.

Two vertical arrays of five tensiometers were installed though the wall of the access shaft at depths from 0.9 to 2.1 m. The vacuum inside the trays is regulated by a data logger via solenoids so that it equals the average potential measured by the two tensiometers at 2.1 m depth. The vacuum is adjusted every 15 minutes. At the same time the weight of drainage in the collection tanks and the soil water potentials measured by the tensiometers are recorded. The collection tanks can be isolated from the trays to allow emptying.

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.

Results

The lysimeter monitored both the 2006-07 and the 2008-09 irrigation seasons, although data monitoring was not automatic for the first of these. The amounts of drainage recorded after each irrigation are shown in Table 1. Cumulative drainage is shown in Figure 1. The total drainage for the seasons varied by a factor of 1.75 due to different conditions before and during the seasons. The subsoil was relatively wet at the start of the 2006-07 season. However, there was little rain before sowing, so the crop required irrigation shortly after sowing. In addition, in-season rainfall (September-April) was only 224 mm and the crop required a total of 8 irrigations. In contrast, the subsoil was relatively dry at the start of the 2008-09 season, but there was sufficient rain in the early part of the season that irrigation was not required until 22 December. There was more than twice the in-season rainfall, 498 mm, and only 6 irrigations were required.

Table 1. Drainage after each irrigation during the 2006/07 and 2008/09 irrigation seasons.

2006/07 season		**2008/09season**	
Irrigation date	**Drainage, mm**	**Irrigation date**	**Drainage, mm**
24 Oct	8.8		
22 Nov	22.0		
12 Dec	34.7	22 Dec	13.4
03 Jan	3.6	12 Jan	7.3
16 Jan	0.2	22 Jan	8.6
30 Jan	0.5	05 Feb	9.3
14 Feb	2.1	06 Mar	2.5
28 Feb	2.3	19 Mar	1.5
Total for season	**74.2**		**42.5**

2008-09 irrigation season

Figure 1 shows that the amount of drainage was greatest after the earlier irrigations and declined to very low values after the fifth and sixth irrigations. At the start of the season the subsoil below 0.75 m was relatively dry with a deficit of 88 mm between 0.75 and 1.95 m depth (Figure 2). There was 200 mm of rainfall before the first irrigation, which reduced the deficit to 49 mm. The first irrigation wet the soil above 0.75 m and, to some degree the soil below this. The crop was reasonably advanced by the first irrigation, and dried the soil above 0.75 m considerably after each irrigation. This helps explain why the 0.75-1.35 m layer was only slightly wetted up by each irrigation and, overall, dried from January onwards.

The 1.35-1.95 m layer was scarcely affected by each irrigation and reached a minimum deficit of 15 mm. It too dried from March onwards. This is also reflected in the matric potential at the bottom of the root zone (Figure 3) which reached a maximum of only -18 kPa. Despite the subsoil remaining reasonably dry, drainage still occurred throughout the season. The rate of drainage sharply increased about 6 hours after each irrigation front passed over the lysimeter, as shown in Figure 4 for the irrigation on 12 January 2009.

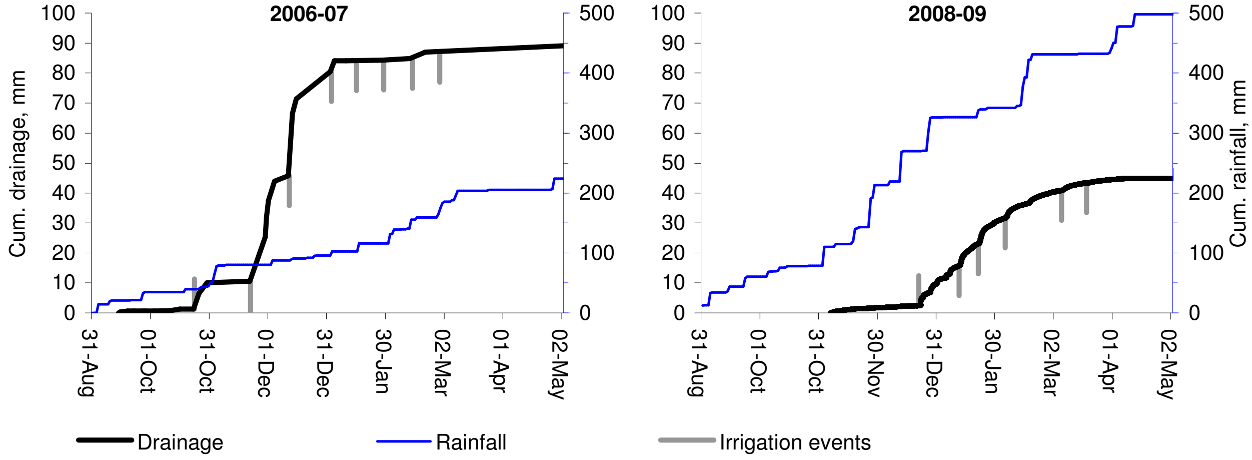

Figure 1. Cumulative drainage (left vertical axis) and cumulative rainfall (right vertical axis) during the 2006/07 and 2008/09 irrigation seasons. Dates of irrigation events are shown as vertical bars.

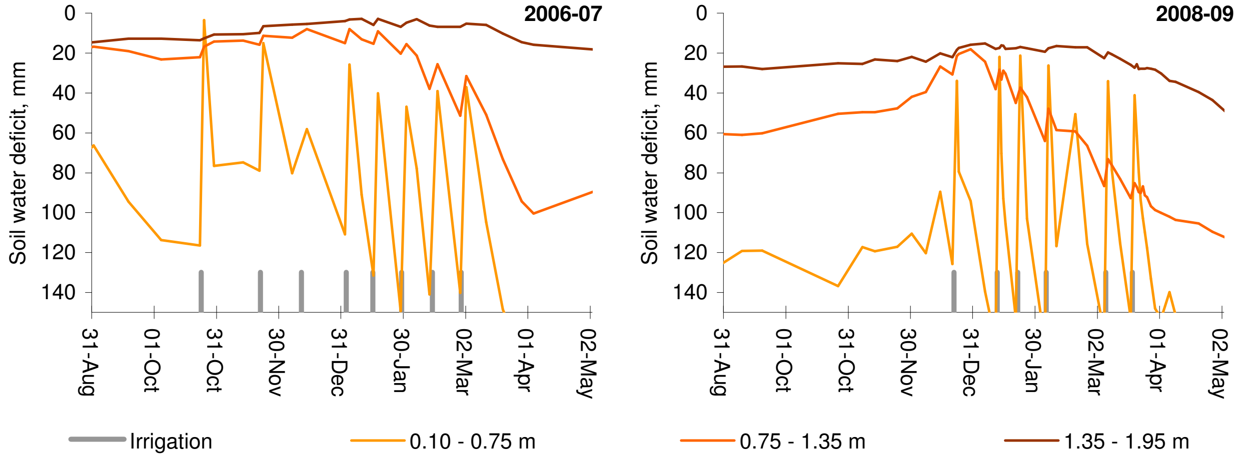

Figure 2. Soil water deficit of three layers during the 2006/07 and 2008/09 irrigation seasons calculated from measurements made by neutron moisture meter (means of 4 replicates). Dates of irrigation events are shown as vertical bars.

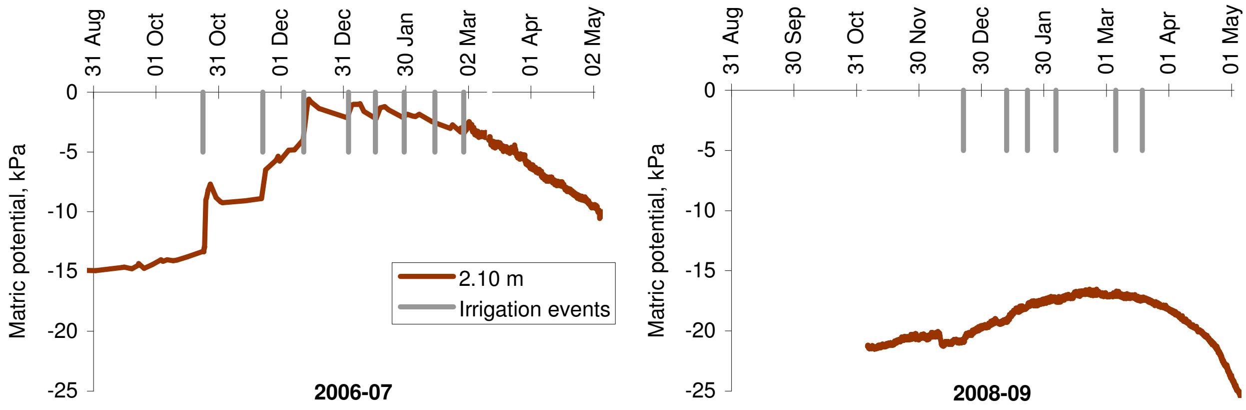

Figure 3. Matric potential of the soil at 2.1 m depth during the 2006-07 and 2008-09 irrigation seasons (means of 2 replicates).

The soil water potential of the soil below 1 m showed no response to this water movement. In fact the hydraulic gradient at 2.1 m during this event was upwards, with a downward gradient only occurring above 1.5 m (Figure 4). This suggests that most of the drainage occurring during the 2008-09 season was due to by-pass flow – that is flow through macropores that by-passes the soil matrix. Given that cracks only occur within the top metre or so, the likely route for by-pass flow was through slickensides that occur deep in this profile and which were observed during installation of the lysimeter. Interestingly, drainage occurred continuously between irrigations long after free water had disappeared from the soil surface, albeit at a decreasing rate. As the season progressed, the gradually increasing deficit in the 0.75-1.35 m layer increased the amount of irrigation water that was ‘captured’ before it could become drainage, thereby reducing the drainage rate.

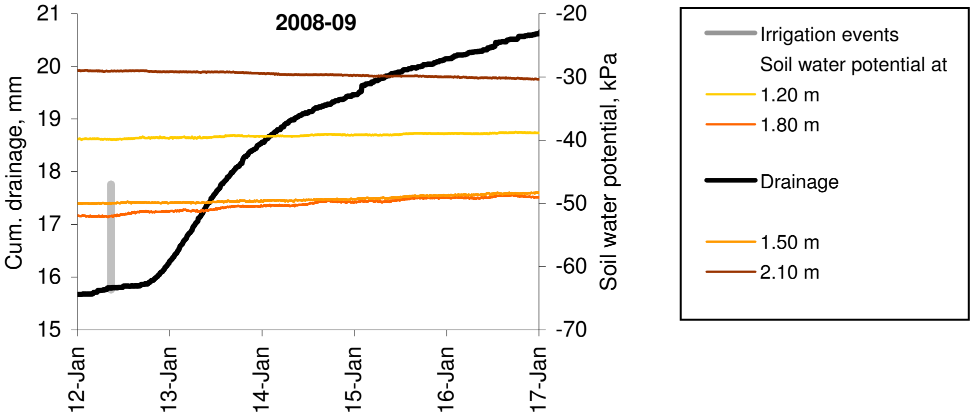

Figure 4. Detail of cumulative drainage after an individual irrigation event on 12 January 2009. Also shown is the soil water potential (matric + gravity) at 4 depths (means of 2 replicates). The time the irrigation front passed over the lysimeter is shown by a vertical bar.

2006-07 irrigation season

Drainage during the 2006-07 season was 1.75× greater than during the 2008-09 season. At the start of the season the soil water deficit from 0.75-1.95 m depth was 32 mm. There was little rain in the early part of the season, and by the third irrigation the deficit had been reduced to 13 mm (Figure 2). Figure 3 shows that this was accompanied by a rapid rise in matric potential at 2.1 m depth from -15 kPa to close to saturation. The crop was relatively undeveloped up to the fourth irrigation, and created only small deficits between irrigations. This resulted in large quantities of drainage after the second and third irrigations. Drainage after the first irrigation was presumably mitigated as the profile wet up. As the season progressed, the rate of drainage decreased as the crop created increasingly large deficits between irrigations.

Conclusions

Antecedent conditions are very important in determining drainage during the cotton season. The deficit of the subsoil below 0.75 m depth plays an important role. In addition, the need for early season irrigation, before the crop is able to extract significant quantities of water, causes rapid wetting of the deep subsoil and high drainage rates. However, it appears that some drainage via by-pass flow is unavoidable due to the presence of free-standing water on the surface during furrow irrigation. It is possible that surface cracks increase by-pass flow by connecting the surface to slickensides in the deep subsoil. If so, then early season rainfall in 2008-09 could have caused the surface cracks to close and reduced the amount of water reaching the deep subsoil. In contrast, the early irrigations in 2006-07 could have reached the subsoil much faster due to surface cracks, and resulted in more bypass flow.

Acknowledgements

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References

Brye KR, Norman JM, Bundy LG, Gower ST (1999) An equilibrium tension lysimeter for measuring drainage through soil. *Soil Science Society of America Journal* **63**, 536-543.

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).