Soil water dynamics and components of the water balance for irrigated lucerne in southern NSW

M. Edraki, E. Humphreys and N. O'Connell

CSIRO Land and Water, Griffith

August 2003

Murray Irrigation Limited
A.C.N. 067 197 933

Coleambally IRRIGATION

NATIONAL PROGRAM FOR Sustainable Irrigation

CSIRO Land and Water Technical Report 41/03

Acknowledgements

This work was undertaken as an activity under the project "Rigorously determined water balance benchmarks for irrigated crops and pastures". The project was a collaborative project between CSIRO Land and Water and Murray Irrigation Ltd, with supplementary funding from the Land and Water Australia National Program for Irrigation Research and Development (LWA-NPIRD) and Coleambally Irrigation Cooperative Ltd.

We thank:-

- Roy Zandona of CSIRO Land and Water for much assistance in the design, acquisition and installation of electronic logging equipment, and David Smith and Brad Fawcett for assistance in installation of soil water monitoring equipment and particle size analyses

- Nadja Meister, a work experience student from the University of Kassel, Germany, who contributed to the determination of soil hydraulic properties.

- NSW Agriculture staff for advice and assistance, especially Vivien Naimo, John Thompson and Sam North

- Steve Langman of Deniliquin for casual assistance.

- the members of the steering committee for initiating the work and for participation in meetings and for their suggestions and feedback, in particular Max Goudie, Ian Gillett, Geoff McLeod, Derek Poulton, Geoff Beecher, John Thompson

- Phil Snowden and family for the opportunity to undertake monitoring in their field, and for their assistance in many ways.

Table of contents

Summary

Soil water dynamics and components of the water balance were determined for irrigated lucerne near Finley, NSW, over four irrigation seasons from 1998 to 2002. The lucerne was growing on Cobram loam, a soil with a deep loam topsoil and medium clay subsoil, rapidly changing to sand below 2 m. The watertable was at about 3.3 m at the start of the monitoring period in November 1998.

Soil water status was monitored using Enviroscan sensors and Watermark granular matrix sensors, the groundwater was monitored in piezometers at 0.75 and 3.5 m, and irrigation applications were measured using a Dethridge Wheel and Starflow meters. Crop water use was estimated from reference evaporation (ETo) and crop factors from empirical determinations in weighing lysimeters.

The lucerne received 10 to 13 irrigations each season, on average after every 110 mm of evaporative deficit (ETo-R). An irrigation interval of 100 mm has previously been shown to avoid water deficit stress and ensure maximum production in this region. Total irrigation application ranged from 693 mm in a season with ETo-R about 100 mm lower than the long term average at Finley, to 986 mm in a season with ETo-R about 120 mm higher than average.

At the start of the irrigation season there was evidence of soil wetting to at least 1.8 m, and the soil at 1.2 m and deeper became saturated and remained saturated throughout the irrigation season. During the irrigation season soil water extraction was largely confined to the upper 0.6 m of the soil profile. At the end of the season the lucerne progressively dried the soil profile in deeper and deeper layers, with significant drying observed at 1.8 m.

A lumped monthly water balance suggested that drainage beyond 1.2 m only occurred in a few months when there was significant rainfall during the irrigation season, and during winter. Water use from below 1.2 m was substantial in some months, particularly prior to the start of the irrigation season in 2000 and 2001, and during the 2001/2 season with higher than average evaporative deficit. Over the four seasons the lumped water balance suggested net water use of about 1,300 mm from below 1.2 m.

The watertable remained at 3.3 m or deeper throughout the period, and there was no evidence of recharge associated with irrigation.

The results suggest that over each full year, there was net discharge from below 1.2 m from irrigated lucerne, despite frequent irrigation and mowing during the growing season. Any water that moved below 1.2 m during the irrigation season was used by the lucerne during the non-irrigated period. Other studies have shown that in the presence of a shallow watertable, frequently irrigated lucerne acquires a significant proportion of its water use from upflow from the watertable. Thus well-managed lucerne can be a productive irrigated landuse and at the same time assist watertable control in both deep and shallow watertable areas.

Introduction

The development and implementation of Land and Water Management Plans for major irrigation areas in southern Australia commenced in the 1980s, in response to problems of rising watertables and salinisation (MDBC, 2001; McLeod, 1998). These plans have provided a set of initiatives directed primarily to control watertables and secondary salinisation through net recharge management, where net recharge is the result of recharge of the watertable (from irrigation and rain) and discharge (from lateral flow, downwards leakage, capillary upflow, plant transpiration and soil surface evaporation). However, the fate of water applied to the range of irrigated land uses across the range of site conditions and management has seldom been quantified. Increasingly, Land and Water Management Plans need to rely on water balance models of fields, farms and regions to help identify sustainable and affordable land and water management options (Khan et al., 2001). Calibration and validation of such models are critical for ensuring that guidelines and policy are soundly based, and to give policy makers and landholders the confidence to follow through to implementation. Therefore Murray Irrigation Ltd and Coleambally Irrigation Cooperative Ltd sponsored a field monitoring project with the National Program for Irrigation Research and Development (NPIRD) to determine components of the water balance, watertable behaviour and soil parameters for a range of irrigated crops including maize, winter cereals, annual pasture and lucerne (Humphreys and Edraki 2003). This report presents the findings from the determination of components of the water balance for lucerne during the period October 1998 to March 2002 in southern New South Wales.

Methods

Site

Components of water balance were determined for Lucerne (*Medicago sativa* L.) cv. Aquarius from November 1998 to April 2002. The 24 ha field was located on a private farm approximately 12 km west of Finley, NSW, Australia (145^0 33_ E, 35^0 39_ S). The soil has a fine sandy loam topsoil, changing to a light to medium clay below 30 cm, and is locally known as Cobram loam (Smith 1945), a Red Brown Earth (Stace et al. 1972) or Xeralf (Soil Survey Staff 1975). Soil physical properties are summarised in Table 1. A shallow prior stream (sandy aquifer) ran under the farm and the farmer pumped groundwater from the aquifer to supplement surface irrigation water supplies, however the field in this study was not irrigated with groundwater. Salinity of the groundwater was around 0.6 dS/m

The field grew sub-clover prior to sowing lucerne in spring 1997 on a border check layout with a grade which varied from 1:200-1:1000. The bay widths were 40 m and lengths varied from 150-400 m. The monitored bay was about 300 m long.

In August 1998, the field was surveyed using electromagnetic inductance (EM31) to identify the spatial distribution of the bulk soil conductivity over the soil profile to a depth of about 5 m (Beecher et al. 2002). EM31 values are influenced by a range of soil properties including water content, salinity and clay content, and low EM31 values are often associated with high infiltration rates (Beecher et al. 2002). The results of the survey were used to identify sites of low and high conductivity for the installation of monitoring equipment (Figure 1), with the objective of determining components of the water balance at sites covering likely extremes of soil permeability in the field. The low and high EM sites were located in the same bay. Subsoil clay content from ~60-240 cm was higher at the high EM site (Figure 2). Below 2 m, the clay content of the soil decreased at both sites with sand content rapidly increasing with depth to about 90% at 3 m.

Figure 1. EM31 survey of lucerne field

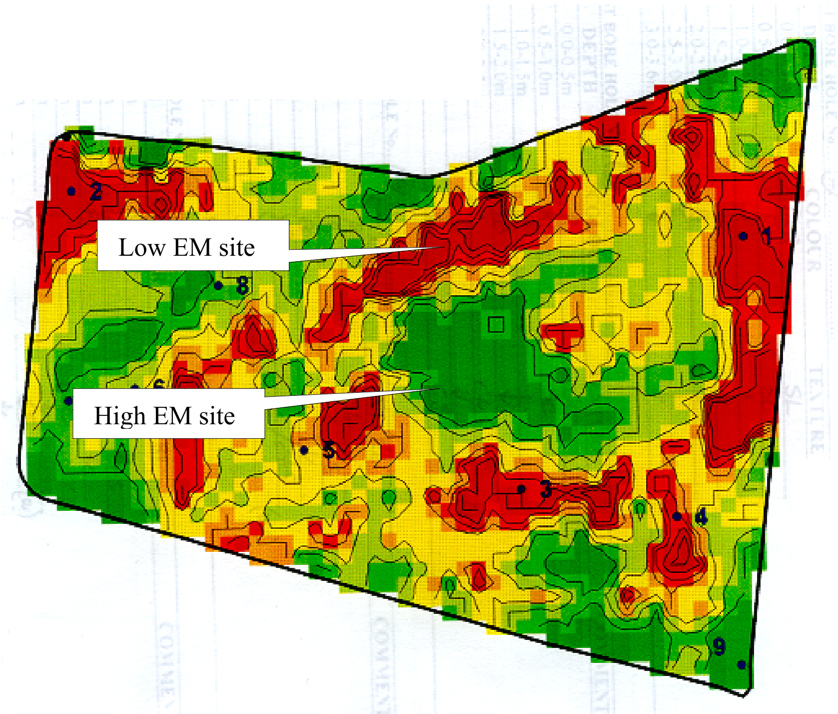


Figure 2. Soil profile clay and sand contents at the two EM31 sites

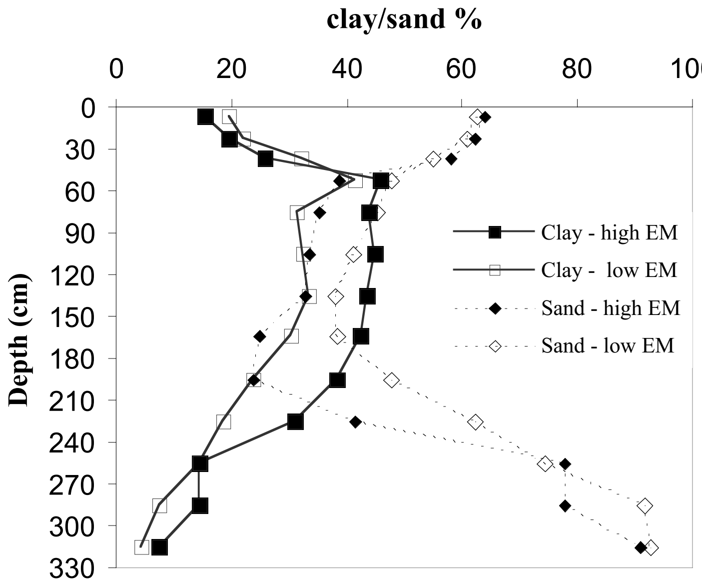


Table 1. Soil properties at the two monitoring sites (low, high) [a]

Depth interval (cm)	Bulk density (g/cm³)		% clay		% silt		% sand		Hydraulic cond (mm/h) at specified d		
									4 cm tension		
	Low	High	Low	High	Low	High	Low	High	Low	High	
0-15	1.48 (0.06)	1.44 (0.07)	20	16	18	20	63	64	9.0 (2.9) 5 cm	13.6 (8.5) 5 cm	6.
15-30	1.59 (0.02)	1.60 (0.07)	22	20	17	18	51	62			
30-45	1.74 (0.04)	1.65 (0.17)	32	26	13	16	55	58			
45-60	1.70 (0.09)	1.69 (0.05)	42	46	11	16	48	39	0.6 (1.01) 50 cm	0.4 (0.03) 60 cm	0.7
60-90	1.72 (0.07)	1.70 (0.03)	32	44	23	21	45	35			
90-120	1.86 (0.23)	1.86 (0.26)	32	45	26	22	41	34	2.1 (1.2) 100 cm	0.9 (0.51) 100 cm	0.
120-150	1.72	1.76 (0.16)	34	44	28	24	38	33			
150-180			30	43	31	33	38	25			
180-210			24	39	28	38	48	24			
210-240			19	31	19	27	62	42			
240-270			15	15	11	8	74	78			
270-300			8	15	1	8	92	78			
300-330			4	8	3	2	93	91			

[A] low and high refer to apparent electrical conductivity as determined by EM31 survey.
[B] determined using disk permeametry (Meister 2002)
[C] standard deviation in brackets (n=3)

Management

The lucerne was harvested (cut and bailed) regularly by the farmer, mostly for hay production, during late spring, summer and early autumn. Dates of cuts are shown in Table 2. Lucerne yield was monitored in the first irrigation season by hand harvesting 0.5 m^2 quadrats. There was good agreement between the hand harvests and the farmer yields, and since the farmer was regularly mowing the paddock and recording yields, it was decided to use the farmer's yields for future harvests.

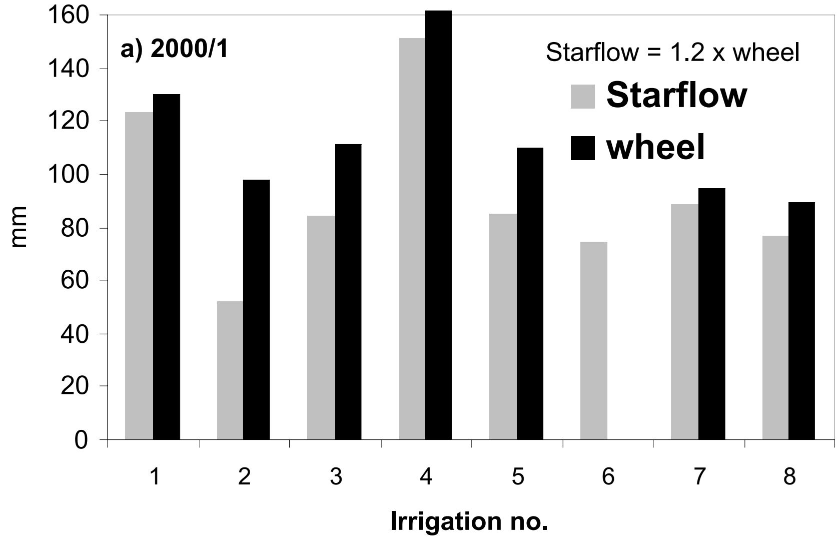
Prior to each irrigation season, poultry manure was applied at 4 t/ha. In the 2001/2 season, the paddock was topdressed with potassium chloride ("potash") at 250 kg/ha. There was no significant damage due to weeds and pests, which were controlled periodically by spraying for weeds with Sprayseed @ 2 L/ha and Diurex @ 1.5 kg/ha in late winter, and for pests with Fastac @ 200mL/ha, and Dimethoate @ 85mL/ha in March/April.

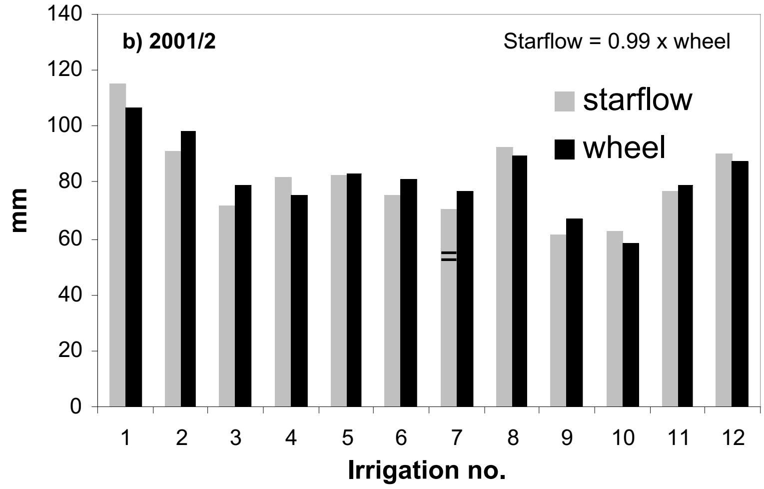
The field was flood irrigated using river water (~0.05 dS/m) via a channel which ran along the top of the field. The duration of irrigations for the whole field varied from 3 to 5 days. The farmer used an electronic sensing and alarm system to inform him when the irrigation water front had reached two-thirds the way down the bays so that he could switch water to the next bays and avoid overwatering.

Irrigation, surface drainage and rainfall

Water was diverted from the district irrigation channel to the farm supply channel through a Dethridge wheel with a manual counter which was read weekly during the irrigation season by Murray Irrigation Ltd staff. The farm supply channel was connected to a field supply channel through a pipe (480 mm ID) which always ran full when irrigating. An automatic ultrasonic flow meter (Starflow®) was installed near the outlet of the pipe, with in excess of 10 pipe diameters of straight pipe upstream from the meter, and 2 pipe diameters downstream. The Dethridge and Starflow® meters were in close proximity (~20 m). Flow rate was logged hourly using the Starflow® meter. There was a reasonably strong relationship between wheel and Starflow® measurements, however the relationship was inconsistent across years. Examples of the comparison between the wheel and Starflow® estimates are given for the 2000/1 and 2001/2 seasons (Figure 3) using a different Starflow® meter each year. The Starflow® measurements were on average 35% higher than the wheel in 1998/9, 20% higher in 2000/1, and similar in 2001/2. Therefore there was considerable uncertainty in the Starflow data, and the Dethridge wheel data were used in the water balance calculations. The logged data were useful for identifying the exact dates of irrigation.

Figure 3. Comparison of the wheel and flowmeter irrigation depths in a) 2000/1, and b) 2001/2 irrigation seasons





The field was irrigated between November and March in 1998/9 and 2000/1, and between September and March in 1999/2000 and 2001/2 due to dry spring weather.

Surface runoff was collected in a recycling system and pumped back into the field supply channel. Rainfall was measured by the farmer in a manual rain gauge at the edge of the field.

Groundwater levels

Piezometers were installed to depths of 0.75 and 3.3 m at the high and low EM31 sites in November 1998. The piezometers were read manually, and were always dry except at the date of installation. Therefore a deeper (4 m) piezometer was installed in November 2000 at the high EM sites. Attempts to install a 4 m piezometer at the low EM site were unsuccessful due to the sides of the hole collapsing,

The piezometers consisted of PVC (50 mm OD) pipes perforated along the bottom 0.5 m. The piezometers were installed by augering a hole wider than the diameter of the piezometers, backfilling the hole with gravel adjacent to the perforations, then backfilling with bentonite plugs and soil to prevent artificial flow of water down the outsides of the piezometer pipes.

Soil water content

In late October 1998, Enviroscan®[1] probes were installed at the two EM 31 locations with sensors at 20, 30, 40, 60, 120 and 250 cm. Because of concerns of possible bypass flow down the sides of the Enviroscan® tubes (as suggested by the rapid rise in soil water content at all depths immediately following irrigation), the probes were reinstalled and recalibrated in November 2000. The sensors were reinstalled at the same depths except that the deepest sensor was at 180 cm instead of 250 cm. Soil water content was logged hourly. The change in volumetric soil water content at 180 cm was negligible, therefore the total profile water content reported here is the sum of water content from 0 to 120 cm.

Calibration of the sensors at each EM site was carried out by regressing the Enviroscan readings against volumetric soil water content determined from 3 cores (10 cm diameter x 10 cm long) taken from each monitoring depth using brass rings. Raw readings were converted to the depth of water (mm) stored in each 10 cm layer at the sensor depths. The data from both EM31 sites and all soil layers fitted well in the one regression, therefore a single calibration equation was used for all depths and both sites for the initial installation (Figure 4a), and calibration was repeated and a new equation developed following reinstallation in November 2000. Soil water content between the sensors was determined by interpolation, and the water content in the 0-20 cm layer was assumed to be the same as the reading at 20 cm (15-25 cm layer).

[1] Use of registered trade names does not imply endorsement

Figure 4a. Initial Enviroscan® calibration

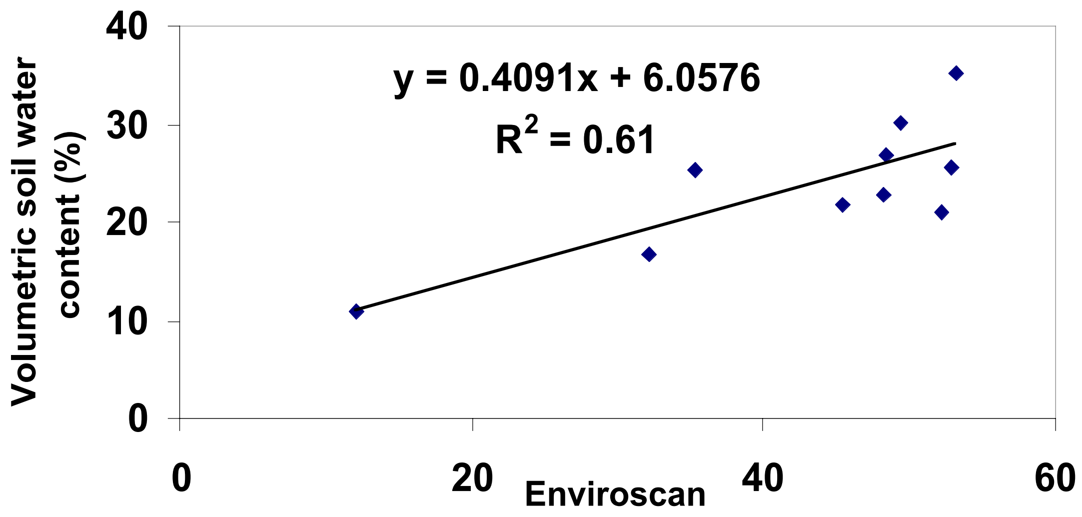
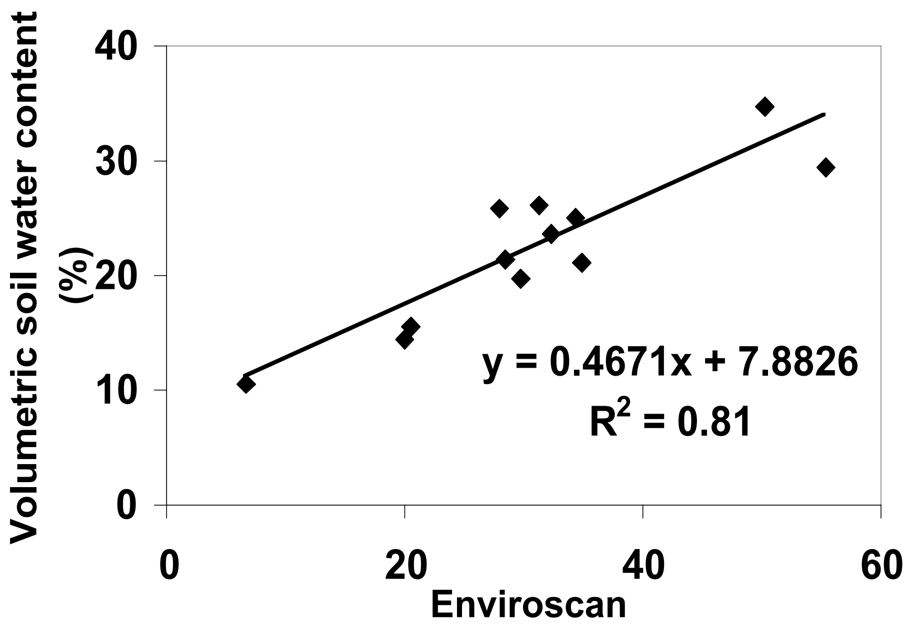


Figure 4b. Enviroscan calibration after reinstallation in November 2002



Soil water potential

In November 2000, granular matrix block sensors (Water Mark®) were installed in the high EM site at the same depth as the Enviroscan® sensors, and logged with a Campbell® logger to monitor the changes in soil matric potential. The main purposes were to observe wetting and drying in deeper soil layers and to detect evidence of drainage from the root zone to the deeper layers as a result of irrigation.

Manually read tube tensiometers were also installed in close proximity to and at the same depths as the Enviroscan® sensors at the high EM site and monitored during 2001/2. Occasional readings of the tensiometers were made with a manual (Loktronic®) pressure transducer, and the data were used to determine the soil water characteristic with simultaneous readings of the Enviroscan® sensors.

Unsaturated soil hydraulic conductivity

Unsaturated hydraulic conductivity was determined in the major soil horizons at depths of 5, 50-60 and 100 cm at both EM sites using disc permeameters (Anon. 1988). Soil pits were excavated in the vicinity of the low and high EM sites after the end of the irrigation season in 2002, and determinations were done in triplicate at soil water potentials of -0.4 and -0.8 kPa. The methods are described in greater detail in Meister (2002).

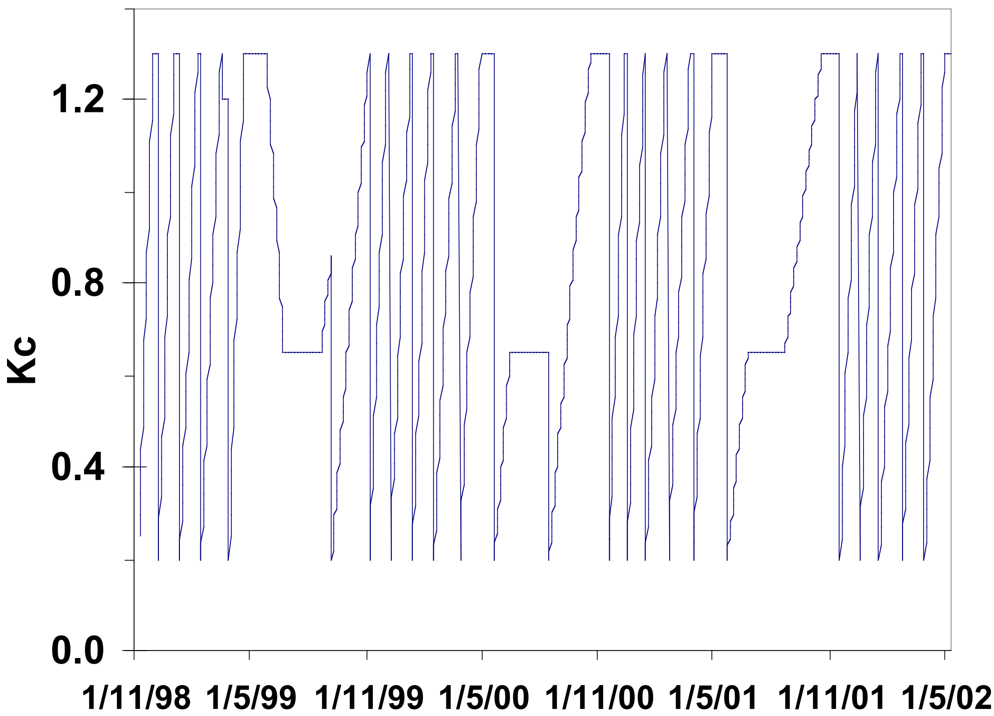
Saturated hydraulic conductivity

Saturated conductivity at 4 m was determined using a slug test (Smith and Mullins 1991) in the 4 m piezometer at the high EM site in March 2002.

Weather data and reference evapotranspiration

Temperature, radiation, windspeed, rainfall and humidity were logged hourly at the CSIRO Finley weather station about 12 km from the field. Reference evapotranspiration (ET_o) for the period was calculated using a locally calibrated modified Penman equation (Meyer 1999). Crop evapotranspiration (ETc) was estimated from K_c x ET_o, where K_c is the crop factor derived from the relationship in Figure 20 in Meyer et al. (1999), noting that Kc declined to 0.2 upon cutting, and increased rapidly to 1.3 over a period of about 20 days. The values of Kc used for this study are shown in Figure 5.

Figure 5. Kc values used in calculation of ETc (derived from Figure 20 in Meyer et al. 1999) and actual lucerne cutting dates



Deep drainage

Deep drainage (DD) was estimated from the water balance equation on a monthly basis:

DD= I+R-ΔSWC-ETc

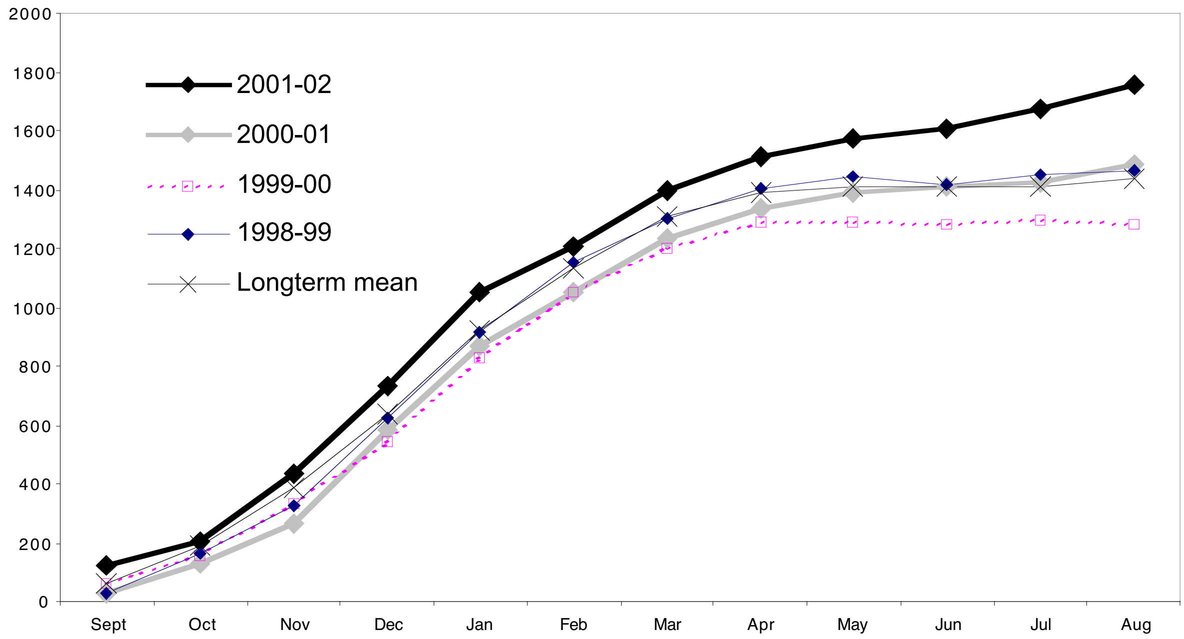
where I = irrigation, R= rain, ΔSWC=change in soil water content (final minus initial). There is no surface runoff term in this equation as all runoff was captured and reused on the field.

Results and discussion

Weather

Evaporative deficit (potential evaporation minus rain, ETo-R)) was about 120 mm higher than average in the 2001/2 growing season (September to April), about average in 1998/9, 60 mm lower than average in 2000/1 and 100 mm lower than average in 1999/0 (Figure 6). This was largely a result of high ETo in 2001/2, and high rainfall during the growing season in 1999/0 and 2000/1, while

Figure 6. Evaporative deficit (ETo-R) at the CSIRO Finley weather station

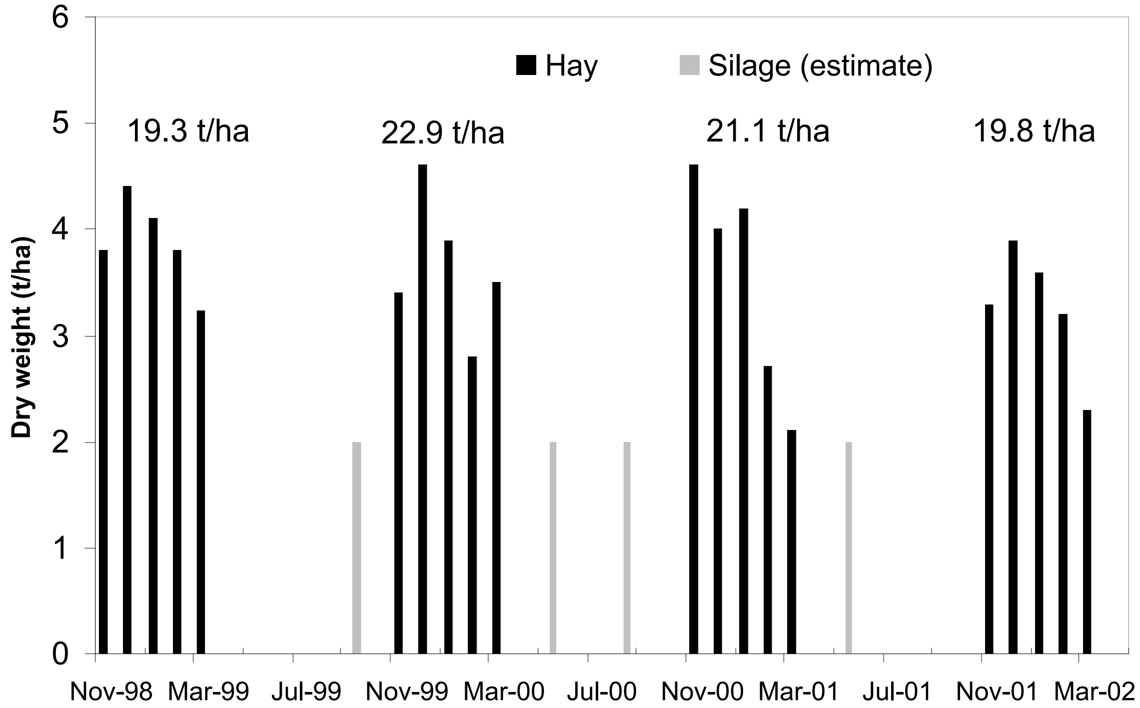


Lucerne production

The number of lucerne cuts and hay yields, and estimates of the dry weight of cuts for silage, are shown in Figure 7. Each season there were 5 cuts for hay, and there were two cuts for silage before and after the irrigation season in 1999/0 and 2000/1. Total dry matter yields (hay plus silate) ranged from 19 t/ha in 1998/9 to 24 t/ha in 1999/0. Meyer et al. (1996) recorded yields of 25 and 19 t/ha for second year lucerne in weighing lysimeters with a shallow, fresh (0.6 dS/m) watertable at 0.6-1 m at Griffith. The higher yield was achieved on a Hanwood loam, while the lower yield occurred on a poorly structured Mundiwa clay loam.

Irrigation management appears to have been adequate for good lucerne production. On average the lucerne was irrigated when ETo-R reached 110 mm (range 43 to 302 mm, standard deviation 49 mm, median 91 mm), and 39 of the 46 irrigations occurred before ETo-R reached 151 mm. Lattimore et al. (1994) found that lucerne yield was similar for irrigation frequencies of 75, 100, 150 and 200 mm during the second and third years after establishment, but were substantially reduced (by 27%) at frequencies of 150 and 200 mm in the fourth year.

Figure 7. Yield of lucerne over the four seasons

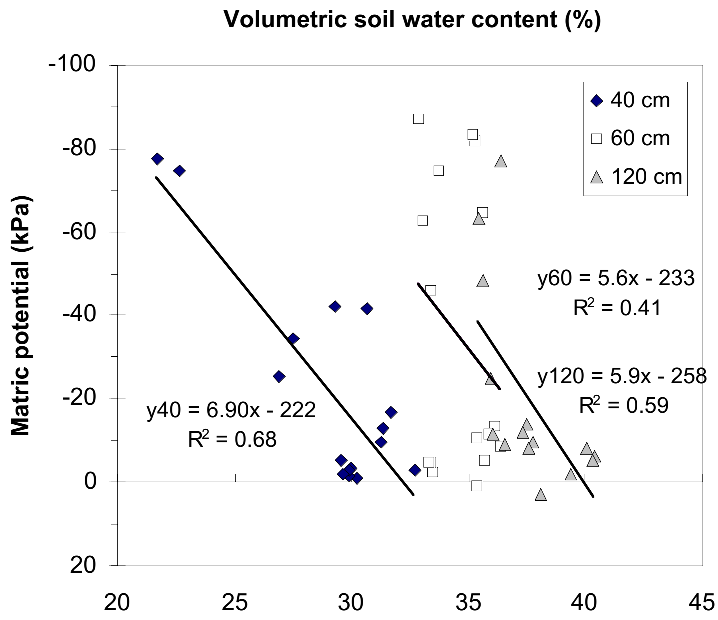


Soil hydraulic properties

Soil water characteristic

The soil water characteristics for different soil layers were developed from concurrent readings of the manual tensiometers and the Enviroscan® sensors. Figure 8 shows this comparison for the 40, 60 and 120 cm depths at the high EM 31 site, which indicates a lower water holding capacity of the 40 cm layer than the other layers consistent with its lower clay content (Table 1). The 60 and 120 cm depths showed very similar water characteristics consistent with their similar clay contents of around 45%.

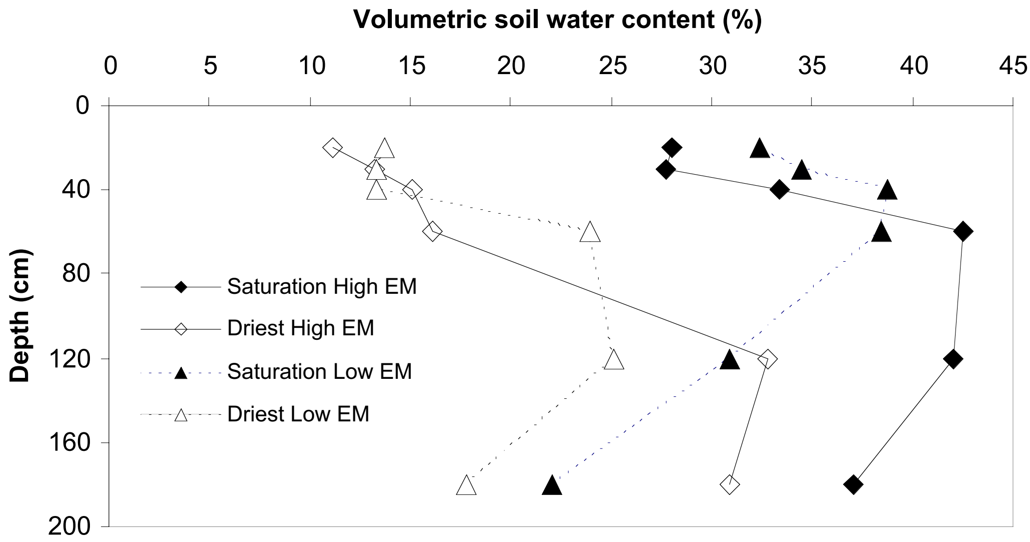
Figure 8. Relationship between volumetric soil water content and matric potential at 40, 60 and 120 cm at the high EM site



Saturation and lowest observed soil water content

Soil water content profiles were constructed for the high and low EM31 sites from the maximum and minimum observed water contents over the monitoring period of three and a half years (Figure 9). The maximum soil water contents represent saturation, the lower values in the topsoil of the high EM site reflecting the lower clay content in these layers.

Figure 9. Highest (saturation) and lowest observed soil water contents at each depth a tht low and high EM sites



Soil hydraulic conductivity

Unsaturated hydraulic conductivity was least at 50-60 cm where clay content was highest (42-46% clay), and was similar at both sites (0.3 mm/h at 8 cm tension and 0.4-0.6 mm/h at 4 cm tension).

Saturated conductivity at 3.5-4 m was very high at 42.6 cm/d in the sandy layer in which the 4 m piezometer was installed.

Lumped water balance

From 10-13 irrigations were applied in each of the four irrigation seasons, with total application varying from 693 mm in the season (2000/1) with least evaporative deficit, to 783 mm in the "average" season (1998/9), to 985 mm in the 2001/2 season (Table 2). In an average season at Griffith Meyer et al. (1996) applied a comparable amount (833 mm) to second year lucerne stand growing in weighing lysimeters with a fresh (0.2 dS/m) water maintained at 0.6 m during most of the growing season, and lowered to 1 m on 1 March.

Monthly estimates of deep drainage from the water balance equation varied within and between years, and ranged from 33 to –141 mm (negative = crop water use from below 1.2 m) (Table 3, Figure 10). Drainage beyond 1.2 m was associated with significant rain in winter, or irrigation plus rain in summer, except for December 2001 when the total irrigation application was 238 mm. Crop water use from below 1.2 m was greatest in the year of greatest evaporative deficit (2001/2) and least in the year of least evaporative deficit (1999/0). Over the four years cumulative net discharge from below 1.2 m was 1,260 mm.

Table 2. Components of the water balance determined for each irrigation season (Sep-Apr) and the intervening period (May-Aug) over four years

[A]September 98 application of 58 mm not included in the balance as soil water monitoring did not commenced until November - total irrigation application for the season was 785 mm.

	Irrigation	**Rainfall**	**ΔSWC (0-1.2 m)**	**ET_0 (Finley)**	**ETc (ET_0*Kc)**	**DD/Upflow**
	mm	**mm**	**mm**	**mm**	**mm**	**mm**
Nov 98-Apr 99 1998-1999	724[A]	134	2	1381	1135	-6
May-Aug 1999	0	134	-5	200	151	-13
Sept-Apr	809	329	-14	1603	1237	166
1999-2000	***809***	***463***	***-19***	***1803***	***1388***	***153***
May-Aug	0	217	33	181	374	67
Sep-Apr	693	313	-47	1696	1205	-118
2000-2001	***693***	***530***	***-14***	***1878***	***1580***	***-51***
May-Aug	0	78	-34	249	173	-62
Sept-Apr	986	191	110	1759	1541	-490
2001-2002	***986***	***269***	***76***	***2008***	***1714***	***-551***

Table 3. Components of the water balance determined monthly (negative values of deep drainage (DD) indicate crop water use from below 1.2 m)

	Irrigation I mm	Rain R mm	ΔSWC (0-1.2 m) mm	Finley ET_0 mm	Kc	ETc (ET_0*Kc) mm	DD mm	Use	Yield t/ha
Nov-98	133	48	16	215	0.75	161	3	hay	3.8
Dec-98	200	9	21	307	0.84	259	-70	hay	4.4
Jan-99	198	27	11	319	0.84	267	-53	hay	4.1
Feb-99	135	6	0	243	0.79	192	-52	hay	3.8
Mar-99	58	31	-15	181	1.02	185	-81	hay	3.2
Apr-99	0	13	-32	115	0.61	70	-26		
May-99	0	30	-14	65	0.91	60	-17		
Jun-99	0	54	19	30	0.68	20	14		
Jul-99	0	7	-14	37	0.65	27	-7		
Aug-99	0	44	4	63	0.70	44	-3		
Sep-99	83	42	46	104	0.50	52	27	silage	2
Oct-99	0	66	-27	156	0.84	137	-44		
Nov-99	98	55	-6.7	209	0.75	171	-11	hay	3.4
Dec-99	156	58	21	283	0.76	202	-9	hay	4.6
Jan-00	170	11	-5	295	0.79	234	-49	hay	3.9
Feb-00	199	35	11	238	0.8	190	33	hay	2.8
Mar-00	65	39	-35	197	0.84	162	-23	hay	3.5
Apr-00	38	24	-18	119	0.77	90	-9		
May-00	0	60	-4	55	0.81	44	19	silage	2
Jun-00	0	42	10	30	0.59	18	15		
Jul-00	0	34	0	43	0.65	28	5		
Aug-00	0	82	27	53	0.50	27	28	silage	2
Sep-00	0	58	-10	90	0.86	80	-12		
Oct-00	0	57	-12	153	1.18	180	-112		
Nov-00	98	66	32	212	0.93	202	-70	hay	4.5
Dec-00	201	4	29	322	0.78	251	-75	hay	3.9
Jan-01	182	61	7	333	0.77	255	-19	hay	3.8
Feb-01	135	28	2	243	0.82	199	-39	hay	2.8
Mar-01	77	22	-43	204	0.87	178	-37	hay	2.1
Apr-01	0	19	-52	131	0.96	125	-55		
May-01	0	3	-29	67	0.82	55	-22	silage	2
Jun-01	0	23	-1	44	0.58	25	-2		
Jul-01	0	28	-2	41	0.65	26	3		
Aug-01	0	24	-2	97	0.69	66	-40		
Sep-01	106	35	113	142	0.91	129	-101		
Oct-01	0	27	-23	156	1.18	184	-135		
Nov-01	98	16	29	250	0.90	226	-141	hay	4.6
Dec-01	238	9	-1	303	0.78	237	11	hay	4.7
Jan-02	248	4	61	328	0.79	258	-66	hay	4.5
Feb-02	125	60	-20	225	0.86	193	12	hay	3.5
Mar-02	171	29	-7	231	0.83	193	14		
Apr-02	0	12	-42	124	0.98	122	-68	hay	2.5

Fig. 10. Deep drainage below 1.2 m (positive values) and crop water use from below 1.2 m (negative values) as estimated from the water balance

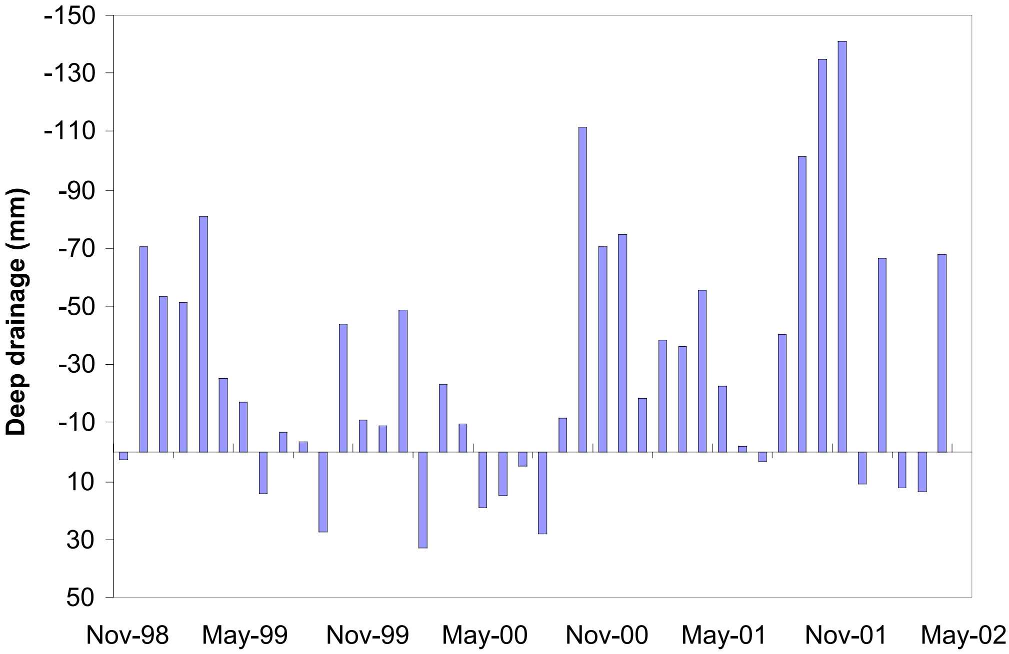
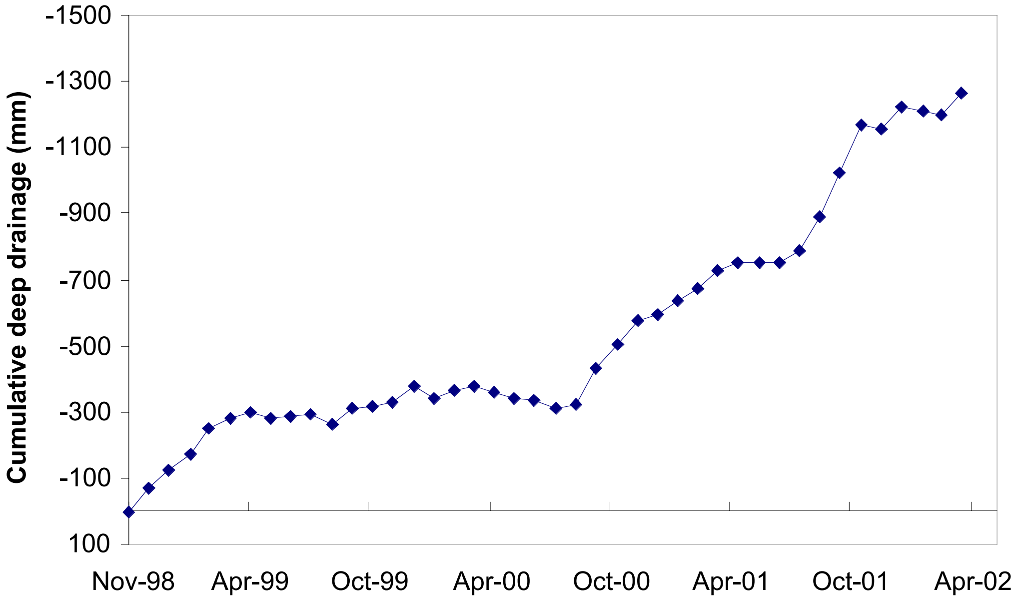


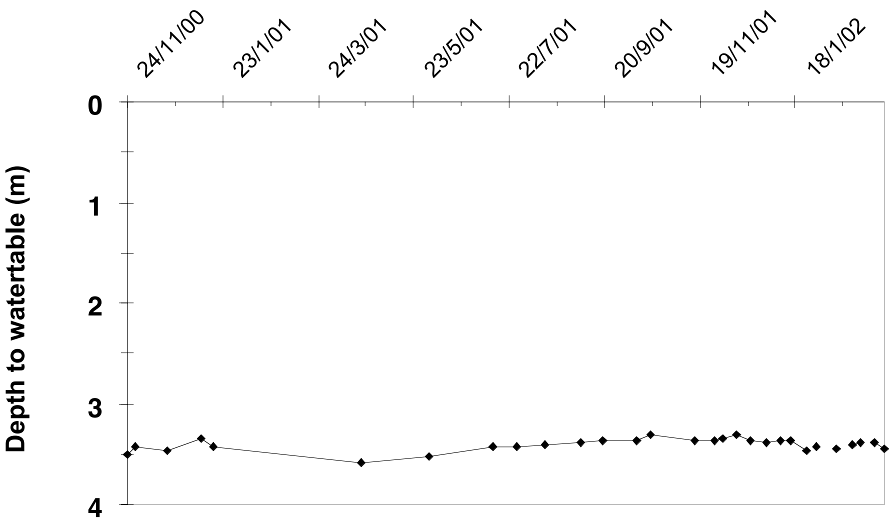
Fig. 11. Cumulative deep drainage below 1.2 m



Piezometric levels

No groundwater was detected in the 3.3 m piezometers except at the time of installation in November 1998. The pressure level in the 4 m piezometer installed in November 2000 remained fairly steady at around 3.5 m from November 2000 to March 2002 (Figure 12). The groundwater discharge and recharge processes appeared to be in equilibrium.

Figure 12. Pressure levels in the 4 m piezometer at the high EM site



Soil water dynamics

The first irrigation each season increased the volumetric water content of the soil profile to at least 1.2 m, and reduced matric potential to at least 1.8 m (Figures 14-18). Changes in volumetric soil water content at 2.5 m (for the first two years) and at 1.8 m (for the second two years, after the reinstallation of the access tubes), were small. The cycles of wetting and drying associated with irrigation and crop water use were of greatest magnitude in the upper layers, and during the irrigation season water extraction was largely confined to the upper 0.6 m. Taylor and Marble (1986) found that soil water extraction on Shepparton fine sandy loam, a red-brown earth, was confined to the upper 0.6 m for lucerne irrigated when Epan-R=75 mm. The proportion of crop water use from below this depth increased from 12% at a frequency of 75 mm to 37% at a frequency of 150 mm. Crop water use from below 1.2 m was very low on this soil, which has a heavy clay subsoil unsuited to lucerne. At Leeton, Lattimore et al. (1994) found that the depth of soil moisture depletion on Gogeldrie clay with watertable deeper than 3 m increased from 0.9 to 1.3 m as irrigation interval increased from 75 mm to 200 mm.

Figures 17 and 18 show that matric potential was high to at least 1.3 m before the start of the irrigation season at the end of September 2001. There are no matric potential data for shallower depths before the start of the irrigation season because the soil was drier than the detection range of the sensors (potentials higher than –200 kPa). The soil dried beyond the detection limit at 1.2 m around the end of August 2001, and significant drying commenced at

180 cm in September 2001. Irrigation at the end of September 2001 wet the soil to at least 180 cm, but there was again evidence of drying at 1.2, 1.3 and 1.8 m during November 2001. From the end of November the soil matric potential at 1.2-1.8 m gradually declined to saturation between mid-January and late February 2002, indicating wetting of the soil to at least 1.8 m as a result of irrigation and rain, and remained saturated to the end of the monitoring period in May 2002.

After the cessation of irrigation in March each year, the soil layers gradually dried from the surface downwards, with drying evident at 1.2 m in early April in 2001 (Figures 13,14). The data are consistent with the observations of Meyer et al. (1996) that lucerne will only use water from depth once the upper soil layers have dried down. The more rapid drying at 130 cm compared with 120 cm is possibly due spatial variation in root distribution.

Fig. 13. Soil water content (10 cm layers), irrigations and rain at the high EM site from October 2000 to September 2001

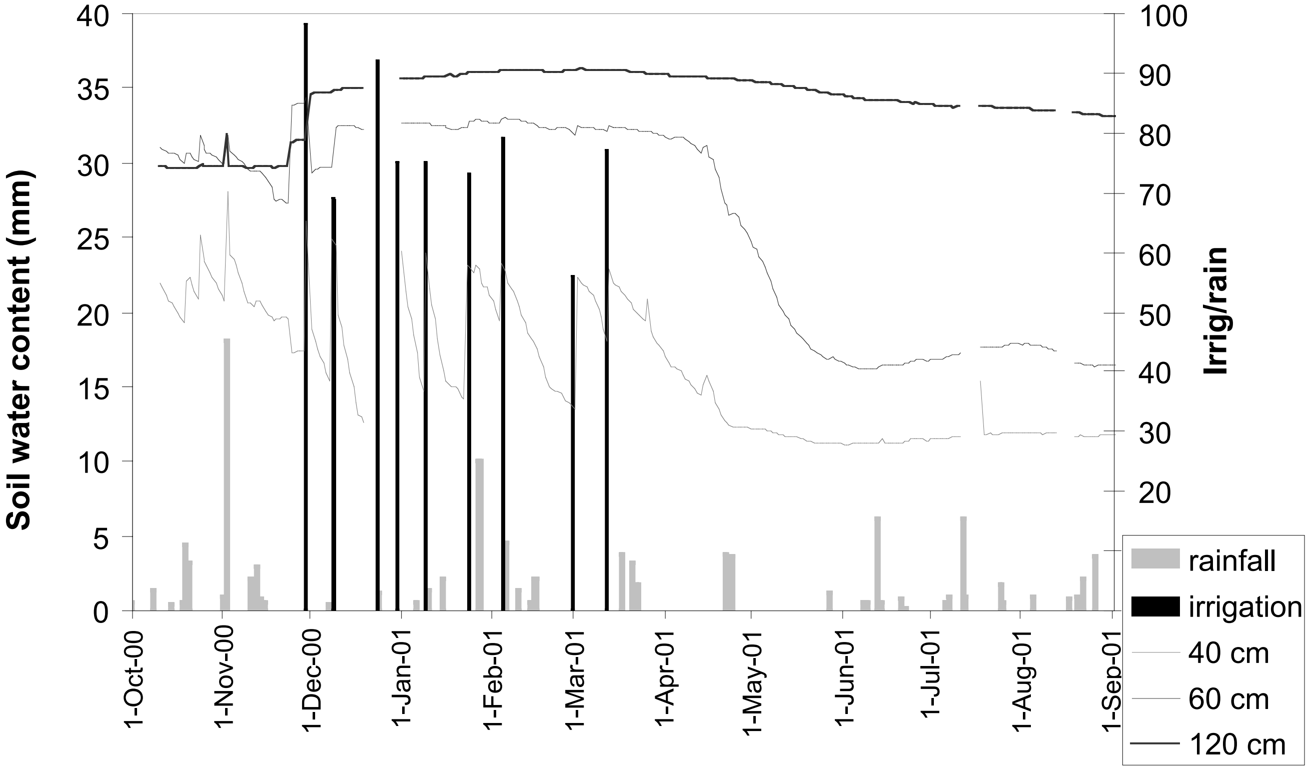


Fig. 14. Matric potential at the high EM site from December 2000 to June 2001

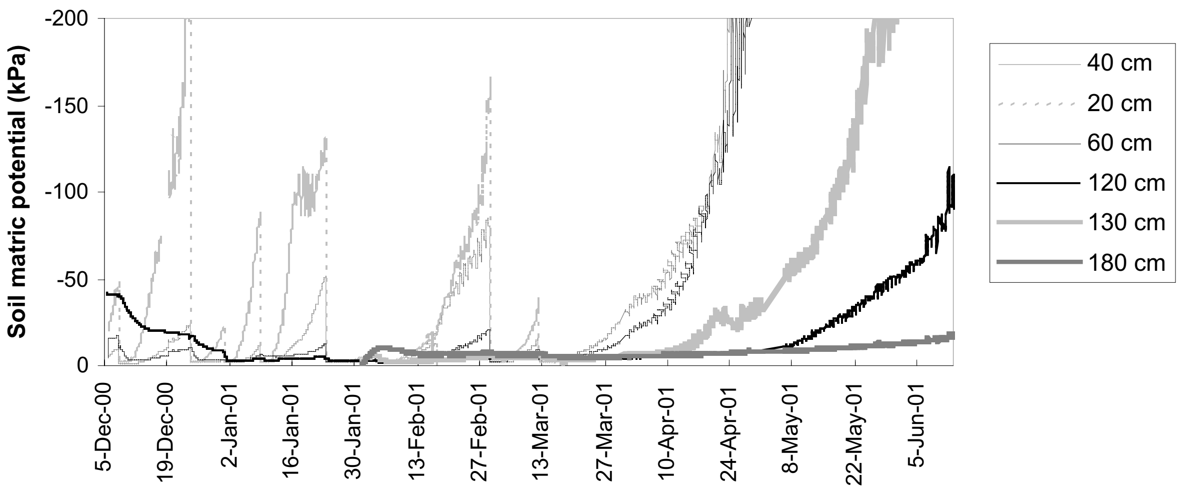


Fig. 15. Soil water content (10 cm layers), irrigations and rain at the high EM site from August 2001 to May 2002

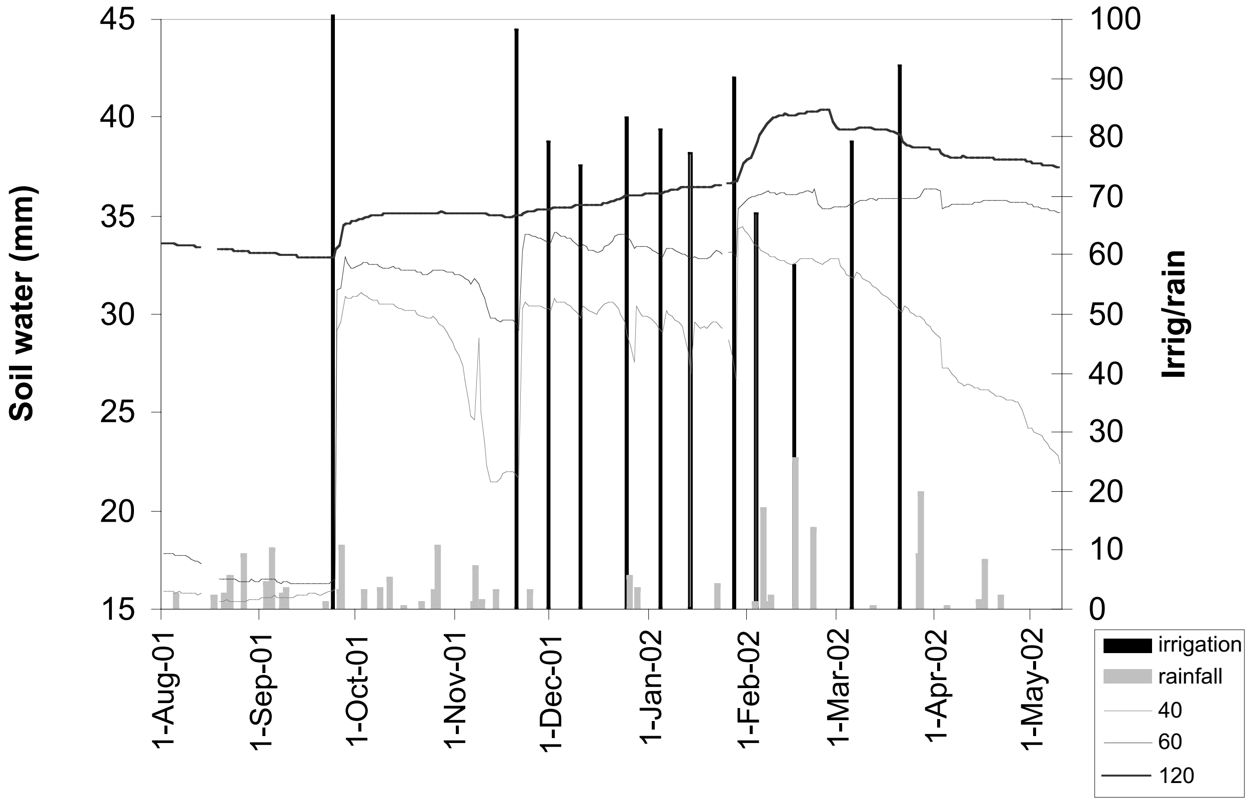


Fig. 16. Soil matric potential in upper layers at the high EM site from August 2001 to May 2002

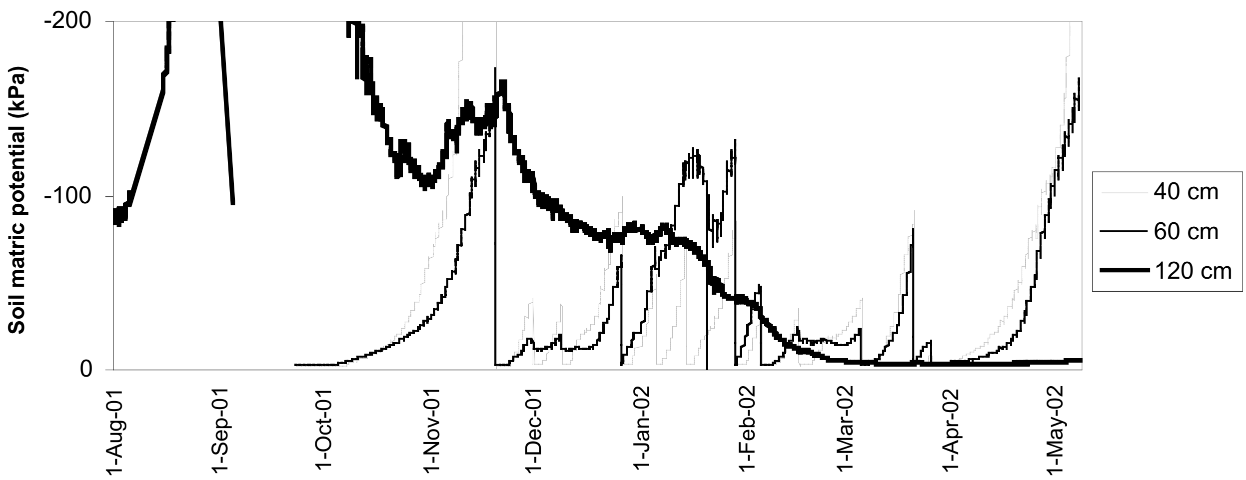
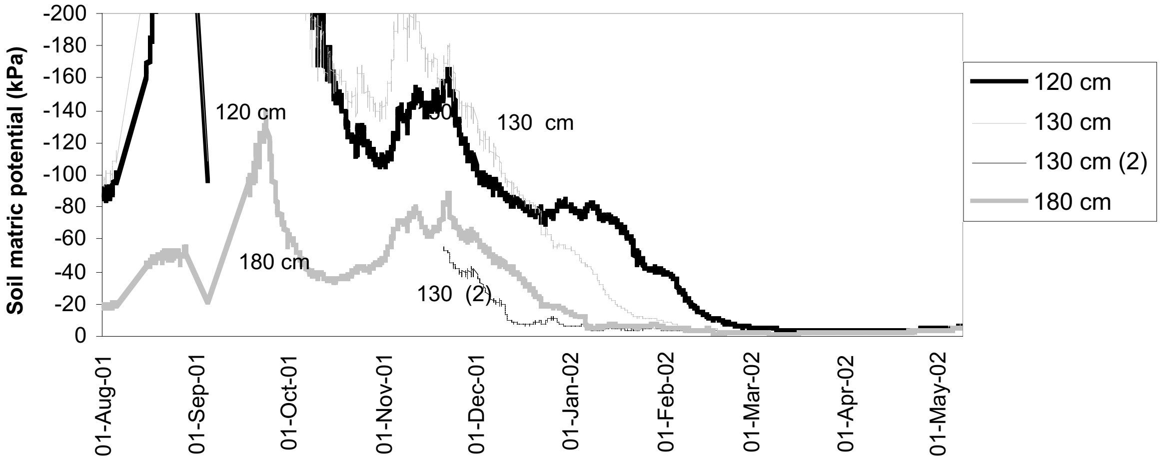


Fig. 17. Soil matric potential in deeper layers at the high EM site from August 2001 to May 2002
(the data labeled 130(2) are from a second sensor installed in late November)



Conclusions

There was evidence of deep drainage to at least 1.8 m early in the irrigation season, and the soil remained saturated from 1.2-1.8 m during the irrigation season. However, the watertable level remained fairly steady at around 3.3 m or deeper, and there was no evidence of water draining into the watertable as a result of irrigation or drainage. Water use by the lucerne was largely confined to the upper 0.6 m during the irrigation season, and progressively dried the soil in deeper and deeper layers after the end of the irrigation season.

The results suggest that over each full year, there was net discharge from below 1.2 m from irrigated lucerne, despite frequent irrigation and mowing during the growing season. Any water that moved below 1.2 m during the irrigation season was used by the lucerne during the non-irrigated period. Other studies have shown that in the presence of a shallow watertable, frequently irrigated lucerne acquires a significant proportion of its water use from upflow from the watertable. Thus well-managed lucerne can be a productive irrigated landuse and at the same time assist watertable control in both deep and shallow watertable areas.

References

Anon. 1988 CSIRO Disc Permeameter Instruction Manual. CSIRO Centre for Environmental Mechanics, Canberra, ACT.

Beecher, H.G., Hume, I.H., Dunn, B.W. (2002) Improved method for assessing rice soil suitability to restrict recharge. Australian Journal of Experimental Agriculture 42: 297-307.

Humphreys, E. and Edraki, M. (2003). Rigorously determined water balance benchmarks for irrigated crops and pastures. Project CLW21 Final Report to NPIRD. CSIRO Land and Water Consultancy Report.

Lattimore, M.E., Thompson, J.A. and O'Callaghan, K.L. (1994). Irrigation frequency for white clover and lucerne on a cracking clay in the Murrumbidgee Valley, New South Wales. Australian Journal of Experimental Agriculture 34: 41-49.

Khan, S., Robinson, D., Xevi, E., O'Connell, N. (2001) Integrated hydrologic economic modeling techniques to develop local and regional policies for sustainable rice farming systems. 1st Asian Regional Conference on Agriculture, Water and Environment, ICID, September 2001, Seoul, Korea.

McLeod, G.D. (1998). Achieving sustainable change-An Australian Experience . Proceedings : Watershed Management: Moving from theory to implementation. May 3-6 ,1998. Denver , Colorado, USA

MDBC, (2001). Review of Natural Resources Planning and implementation Processes in selected Irrigated Regions through Australia. Volume 1, Jun 2001. Prepared by SMEC Australia Pty Ltd

Meister, N. 2002. Saturated and Unsaturated Hydraulic Conductivity of Soils in the Murray Irrigation Area. CSIRO Land and Water Studentship Report. Griffith, NSW.

Meyer, W.S. (1999). Standard reference evaporation calculation for inland, south eastern Australia. CSIRO Land and Water Technical Report 35/98.

Meyer, W.S., Smith, D.J. and Shell, G. (1999). Estimating reference evaporation and crop evapotranspiration from weather data and crop coefficients. CSIRO Land and Water Technical Report 34/98.

Meyer, W.S., White, B. and Smith, D. (1996). Water use of lucerne over shallow watertables in Australia. In 'Evapotranspiration and irrigation scheduling'. Proceedings of the International Conference, 3-6 Nov. 1996, San Antonio, Texas. ASAE, IAA, ICID. Pp. 1140-1145.

Smith, R. 1945. Soils of the Berriquin Irrigation District, N.S.W. Council for Scientific and Industrial Research Bulletin No. 189. CSIR, Melbourne, Vic.

Smith, K.A. and Mullins, C.E. (eds) (1991). Soil Analysis, Physical Methods. Marcel Dekker Inc.

Soil Survey Staff (1975). Soil Taxonomy: A Basic system of Soil Classification fro Making and Interpreting Soil Surveys. USDA Handbook 436. Washington, USA

Stace, H.C.T., Hubble, G.D., Brewer, R., Northcote, K.H., Sleeman, J.R., Mulcahy, M.J. and Hallsworth, E.G. (1972). A Handbook of Australian Soils. Rellim Technical Publications, Glenside, SA, Australia.

Taylor, A.J. and Marble, V.L. (1986). Lucerne irrigation and soil water use during bloom and seed set on a red-brown earth in south-eastern Australia. Australian Journal of Experimental Agriculture 26: 577-581.