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Measuring components of the water balance for furrow irrigated cotton
Détermination des composantes du bilan hydrique pour une irrigation du coton à la raie

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INTRODUCTION

A major problem facing the Australian cotton industry is the availability of water for irrigation and the impact of the industry on downstream water quality and quantity. Efficient irrigation practices are essential for optimising the use of water and for avoiding environmental problems such as salinity. To achieve this an understanding of the soil water balance is required. The aim of this research is to quantify components of the soil water balance for irrigated cotton.

METHODS AND MATERIALS

This paper presents the finding from the first of three seasons of fieldwork. The field site was located in the Namoi River Valley in Northern New South Wales, Australia. The soil was a cracking grey clay (Typic Pellustert), typical of soils used for irrigated cotton production. Cotton is produced under furrow irrigation. The water is lifted from the Namoi River using pumps, then it flows by gravity along the main channels. Gates along these channels allow water to flow into the head ditch from which the field was irrigated using 50 mm OD siphons. The field was 200 m long with a slope of 1 in 1176. The siphons were pulled from the headditch once the water reached the tail drain at the end of the field. The tail drain was used to collect runoff from the field during an irrigation or heavy rainfall event.

The soil water balance is described by Equation 1, which states that water input (P+I) is equal to water output (R+Et+D) plus soil water storage (S).

$$P+I = R+Et+D+\Delta S \qquad (1)$$

where P = precipitation
I = irrigation
R = runoff
Et = evapotranspiration
D = drainage
ΔS = change in soil water storage

The quantity and intensity of rainfall was measured using a tipping bucket rain gauge.

The amount of irrigation water applied and runoff at the end of the rows was measured using a long throated venturi flume (Australian Standard 1991). Each flume collected the flow from two furrows, one trafficked and one not. A flume creates an artificial constriction in the furrow, which, by producing a change in the velocity and depth, facilitates the measurement of discharge. The flow changes from a deep slow moving stream to a fast shallow stream through the flume, and a hydraulic jump forms at the exit. When this set of flow conditions occurs there is a fixed mathematical relationship between upstream depth and the quantity of water flowing (Equation 2).

$$Q = 1.71Cbh^{1.5} \qquad (2)$$

where Q = flowrate (L/s)
C = coefficient of discharge (typically 0.98)
b = width of flume at throat (mm)
h = depth of water upstream (m)

Actual evapotranspiration was measured using the Bowen ratio method. This involves estimating Et from climatic measurements concerned with the energy balance equation (Equation 3).

$$Rn = H + LEt + G \qquad (3)$$

where Rn = net radiation
H = sensible heat exchange between the earth’s surface and the atmosphere
L = latent heat of vaporisation
Et = evapotranspiration
G = heat flux into the earth’s surface

Rn and G can be measured directly using a net radiometer and soil flux plate respectively. However, H is more difficult to measure. Bowen (1926) proposed the use of the ratio of sensible and latent heat fluxes to facilitate the determination of Et. The Bowen ratio β, is defined by Equation 4.

$$\beta = H/(LEt) = [\rho CpKh(dT/dz)] / [\rho LKe(dq/dz)] \qquad (4)$$

where ρ = density of air
Cp = specific heat of air \at constant pressure
Kh = coefficient for eddy diffusion of sensible heat
Ke = coefficient for eddy diffusion of latent heat
dT/dz = temperature gradient above crop
dq/dz = specific humidity gradient above crop

Given that the coefficients of eddy diffusion of sensible (Kh) and latent (Ke) heat are the same (Faulkner 1992) Bowen's ratio takes the following form:

$$\beta = [Cp(T1-T2)]/[L(q1-q2)] \qquad (5)$$

where $T1$ and $T2$ are the temperatures within the crop canopy and above the crop canopy

$q1$ and $q2$ are the specific humidity within the crop canopy and above the crop canopy.

As specific humidity cannot be measured directly Faulkner (1992) modified the expression to involve gradients of vapour pressure rather than specific humidity to obtain the modified Bowen's ratio.

$$\beta = \gamma(T1-T2)/(e1-e2) \qquad (6)$$

where γ is the psychrometric constant

$e1$ and $e2$ the vapour pressure within and above the crop canopy.

Equation 4 can then be rearranged to calculate Et:

$$Et = (Rn-G)/(L+\beta) \qquad (7)$$

A Direct Reading Evapotranpsiration Assessment Monitor (DREAM system) developed by Faulkner (1992) was used to measure the inputs required to determine Bowen's ratio and the corresponding Et.

Drainage of water below the root zone was measured by taking successive measurements of water content at appropriate depths and calculating the daily change in water storage. Soil water storage was measured directly using a neutron probe. Measurements were taken at 10 cm intervals from 20 –130cm.

Hydraulic gradients measured using tensiometers indicated the direction of water movement. Under saturated conditions drainage was estimated from the soils hydraulic conductivity measured with a well permeameter.

RESULTS

The components of the water balance are presented in Table 1. There was no precipitation over the test periods. During the first irrigation 94 mm (0.94ML/ha) of irrigation water was applied which is close to the industry standard application rate of 1ML/ha. A total of 4.4mm of water was lost through runoff and deep drainage. The change in soil water storage (ΔS) as measured with the neutron probe is close to the ΔS calculated from the water balance equation given the measured components.

For the second irrigation, the soil was wetter prior to irrigation compared to the first irrigation, leading to greater runoff. Unfortunately there was some leakage from an adjoining furrow when a siphon was inadvertently re-started, which could also increase runoff from the monitored furrow. This could account for the difference between actual and calculated ΔS.

Table 1: Components of the soil water balance

	I (mm)	R (mm)	Et (mm)	D (mm)	ΔS (mm)	Calculated ΔS (mm)
Irrigation 1 (23rd Feb – 27th Feb)	94	2.4	22.9	2.04	65.1	66.7
Irrigation 2 (12th Mar – 14th Mar)	82	6.4	10.0	1.02	55.9	64.6

The irrigation application efficiency, defined as the ratio of the amount of water available for plant uptake to the volume of water applied, for the first and second irrigation events are 95 and 90 per cent respectively. Raine (1995) measured the irrigation application efficiency of furrow irrigated sugar cane grown on a cracking clay soil. The average efficiency of seven monitored irrigation events was 62 per cent. Factors that affect the efficiency of an irrigation include field slope, row length, soil type, water application rate, time when water application ceases and initial soil moisture content.

CONCLUSIONS

This research has developed a means of quantifying the components of the water balance. The set of preliminary data collected show that drainage from heavy grey clay soils is a small component of the soil water balance, and that irrigation application efficiencies of at least 90 per cent were achieved. The experiments will be repeated over the next two cotton seasons on two different soil types, a heavy clay and a lighter alluvial soil.

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