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Irrigation Scheduling for Water and Salinity Management in the Ord River Irrigation Area

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Ivanhoe Plain, Ord River Irrigation Area (photo taken during 2004)

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SUMMARY

The Ord River Irrigation Area (ORIA) is located within Western Australia near the Northern Territory border. Irrigated agriculture started in the early 1960s in this area. Since its commencement the groundwater levels have been continuously rising, mainly due to vegetation clearing, excessive irrigation and leakage from the network of supply channels, drains and Kununurra Diversion Dam. The water table is already close to the soil surface in some parts of Ivanhoe and Packsaddle plains. Due to the changed hydrological conditions, the chemistry of the groundwater also has changed over time. The shallow groundwater now is saline throughout most of the ORIA and is at extreme levels in some parts of Ivanhoe and Packsaddle plains. Because the groundwater is shallow and saline in some areas, the risk of developing soil root zone salinity is high. This research evaluated irrigation and salinity management strategies for maize and sugarcane crops grown over deep and shallow, non-saline and saline water tables in the ORIA. The LEACHC model was used to predict and evaluate the affects of various irrigation management strategies.

Model Calibration

The LEACHC model was calibrated for two crops (maize and sugarcane) grown on Cununurra clay, which is the dominant soil type in the ORIA. A separate calibration was performed for each crop using the observed soil, crop, irrigation and weather data. For the maize crop, the observed soil moisture and salinity data were available at three different dates during the growing season. For the Sugarcane crop, these data were available at five different dates during the growing season. The observed soil moisture and soil salinity profiles were compared with the model predictions. Two parameters in the retention equation were adjusted slightly to achieve a reasonable agreement between the observed and predicted soil moisture and salinity data. The calibrated model simulated the observed soil moisture and salinity profiles reasonably well. The Willmott's d-index, a measure of goodness of fit, was around 0.5.

Irrigation Scheduling of Maize Crop – Deep Water Table

Irrigation application amounts equal to 100% of total fortnightly pan evaporation and applied at 14 day intervals were found to be the best irrigation strategy for the maize crop grown over a deep water table. This strategy would require around 11 ML/ha of irrigation water (with 100% application efficiency) during one growing season, which is about 23% less than the existing practice. Irrigation application amounts equal to 75% of total fortnightly pan evaporation, applied every fortnight during first half of the growing season, and 75% of total weekly pan evaporation, applied on a weekly basis during the second half of the growing season, would be a better irrigation strategy if it is feasible to change the irrigation interval from 14 to 7 days. This irrigation management practice would require around 8.4 ML/ha (with 100% application efficiency) and the predicted irrigation water use was around 40% less than the existing irrigation practice. Most of the savings would result from reductions in surface runoff and deep drainage. The predicted salinity risks from this irrigation strategy were minimal.

Irrigation Scheduling of Sugarcane Crop – Deep Water Table

The study found that the best irrigation strategy for a sugarcane crop grown on Cununurra clay would be irrigation application amounts equal to 50% of the total fortnightly pan evaporation, applied every fortnight during first quarter of the growing season, and irrigation application amounts equal to 100% of total weekly pan evaporation, applied every week during rest of the season. This irrigation strategy would not cause more than the allowed soil moisture depletion. A total of about 2200 mm of water would be required for irrigation if the crop was irrigated when half the total available water content was depleted. This amount equates to 22 ML/ha with 100% application efficiency. Around 78% of this water was predicted to be used at ET and the rest was lost as surface runoff and deep drainage. There would not be any soil salinity risks from this irrigation strategy.

Irrigation Scheduling of Sugarcane Crop – Non-saline Shallow Water Tables

The best irrigation strategy for a sugarcane crop grown on Cununurra clay over a non-saline, shallow water table of 1 to 2 m depth would be irrigation application amounts equal to 50% of total fortnightly pan evaporation applied every fortnight. The model predicted that this irrigation strategy would result in the best water use efficiency because it will use the maximum amount of groundwater from the shallow water table to meet the crop ET requirements. This also would help to manage the water table. The model also predicted that this irrigation strategy would not cause excessive salt accumulation in the soil profile over time.

Irrigation Scheduling of Sugarcane Crop – Saline Shallow Water Tables

The best irrigation strategy with respect to water use efficiency will be irrigation application amounts equal to 50% of the total fortnightly pan evaporation applied every fortnight. However, all of the simulated irrigation strategies resulted in high salinity risks. The lowest salt accumulation resulted from the above irrigation strategy but it was well above the levels that can be tolerated by the sugarcane crop. Therefore, the soil salinity risks will be high if a sugarcane crop is grown for long periods over a saline shallow water table of less than 2 m depth. The best management strategy would be to first lower the water table below 2 m by artificial drainage and then adopt the above irrigation strategy with regular leaching applications (every three months) to flush excess salts from soil into the drainage system.

1. INTRODUCTION

The Ord River Irrigation Area (ORIA) is located at Kununurra in the East Kimberley region of Western Australia near the Northern Territory border (Figure 1.1). This area has had a stable climate for the past 7000 years. It is semi-arid with summer monsoonal rains, mainly between December and March; rainfall is minimal during rest of the year. The mean minimum and maximum temperatures are around 14 and 30°C in July and 25 and 39°C in November. The region is frost-free (Delane, 1987). Pan evaporation is around 3000 mm/year for the Kununurra area (Ruprecht and Rodgers, 1999).

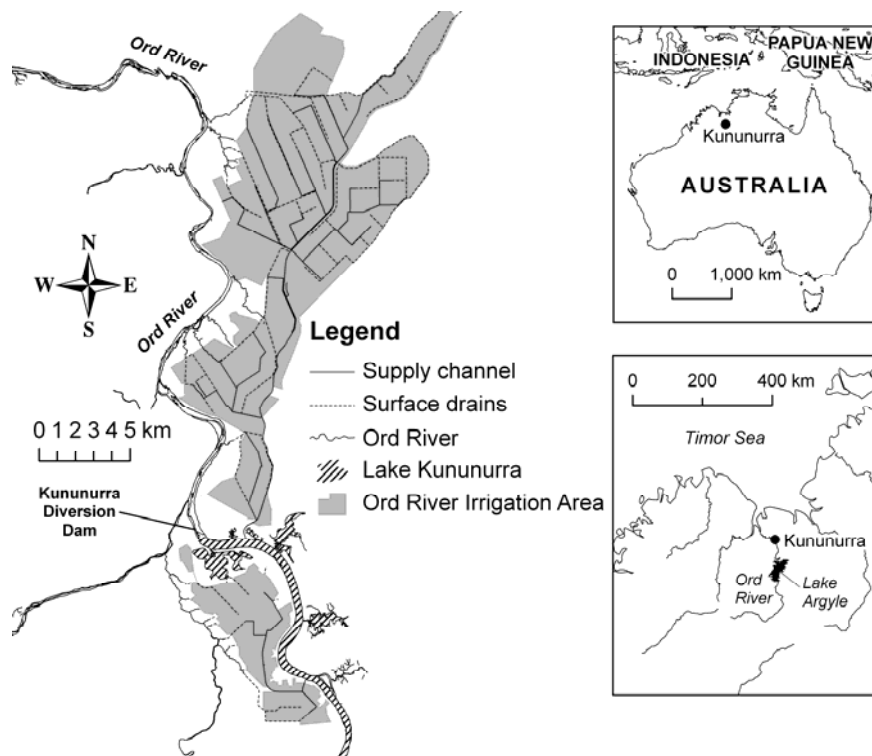


Figure 1.1. Map showing the location of the study area in northern Western Australia

The dominant soil types in the ORIA include cracking clays from the Cununurra and Aquitaine families. Levee type soil and sands also exist. The Cununurra clays occur in normal, alkaline and leached phases. Detailed information relating to soils can be found in survey reports for a number of general and specific studies conducted in the area since Burvill's initial work in the Ord River area (Stoneman, 1972; Aldrick *et al.*, 1990; Burvill, 1991; Schoknecht, 1996; Schoknecht and Grose, 1996). The normal phase of Cununurra Clay occurs in large areas of the Packsaddle Plain and has a darker colour with medium texture and poor drainage. The alkaline phase consists of imperfect to poorly drained brown clays with fine topsoil and exists in a large area south of the Kimberly Research Station on Ivanhoe Plain. The leached phase occurs in the north and east. It generally has a coarser structure and higher clay content and poor to very poor drainage. Aquitaine soils are bluish-grey to yellow cracking clays. They exist in areas subjected to prolonged inundation, such as

swamps, and have very poor drainage. Smaller areas of the alkaline and acid phases also occur. Packsaddle loamy sands exist adjacent to the Cununurra clays. These are better drained and well suited to intensive horticultural activities. The light textured Ord loamy sands are located near the river.

The Hydrogeology of the ORIA consists of superficial sediment overlying a palaeo-topographic surface of basalt, sandstone and limestone. The geological structure is a superficial sequence consisting of river gravels; sandy, poorly cemented sands or sandstones; and silty clays and clays; which show extreme variation in lateral and vertical distribution (McGowan, 1983). The stratigraphy reflects deposition in a complex sedimentary environment involving two braided river systems. McGowan (1983) classified the sediments in terms of two predominant lithotypes: gravels and clays. Two major gravel units, representing two palaeo-river systems, have been identified. The upper unit is less than 10 m thick and the thickness of lower unit varies between 5 and 20 m. Both of these units exist over significant areas of the Ivanhoe Plain (McGowan, 1983).

To identify irrigable areas in the Ivanhoe and Packsaddle plains, a detailed survey of the area was conducted in 1944. The irrigation development project was implemented in stages. The Kununurra Diversion Dam (KDD) and a network of supply channels and drains were constructed to service the irrigated area. Initially, only five farms on Ivanhoe Plain were released for irrigation in 1962. By 1969, a total of 30 farms (5,540 ha) were released. A main storage dam (Ord River Dam) was constructed upstream of the KDD and officially opened in 1972 with a storage capacity of 5,720 Mm³ (Adrick *et al.*, 1990). The irrigation area is now situated on both Ivanhoe and Packsaddle plains.

With the commencement of irrigated agriculture, the groundwater levels started rising due to vegetation clearing, increased deep drainage below irrigated fields, and leakage from unlined supply channels and drains servicing the area. Deep percolation from monsoonal rainfall has become more important as the water table has risen. A significant fraction of the applied irrigation water, in the form of return flow from irrigation fields, is drained into the lower Ord River where it contributes nutrients, pesticides and salts. The two of the main crops are sugarcane and maize. Sugarcane is a relatively new crop in the Ord Irrigation Area (ORIA) where its commercial production commenced in 1995 (Muchow and Keating, 1998).

Prior to irrigated agriculture, the depth to shallow groundwater was relatively deep in the ORIA (Table 1.1). Since 1965, the water table has risen substantially. By 2004 it was relatively close to the soil surface in some parts of the Ivanhoe Plain (Figure 1.2). Beneath Packsaddle Plain, the water table also has risen substantially in response to the formation of Lake Kununurra and increased replenishment from irrigation and rainfall. A shallow water table has developed in parts of the Lake Kununurra and Packsaddle Creek zones (Table 1.1). Due to the changed hydrological conditions, the chemistry of groundwater probably

changed over time (Salama *et al.*, 2002). The shallow groundwater varies throughout most of the ORIA with Electrical Conductivity (EC) levels ranging from 50 to 2160 mS/m (Ali *et al.*, 2002). In some parts of the Ivanhoe and Packsaddle plains, the shallow groundwater salinity (EC) is at extreme levels. Because the groundwater is shallow and saline in the ORIA, the risk of developing the soil root zone salinity is high.

Table 1.1. Depth to water table beneath Ivanhoe and Packsaddle Plains

Plain	Zone	Depth to water table (m)	
		1965	2001
Ivanhoe	Martins Location	10-21	1-4
	Cave Spring Gap	18	2-3
	Green Location	18	4-6
	North - Dumas Lookout	10-18	5-7
	North -Kimberley Research Station	9-18	4-8
	Central	8-22	4-7
	South	6-20	2-4
Packsaddle	Lake Kununurra	4-9*	1-3*
	Packsaddle Creek	7-10*	3-5*

Note: * Most of the rise occurred during the last five years (no reliable pre 1976 data).

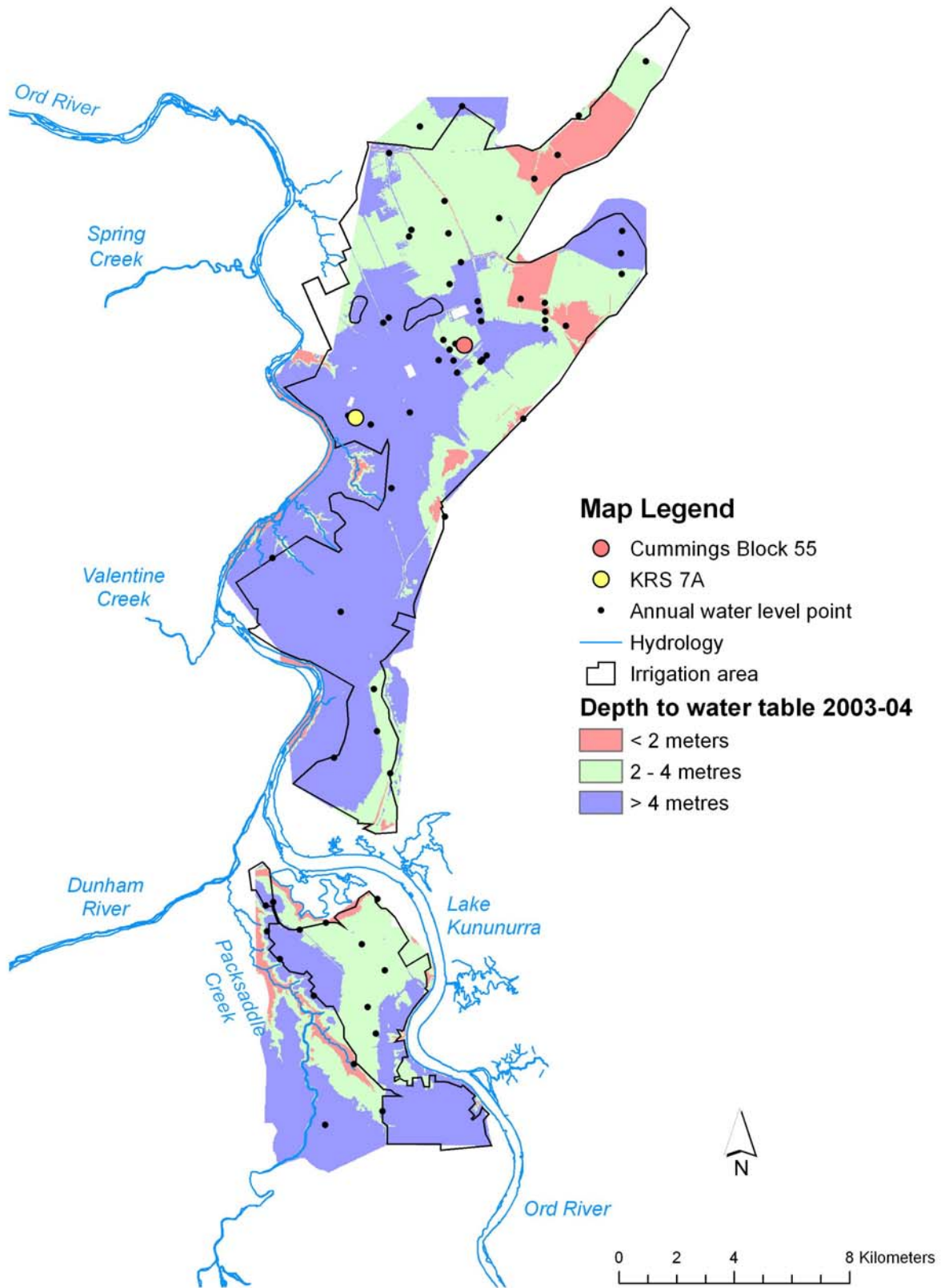


Figure 1.2. Estimated water table depth beneath Ivanhoe and Packsaddle plains in 2002

1.1. Aims of the Study

This research evaluated water and salinity management strategies for the maize and sugarcane crops grown on Cununurra clay in the ORIA. The impacts of both fresh and saline shallow water tables on the water demands and soil root zone salinity were evaluated through modelling.

The objectives were to:

1. Evaluate the existing irrigation practices for maize and sugarcane crops and quantify water losses in the form of deep drainage and runoff;
2. Devise optimum irrigation strategies that will help improve water use efficiency, reduce deep drainage and runoff, and minimise salinity risks; and
3. Assess the impacts of fresh and saline shallow water tables on crop water requirements and soil root zone salinity.

1.2. Project Context

This research was funded under the National Action Plan for Salinity and Water Quality (NAP) Project 033016: *Improved Water Management in the Stage 1 Ord River Irrigation Area*. It was conducted in association with the linked sub-projects *Salinity Modelling and Feasibility Assessment of Groundwater Management Options, Dewatering Bores*; and *Integration of Groundwater Monitoring, Evaluation and Reporting Programs*. The outputs and recommendations in this report reflect a broader understanding of the Ord Stage 1 groundwater systems that was developed in the context of those linked activities.

Regional context for Natural Resource Management in the Ord catchment is provided in the following documents:

- *Draft for Comment: Kimberley Natural Resource Management Plan* (Kimberley Development Commission, 2004);
- *A Strategy for Managing the Natural Resources of Western Australia's Rangelands: A Draft for Public Comment and Review* (Rangelands NRM Co-ordinating Group, 2005); and
- *National Action Plan for Salinity and Water Quality Ord Catchment Priority Projects 2005* (Ord Reference Group, 2005).

2. IRRIGATION AND SALINITY MODEL DESCRIPTION

2.1. Model Overview (LEACHC)

The LEACHC version of LEACHM was selected for irrigation scheduling and assessing the impacts of various fresh and saline shallow water tables on soil salinity built up when the Maize and Sugarcane crops are grown on the Cununurra Clay. LEACHM (Leaching Estimation And CHEmistry Model) is one of the more complex and comprehensive models for simulating processes in crop root zones (Hutson and Wagenet, 1992). It has five different versions: LEACHB, LEACHC, LEACHN, LEACHP and LEACHW. LEACHC describes the transient movement of water and inorganic ions and their equilibrium chemistry. It allows the flexibility of choosing various upper and lower boundary conditions. The LEACHC model can be categorised as a complex model with respect to its approach to soil chemistry because it considers the independent movement of individual ions, including equilibrating the soil solution phase with the solid phase using precipitation-dissolution of lime and gypsum; significant ionic-pairing; and cation exchange.

2.2. Unsaturated Flow and Solute Transport

LEACHC uses a finite-difference solution of the one-dimensional Richard's equation for unsaturated flow. To approximate the hydraulic conductivity, matric potential and moisture content ($K-h-\theta$) relationships, the model uses either the expressions developed by Campbell (1974) or fits the two-part retentivity functions developed by Hutson and Cass (1987). If the retentivity function developed by Hutson and Cass is selected, various regression equations are available (Cosby *et al.*, 1984; Hutson, 1986; Hutson and Wagenet, 1992; and Rawls and Brakensiek, 1985). To approximate evapotranspiration the model uses the method of Childs and Hanks (1975). From weekly pan evaporation totals (P), the model calculates daily potential evapotranspiration (ET_d). To determine daily potential transpiration (T_d), ET_d is multiplied by the crop cover fraction (C_{cf}). The equation developed by Childs (1975) is used to approximate the crop cover. The daily potential surface evaporation (E_d) is the difference between ET_d and T_d . The equations used for root growth and root density distribution as a function of time are based on those given by Davidson *et al.* (1978). The only addition in the model is an adjustable total root depth to accommodate the simulation of various soil profile depths. LEACHC approximates the water uptake rate by roots using equation developed by Nimah and Hanks (1973).

A number of upper and lower boundary conditions are provided in the model. The upper boundary conditions include ponded or non-ponded infiltration and evaporation or zero flux. The five different lower boundary conditions are: a) fixed water table depth; (b) free draining profile; (c) zero flux; (d) lysimeter tank; and (e) fluctuating water table. Use of Richard's

equation for unsaturated flow assumes that the soil is homogeneous horizontally, and that there is no preferential flow.

After the solution of Richard's equation for unsaturated flow, including sinks, the movement and distribution of solutes are modelled by solving numerically the convection-diffusion equation (CDE). The model can handle the movement and distribution of Ca, Mg, Na, K, Cl, SO₄, CO₃, HCO₃, H, OH and their major ion pairs. After the determination of ion movement and distribution, these are equilibrated with exchange and mineral phase including ionic pairing, at certain specified time intervals.

3. MATERIALS AND METHODS

Two experimental sites were selected to collect the field data about soil physical properties; irrigation frequency and application amounts; and soil moisture, water table depth, and soil and water chemistry. The purpose was to monitor temporal changes in the soil moisture and salinity profiles over the growing period to assess any water or salt stress responses by the plants under current irrigation practices. These data also were required to calibrate the irrigation and salinity model (LEACHC) to enable its use for evaluating various irrigation management strategies.

3.1. Kimberly Research Station site – KRS 7A

This 6.6 ha site was located near the Kimberly Research Station (KRS) in block 7A (Figure 1.2). The soil in this block belongs to the Cununurra Clay and a maize crop grown during 2004 was selected for the study. To determine the soil physical and textural properties, soil samples were collected from two locations (7A-1 and 7A-2). At each location, the samples were collected from various segments of the soil profile up to 2 m depth. Each soil section was analysed for soil texture, bulk density, organic carbon, soil moisture and soil chemistry; and those values were used as the initial soil moisture and soil chemical compositions during the model calibration. Textural properties of the soil at KRS 7A-1 and KRS 7A-2 are listed in Table 3.1. The clay was dominant (42 to 55%) at all depths and both locations. The percentage of sand varied between 31 and 41% and the percentage of silt varied between 9 and 20% with an increasing trend with depth at location KRS 7-2A.

The soil texture information, bulk density and organic carbon values from the two locations (KRS 7A-1 and KRS 7A-2) were averaged (Table 3.2) and used as input to the LEACHC model to estimate the soil retention properties. The soil retention properties estimated by the model were similar to those determined through laboratory experiments by Bridge and Muchow (1982) for the Cununurra Clay.

Additional soil samples were collected on 11/06/04, 12/07/04 and 08/10/04. These were analysed for soil moisture and soil chemical properties and then compared to the model predictions during the model calibration. The water table in the experimental block was monitored by taking regular water level readings from an existing bore hole at the site. The observed data suggested that the water table was greater than 4 m below ground surface throughout the growing season. A groundwater sample, collected from the bore hole and analysed for major ions, EC and pH, indicated that the shallow groundwater was saline; EC greater than 400 mS/m. The concentrations of Na and Cl were 495 and 962 mg/L, respectively (Table 3.3).

The Maize crop was sown during the last week of April 2004. The crop germinated during the first week of May and developed its full canopy during the last week of July 2004. It was

harvested during the first week of October 2004. The fertilizer application rates were 250 kg/ha Di-Ammonium Phosphate (DAP), 50 kg/ha Zinc Sulphate Monohydrate, 50 kg/ha Sulphate of Potash and 460 kg/ha Urea.

Irrigation and rainfall amounts are listed in Table 3.4. In total, about 1300 mm of water was applied as irrigation and 15 mm was received from rainfall during the growing season. The irrigation applications remained uniform throughout the growing period. During each watering, 9.5 ML was applied in 12 hours to irrigate 6.6 ha of the Maize crop. Because irrigation water quality was expected not to change in the short term, only three irrigation water samples were collected and analysed for major ions, EC and pH. These values were used to represent the irrigation water quality in the LEACHC model (Table 3.5). The averages of EC and pH of irrigation water samples were 30 mS/m and 8.06, respectively. The weather data were obtained from KRS weather station. The daily pan evaporation data were processed to determine the weekly total pan evaporation values in Table 3.6. Similarly, the daily temperature data were processed to calculate mean weekly temperatures and the amplitudes. The week numbers start from 01/04/04 to coincide with the start of the model simulation period. The model simulation end date was 30/11/04; however, the model required pan evaporation and temperature data for at least one additional week past the simulation end date.

Table 3.1. Soil textural properties at KRS 7A-1 and KRS 7A-2 near Kimberley Research Station

KRS 7A-1 Depth (mm)	Sand %	Silt %	Clay %	OC* (%)	KRS 7A-2 Depth (mm)	Sand %	Silt %	Clay %	OC* (%)
0-100	39.2	16.0	44.8	1.1	0-100	35.9	9.7	54.4	1.0
100-200	39.8	10.1	50.1	0.8	100-200	39.2	10.7	50.1	0.8
200-400	36.6	14.9	48.5	0.5	200-400	35.2	12.4	52.4	0.7
400-800	32.5	15.1	52.4	0.4	400-800	38.6	13.1	48.3	0.4
800-1100	36.3	14.2	49.5	0.4	800-1100	36.3	14.4	49.3	0.4
1100-1500	29.6	18.7	51.7	0.3	1100-1500	42.1	14.7	43.2	0.2
1500-1700	31.2	16.4	52.4	0.2	1500-1700	36.7	19.8	43.5	0.8
1700-2000	41.1	16.0	42.9	0.1					

* Organic carbon

Table 3.2. Average of soil textural properties from KRS 7A-1 and KRS 7A-2 used in LEACHC

Depth (mm)	Sand %	Silt %	Clay %	OC* (%)	Bulk Density (g/cm ³)
0-100	37.6	12.9	49.6	1.06	1.23
100-200	39.5	10.4	50.1	0.84	1.37
200-400	35.9	13.7	50.5	0.56	1.41
400-800	35.6	14.1	50.4	0.41	1.46
800-1100	36.3	14.3	49.4	0.40	1.47
1100-1500	35.9	16.7	47.5	0.27	1.44
1500-1700	34.0	18.1	48.0	0.52	1.50
1700-2000	41.1	16.0	42.9	0.14	1.50

Table 3.3. Groundwater quality at KRS-7A

Ca	Mg	Na	K	Cl	S	HCO ₃	EC	pH
mg/L							mS/m	
68	104	495	3	960	19	475	400	7.78

Table 3.4. Irrigation and rainfall amounts for the Maize crop at KRS-7A

Date	02/05/04	13/05/04	26/05/04	03/06/04	12/06
Irrigation/rainfall amount (mm)	144	144	144	13.5	144
Date	27/06/04	14/07/04	25/07/04	07/08/04	19/08/04
Irrigation/rainfall amount (mm)	144	144	144	144	144

Table 3.5. Irrigation water quality used for the Maize crop at KRS-7A

	pH	TDS	EC	Na	K	Ca	Mg	Cl	SO ₄	HCO ₃
		mg/L	mS/m	mg/L						
Irrigation Water Quality (Diversion Dam)	8.06	178	30	20	3	25	12	14	3	183

Table 3.6. Total weekly pan evaporation and mean weekly temperatures during growing season of the Maize crop at KRS-7A

Week	Pan evaporation (mm)	Mean weekly Temperature (C°)	Amplitude (C°)
1	42.2	29.29	6.91
2	45.3	28.92	7.09
3	47.1	27.41	8.62
4	47.6	28.13	7.59
5	46.4	25.91	7.47
6	39.4	28.08	6.94
7	38	27.42	7.24
8	37.3	28.04	6.02
9	24.3	27.01	7.41
10	31.6	26.29	6.84
11	40.6	23.48	9.26
12	40.4	18.61	9.16
13	36.2	18.41	9.66
14	35.6	22.74	9.53
15	39.8	22.74	9.6
16	47.2	20.54	7.29
17	36.6	20.86	9.6
18	41.1	23.8	10.04
19	40.4	23.31	9.84
20	43.8	23.86	9.71
21	46.8	22.33	11.07
22	49.8	25.96	8.14
23	53.6	24.61	8.83
24	63.6	25.81	8.14
25	54.9	26.46	9.86
26	57	28.34	8.56
27	57.2	30.65	7.82
28	59.7	30.79	9.13
29	64.1	31.59	8.14
30	60.2	32.52	8.56
31	67.5	32.6	7.93
32	60.6	32.01	7.19

3.2. Cummings Farm site – CUM 55

The second site was selected at Cummings farm in block 55 (CUM 55), which has soil type belonging to the Cununurra clays. A sugarcane crop grown on this block during 2004-05 was selected for the study. To determine the soil physical and textural properties, initial soil samples were collected from various segments of the soil profile up to 2 m depth at two locations (CUM 55-1 and CUM 55-2) and immediately before the start of the growing season. The samples were

analysed for soil texture, bulk density organic carbon soil moisture and soil chemistry to provide initial conditions for model calibration.

The textural properties of the soils at CUM 55-1 and CUM 55-2 are listed in Table 3.7. The proportion of clay was greater than 55% at both locations, except in the lower most layer (1500-2000 mm depth) where it was 44% at CUM55-1 and 33% at CUM55-2. The sand content in this layer was 55% at CUM55-2. Due to the increased sand content in the bottom layer its permeability was expected to be greater. According to the distribution of texture, the top soil up to 1500 mm depth can be classed as clay and from 1500 to 2000 mm at CUM55-2 as sandy clay loam. The soil texture, bulk density and organic carbon values at the two locations (CUM55-1 and CUM55-2) were averaged (Table 3.8) and used as input to the LEACHC model to estimate the soil retention parameters.

Additional soil samples were collected on 11/06/04, 12/07/04, 08/10/04, 12/03/05 and 01/07/05. These were analysed for soil moisture and soil chemical properties and then compared to the simulated data during model calibration. The water table in the experimental block was monitored by taking regular water level readings from existing bore holes at the site. According to the observed data, the water table elevation varied between 3.8 and 4.2 m below ground surface during the simulation period. A groundwater sample, collected from one of the bore holes at this site, and analysed for major ions, EC and pH, indicated that the shallow groundwater quality was relatively fresh. The measured EC was 46 mS/m (Table 3.9).

A sugarcane crop was planted during second week of May 2004. It emerged from the ground during the fourth week of May 2004. The crop developed full canopy by the second week of August 2004 and its harvest started during the last week of June 2005. Fertilizer application rates were 250 kg/ha DAP, 10kg/ha Zinc, 15 kg/ha Sulphur and 325 kg/ha Urea.

Irrigation and rainfall amounts are listed in Table 3.10. About 1900 mm (946 ML) was applied through 14 irrigations and around 700 mm was received from rainfall during the growing season. The irrigation application amounts varied between 106 and 168 mm (53 - 84 ML applied as one irrigation to the 50 ha crop). The averages of EC and pH of the irrigation water were 30 mS/m and 8.06, respectively (Table 3.5).

The weather data were obtained from KRS weather station. The pan evaporation data were processed to determine total weekly pan evaporation (Table 3.11). Similarly, the temperature data were processed to calculate the mean weekly temperatures and amplitudes. The week numbers start from 01/04/04 to coincide with the start of the model simulation period. The model simulation end date was 31/07/05; however, the model required pan evaporation and temperature data for at least one additional week.

Table 3.7. Soil textural properties in Block 55 at Cummings Farm (CUM 55-1 and CUM 55-2)

CUM 55-1					CUM 55-2				
Depth (mm)	Sand %	Silt %	Clay %	OC* (%)	Depth (mm)	Sand %	Silt %	Clay %	OC* (%)
0-100	26.0	10.6	63.4	1.12	0-100	23.1	19.3	57.6	0.93
100-200	25.3	16.0	58.7	1.04	100-200	27.2	8.1	64.7	1.16
200-400	27.3	11.5	61.2	0.60	200-400	25.0	14.6	60.4	0.42
400-800	23.4	17.7	58.9	0.47	400-800	23.6	13.6	62.8	0.41
800-1100	22.9	18.8	58.3	0.43	800-1100	25.9	12.2	61.9	0.41
1100-1500	22.2	22.0	55.8	0.53	1100-1500	24.0	13.4	62.6	0.32
1500-2000	22.2	34.1	43.7	0.22	1500-1700	54.9	12.3	32.8	0.15

*: Organic carbon.

Table 3.8. Average of soil textural properties from CUM 55-1 and CUM 55-2 used as input to the LEACHC model

Depth (mm)	Sand %	Silt %	Clay %	OC* (%)	Bulk Density (g/cm ³)
0-100	24.6	15.0	60.5	1.03	1.33
100-200	26.3	12.1	61.7	1.10	1.33
200-400	26.2	13.1	60.8	0.51	1.35
400-800	23.5	15.7	60.9	0.44	1.46
800-1100	24.4	15.5	60.1	0.42	1.47
1100-1500	23.1	17.7	59.2	0.43	1.45
1500-2000	38.6	23.2	38.3	0.19	1.49

Table 3.9. Groundwater quality at CUM 55

Ca	Mg	Na	K	Cl	S	HCO ₃	EC	pH
mg/L							mS/m	
13	16	28	3	27	3	123	46	7.89

Table 3.10. Irrigation and rainfall amounts for the Sugarcane crop at CUM 55

Date	08/05/04	03/06/04	20/06/04	22/07/04	17/08/04	24/09/04	28/10/04
Irrigation/rainfall amount (mm)	168	10.5*	120	148	120	120	168
Date	06/11/04	08/11/04	13/11/04	15/11/04	22/11/04	09/12/04	09/12/04
Irrigation/rainfall amount (mm)	12.5*	15*	106	21.5*	106	144	144
Date	22/12/04	26/12/04	27/12/04	01/01/05	02/01/05	03/01/05	06/01/05
Irrigation/rainfall amount (mm)	16.7*	13.4*	43.1*	17*	130.2*	42.8*	14*
Date	12/01/05	13/01/05	18/01/05	20/01/05	31/01/05	03/02/05	15/02/05
Irrigation/rainfall amount (mm)	20*	13*	168	24.6*	28.8*	34.1*	140
Date	06/03/05	16/03/05	17/03/05	04/04/05	18/04/05	05/05/05	
Irrigation/rainfall amount (mm)	33*	52.6*	74*	120	144	120	

*: Denotes rainfall. Only rainfall amounts of 10 mm or more were used in the model

Table 3.11. Total weekly pan evaporation and mean weekly temperatures during the growing season of the Sugarcane crop at CUM55

Week	Pan evaporation (mm)	Mean weekly temperature (C°)	Amplitude (C°)
1	42.2	29.29	6.91
2	45.3	28.92	7.09
3	47.1	27.41	8.62
4	47.6	28.13	7.59
5	46.4	25.91	7.47
6	39.4	28.08	6.94
7	38.0	27.42	7.24
8	37.3	28.04	6.02
9	24.3	25.80	6.20
10	31.6	26.29	6.84
11	40.6	23.48	9.26
12	40.4	18.61	9.16
13	36.2	18.41	9.66
14	35.6	22.74	9.53
15	39.8	22.74	9.60
16	47.2	20.54	7.29
17	36.6	20.86	9.60
18	41.1	23.80	10.04
19	40.4	23.31	9.84
20	43.8	23.86	9.71
21	46.8	22.33	11.07
22	49.8	25.96	8.14
23	53.6	24.61	8.83
24	63.6	25.81	8.14
25	54.9	26.46	9.86
26	57.0	28.34	8.56
27	57.2	30.65	7.82
28	59.7	30.79	9.13
29	64.1	31.59	8.14
30	60.2	32.52	8.56
31	67.5	32.60	7.93
32	60.6	32.01	7.19
33	63.1	32.95	7.82
34	55.2	31.39	6.95
35	68.6	32.59	7.32
36	64.9	33.55	7.19
37	68.1	34.09	8.41
38	68.1	33.39	7.12
39	58.3	30.44	6.10

Table 3.12 (continued). Total weekly pan evaporation and mean weekly temperatures during the growing season of the Sugarcane crop at CUM55

Week	Pan evaporation (mm)	Mean weekly temperature (C°)	Amplitude (C°)
40	58.3	30.4	4.73
41	43.7	29.2	6.82
42	54.6	30.2	5.51
43	46.6	30.7	6.08
44	54.2	31.3	6.22
45	48.4	31.2	5.00
46	45.0	30.2	6.34
47	47.0	30.7	6.58
48	47.1	30.6	6.95
49	52.8	32.3	6.42
50	52.1	31.5	7.09
51	56.2	31.4	3.64
52	27.9	27.0	7.81
53	46.5	28.9	8.04
54	49.3	29.3	7.96
55	37.6	29.4	9.17
56	48.5	29.0	9.29
57	46.5	28.0	9.25
58	46.0	27.2	10.9
59	44.0	26.8	10.66
60	44.7	24.9	9.42
61	39.0	22.8	9.59
62	43.0	22.6	8.59
63	34.1	22.7	7.04
64	31.0	25.9	7.78
65	31.2	25.3	9.19
66	39.4	21.8	8.1
67	34.8	20.1	8.65
68	32.3	25.7	7.52
69	56.8	24.7	8.12
70	41.9	23.6	7.76

4. MODEL CALIBRATION

4.1. Maize Crop at Kimberly Research Station site – KRS 7A

To calibrate the LEACHC model for the Maize crop, required data were soil textural, physical and chemical properties; crop growth; irrigation amounts and quality; rainfall amounts and quality; total weekly pan evaporation; mean weekly temperatures; and water table depth and quality. These data were obtained through monitoring and soil and water analyses as discussed in detail above. The soil textural properties from KRS 7A-1 and 7A-2 were averaged and used in the LEACHC to estimate the retention parameters (Table 3.2). LEACHC required the total profile depth and segment thickness in mm. The total soil profile depth considered for modelling was 2 m with 20 segments of 100 mm each. The soil textural properties (% clay, % silt, % organic carbon) in these segments varied according to the observed data. The LEACHC model required data about cation exchange capacity and exchangeable cations. These data were obtained from analyses of the soil samples that were collected before the start of growing season. The initial soil moisture and soil chemical composition data also were obtained from analyses of the first set of soil samples collected from the site. Irrigation amounts and quality, rainfall (Table 3.4), pan evaporation and temperature (Table 3.6) were used as input to the LEACHC model. The simulation started on 01/04/04, about one month before the crop sowing date, to enable equilibration of soil moisture in the soil profile before the start of the growing season. The simulation end date was on 30/11/04, approximately 20 days after the crop was harvested on 07/10/04.

Soil samples also were collected during the growing season and analysed for soil moisture and soil chemistry. These data were used for comparison with the model results. The two parameters (α and β) in Campbell's equation (Campbell, 1974) were slightly adjusted to achieve a reasonable agreement between the observed and predicted soil moisture content and salinity profiles.

Figure 4.1 shows the comparison between the observed and predicted soil moisture content at three dates; 27/04/04, 12/07/04 and 08/10/04. The agreement between observed and predicted soil moisture was reasonable except in the top layers of the soil profile. The model over-predicted the soil moisture content in the top layers. The saturated soil moisture was low in the bottom layers due to coarser soil (an increased sand content) and therefore both the observed and predicted soil moisture contents were lower in this layer as compared to middle layers. The Willmott's d-index (Willmott, 1981), a measure of the degree of agreement between the observed and predicted values, was above 0.5. Given the inherent difficulty in estimating the soil retention properties in various layers by either using Campbell's equation or various regression equations, this level of agreement between the observed and predicted water content was viewed as sufficiently accurate for simulating the soil moisture in various irrigation management scenarios.

The predicted soil profile electrical conductivity (EC) was at the predicted moisture content and therefore it was necessary to convert it to E_{Ce} (electrical conductivity of the saturated paste extract) for a meaningful comparison with the observed E_{Ce}. The E_{Ce} will be termed as EC in the rest of the report for simplicity. Comparison of the observed and predicted soil profile EC at the three different dates is shown in Figure 4.2. The agreement between the observed and predicted EC was good except in one layer located just below the middle of the soil profile where it was under-predicted by the model. There was an unusual sudden increase in the observed EC of this layer that can not be explained. However, in general, the model did a very good job of predicting the soil profile EC. The EC in the upper parts of the soil profile did not change significantly during growing season of the maize crop mainly because of low initial value, heavy irrigations causing leaching and a relatively deeper non-saline groundwater level (4 m bgl). EC increased in the middle layers over the growing season but remained well below the thresholds for affecting the crop yield.

A reasonable agreement between the observed and predicted water content and salinity data suggested that the model was able to simulate both water content and salinity profiles for the maize crop grown on the Cununurra clay. This calibrated model was used for irrigation scheduling of the Maize crop to ensure the maximum irrigation water use efficiency and minimal runoff and drainage losses.

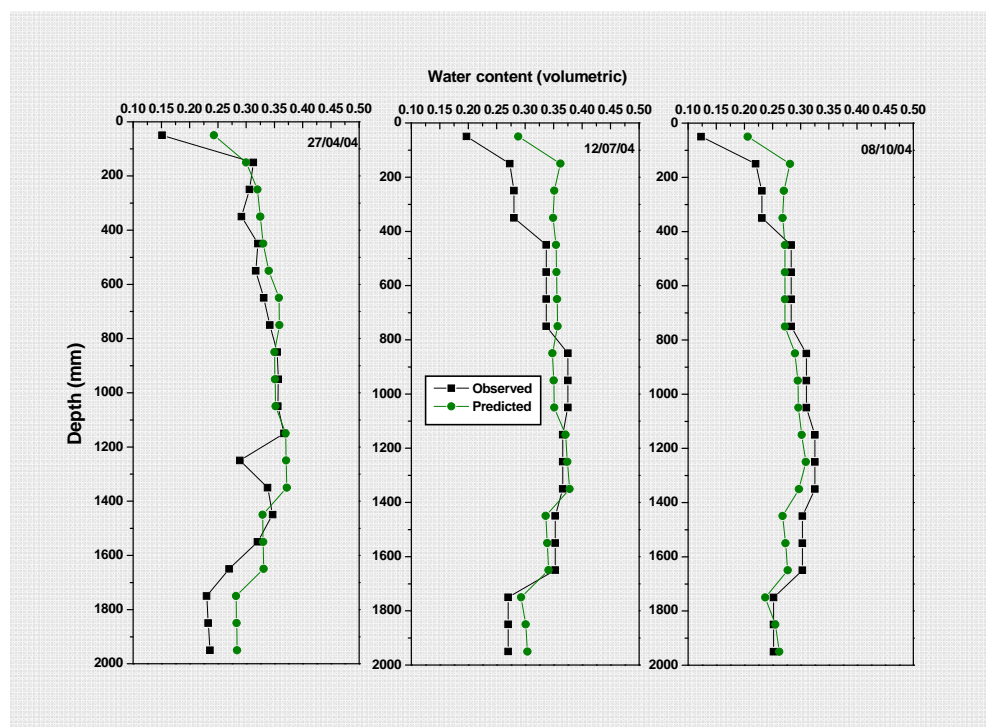


Figure 4.1. Comparison of the observed and predicted soil profile water content at KRS 7A on 27/04/04 (left), 12/07/04 (middle) and 08/10/04 (right)

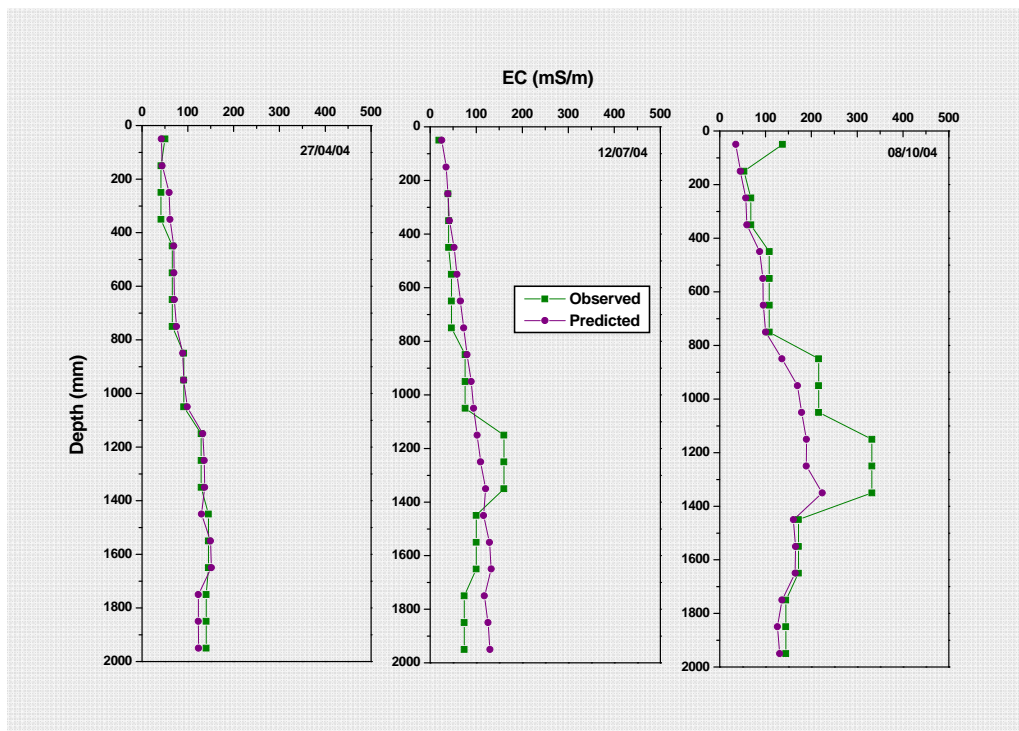


Figure 4.2. Comparison of the observed and predicted soil profile EC at KRS 7A on 27/04/04 (left), 12/07/04 (middle) and 08/10/04 (right)

4.2. Sugarcane Crop at Cummings site – CUM 55

To calibrate the LEACHC model for the Sugarcane crop grown on Cununurra clay required data about soil textural, physical and chemical properties; crop growth; irrigation amounts and quality; rainfall amounts and quality; weekly pan evaporation; mean weekly temperatures; and water table depth and quality. These data were obtained from the CUM 55 site by soil and water analyses, as discussed above, and the weather station located at the KRS. Soil water content and salinity profiles were obtained from various soil segments up to 2 m depth (Table 3.7). The total soil profile depth simulated in the modelling was 2 m, to coincide with monitoring depth, and consisted of 20 segments of 100 mm each. The soil textural properties (% clay, % silt, % organic carbon) from 55-1 and 55-2 were averaged and used in the LEACHC model to estimate the retention parameters. Initial conditions data, including soil moisture, soil chemical composition, cation exchange capacity and exchangeable cations were obtained from analyses of the soil samples collected prior to the start of the growing season. Irrigation and rainfall amounts (Table 3.10) and quality, groundwater quality (Table 3.9), and pan evaporation and temperature (Table 3.11), were used as input in the LEACHC model. Only rainfall amounts ≥ 10 mm were used as input. The simulation started on 01/04/04, about one month before sowing to enable equilibration of soil moisture in the soil profile before the start of the growing season. The simulation end date was 31/07/05, approximately 40 days after the crop was harvested on 22/06/05.

The soil samples collected during the growing season were analysed for the soil moisture and soil chemistry and used for comparison with the model predictions. Slight adjustments to the two parameters (α and β) of Campbell's equation (Campbell, 1974) were made to achieve a reasonable agreement between the observed and predicted soil moisture content and salinity profiles.

Comparisons between the observed and predicted soil moisture contents are depicted in Figure 4.3 and Figure 4.4 for three dates during 2004 (27/04/04, 11/06/04 and 08/07/04) and two during 2005 (12/03/05 and 01/07/05). Overall the agreement between the observed and predicted water content was good except on 08/07/04, when the model under-predicted the soil moisture content in the middle part of the profile. In the upper and lower parts of the soil profile the model predictions were good and matched well with the observed data. As expected, both the observed and predicted water contents in the surface layers were relatively drier. In the remaining profile the water content was relatively uniform at most dates. The Root Mean Square Error (RMSE) ranged between 0.01 and 0.03 in various segments of the soil profile. The Willmott's d-index, a measure of goodness of fit, ranged between 0.45 and 0.55, which was reasonable considering the variation of soil structure and physical properties expected in the various soil layers.

The predicted EC was expressed at the predicted water content. Consequently, these values were converted to ECe to enable meaningful comparison with the observed ECe determined at the saturated paste extract. Figure 4.5 shows a comparison between the observed and predicted soil profile EC on the three dates during 2004 and Figure 4.6 shows this comparison on the two dates during 2005. Overall, the agreement between the observed and predicted EC was reasonable. At some dates (08/07/04, 12/03/05 and 01/07/05) the model slightly over-predicted EC in the middle layers. The prediction was relatively good in the lower layers of the soil profile at most dates. The predicted EC also was close to the observed EC in the top layers of the soil profile except on 27/04/04, when it was over-predicted, and 01/07/05 when it was under-predicted.

A reasonable agreement between the observed and predicted water content and salinity values suggested that the model was able to simulate soil moisture content and salinity profiles reasonably well if it is used for irrigation scheduling of the sugarcane grown on the Cununurra clay soil. This calibrated model was used to devise irrigation management strategies for the sugarcane crop grown on the Cununurra clay soil for various water table depths and salinity conditions.

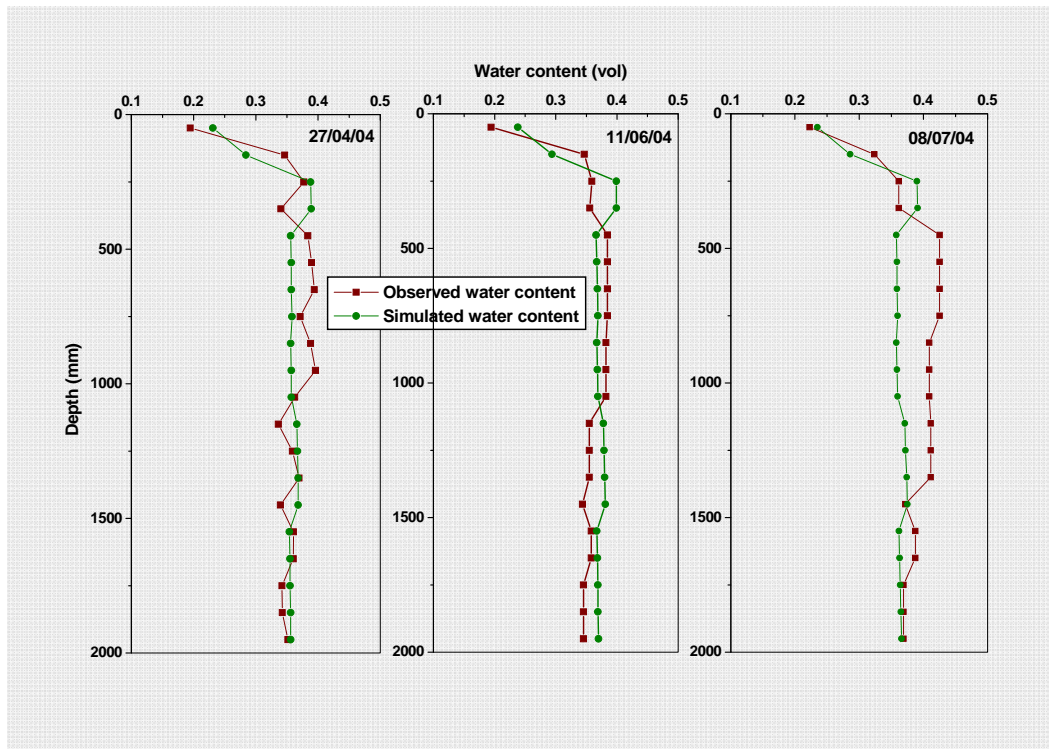


Figure 4.3. Comparison of the observed and predicted soil profile water content during 2004 on 27/04/04 (left), 11/06/04 (middle) and 08/07/04 (right)

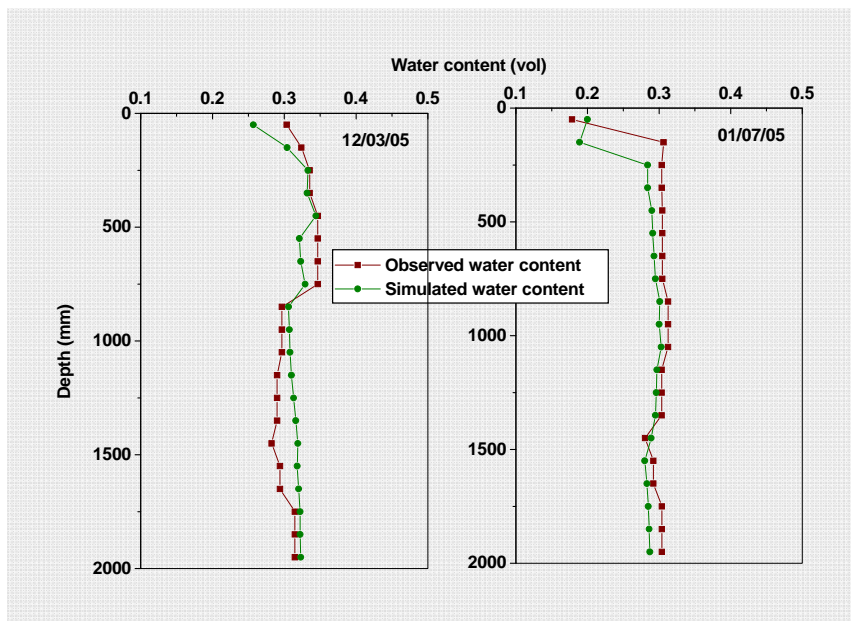


Figure 4.4. Comparison of the observed and predicted water content of the soil profile at CUM 55 on 12/03/05 (left) and 01/07/05 (right)

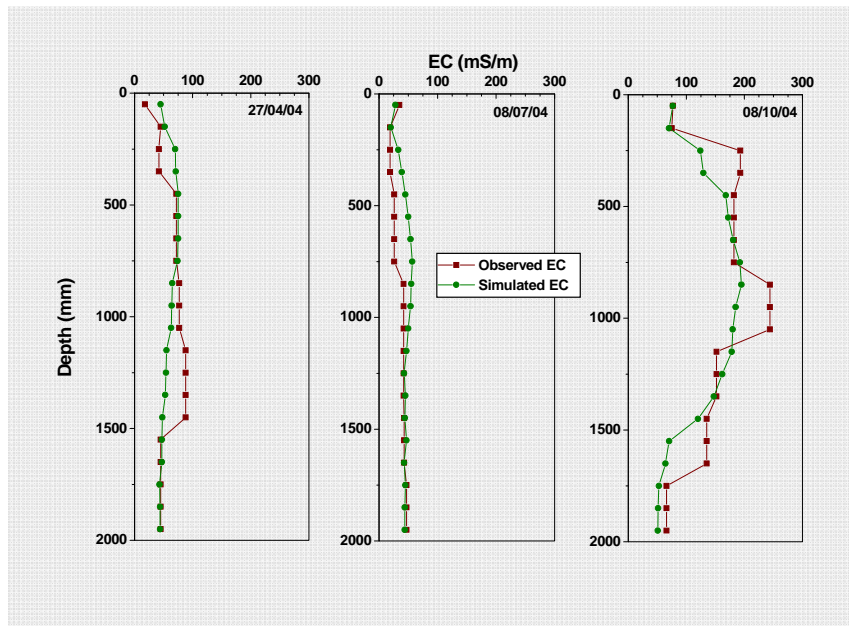


Figure 4.5. Comparison of the observed and predicted soil profile EC at CUM 55 on 27/04/04 (left), 11/06/04 (middle) and 08/07/04 (right)

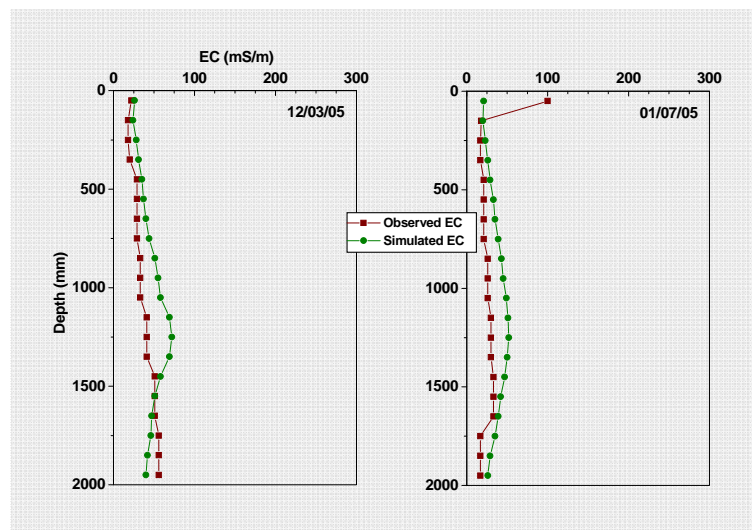


Figure 4.6. Comparison of the observed and predicted soil profile EC at CUM 55 on 12/03/05 (left) and 01/07/05 (right)

5. SIMULATION OF IRRIGATION STRATEGIES

5.1. Irrigation Scheduling of Maize Crop – Deep Water Table

After its calibration, the LEACHC model was used to evaluate various irrigation management strategies for the maize crop if grown on Cununurra clay. Three irrigation application amounts and two irrigation intervals were considered. The purpose was to assess the impact of irrigation application amounts and intervals on the soil moisture availability for the maize crop. Total observed weekly and fortnightly pan evaporation (ET) was calculated for the whole simulation period (April to October 2004). A total of six simulations were performed. In the first three, irrigation application amounts equal to 100%, 75% and 50% of the total fortnightly pan evaporation from the past 14 days were applied every fortnight as irrigation. These simulations will be called IPF100ET, IPF75ET and IPF50ET, where IP stands for irrigation practice, F represents a fortnightly irrigation interval, and 100ET indicates the percent of total fortnightly pan evaporation applied as irrigation. In the other three simulations, the irrigation interval also was changed from 14 days to 7 days during the second half of the growing season. Weekly irrigation application amounts equal to 100%, 75% and 50% of the total weekly pan evaporation from the past 7 days were applied every week as irrigation. These simulations will be called IPM100ET, IPM75ET and IPM50ET, where M indicates a mixed irrigation interval of 14 days during the first half of the simulation and 7 days during second half. The model simulation using the actual observed irrigation data will be called the CIP (current irrigation practice). Water balance and soil moisture availability from the IPF and IPM simulations were compared with those obtained from the CIP.

For the CIP a total of 1420 mm of water was applied as irrigation and rainfall, and about 50 mm was available from the soil profile at the start of the simulation period. The model predicted that out of the 1470 mm, about 50% (740 mm) was used as ET, 43% (630 mm) was lost as runoff and 7% (100 mm) drained below the soil profile (Figure 5.1). Total irrigation-rainfall application for IPF100ET was around 1125 mm, which included about 30 mm of soil water available from the soil profile at the start of simulation. Around 73% (825 mm) of the total applied was used as ET, 23% (115 mm) was lost to runoff and 4% (43 mm) was lost to drainage (Table 5.1). In the case of IPF75ET, about 910 mm of water was applied as irrigation, 771 mm was used as ET, 115 mm was lost as runoff, and 25 mm drained below the soil profile (Table 5.1). For IPF50ET, about 708 mm was applied as irrigation, 664 mm was used as ET, and the rest was lost to runoff (33 mm) and drainage (11 mm).

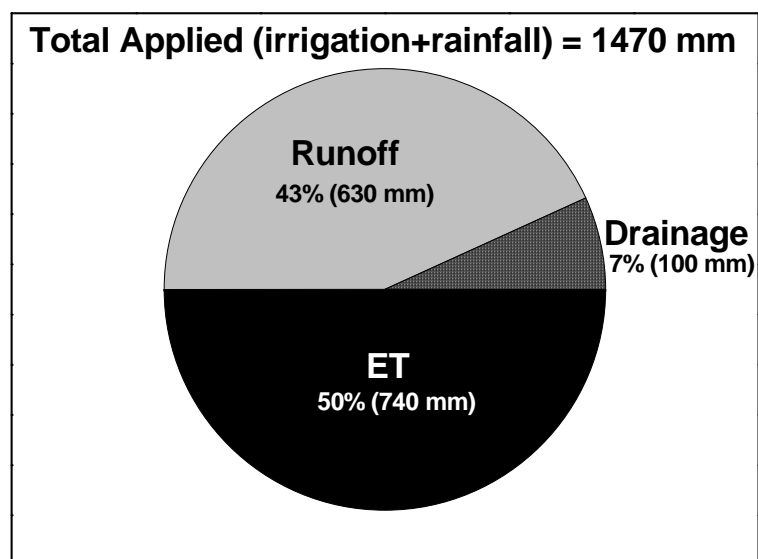


Figure 5.1. Simulated water balance for Current Irrigation Practice (CIP) at KRS 7A: proportions of total applied irrigation water used as ET and lost to runoff and drainage

Table 5.1. Comparisons of total irrigation, ET, runoff and drainage amounts for various irrigation strategies for the maize crop at KRS 7A

Cumulative Irrigation amounts				
Month (end)	CIP	IPF100ET	IPF75ET	IPF50ET
	mm			
4	0	0	0	0
5	1	1	1	1
6	503	269	221	178
7	841	444	353	267
8	1133	605	473	347
9	1423	864	666	476
10	1423	1093	838	591
*Add moisture	47	30	73	117
Total	1470	1123	911	708

Cumulative ET				
Month (end)	CIP	IPF100ET	IPF75ET	IPF50ET
	mm			
4	0	0	0	0
5	12	12	12	12
6	97	87	85	82
7	249	239	235	231
8	423	408	403	397
9	617	591	584	528
10	728	825	771	664

Cumulative Runoff				
Month (end)	CIP	IPF100ET	IPF75ET	IPF50ET
	mm			
4	0	0	0	0
5	0	0	0	0
6	196	60	38	22
7	342	94	53	25
8	491	143	75	29
9	640	204	95	29
10	640	255	115	33

Cumulative Drainage				
Month (end)	CIP	IPF100ET	IPF75ET	IPF50ET
	mm			
4	0	0	0	0
5	1	1	1	1
6	59	17	9	4
7	95	41	24	11
8	99	43	25	11
9	101	43	25	11
10	101	43	25	11

* Add moisture: amount used from previously stored soil water

The total amount of water used as ET in the IPF100ET (825 mm) and IPF75ET (771 mm) was significantly higher than CIP (740). However, ET was lower in IPF50ET (664 mm). The maximum ET will therefore be likely if IPF100ET is adopted as irrigation practice. In fact, both IPF100ET and IPF75ET seem attractive with respect to total ET. The total water lost as runoff in the IPF100ET (255 mm) was significantly lower than CIP (640 mm). It was much lower for both IPF75ET and IP50ET than CIP. The same was true for the total amount lost to drainage (Figure 5.2). Most of the extra water applied as irrigation in the CIP was either lost as runoff or drainage.

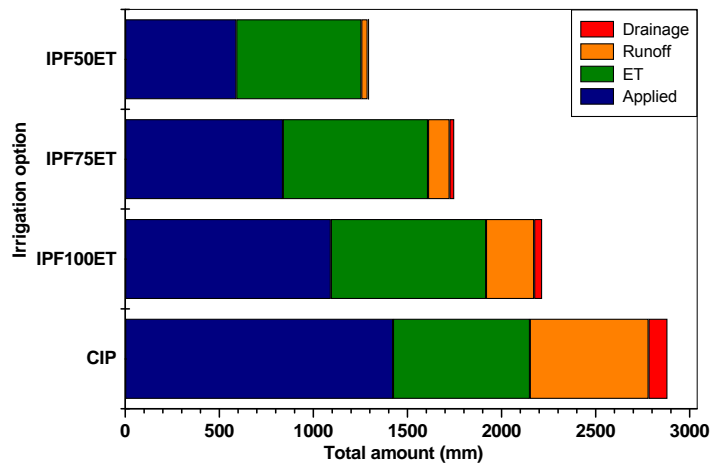


Figure 5.2. Water balances for the simulated irrigation options at KRS 7A; proportions of total applied irrigation water, ET, runoff and drainage

There was a predicted net saving of 330 mm (23%) of water over one growing season if IPF100ET was used as irrigation practice (Table 5.1). If IP75ET was adopted the predicted net saving would be around 500 mm over one growing season. However, the selection of the best irrigation practice should not be based on the total applied, ET, runoff and drainage alone. The availability of soil moisture in various irrigation strategies also should be assessed before recommending the best irrigation strategy. If a particular irrigation practice causes soil moisture stress between irrigations it will affect crop productivity. Any such practice should not be recommended, irrespective of the savings in the total applied water, or reductions in the runoff and drainage amounts. Comparison of the soil moisture profiles from the various irrigation strategies is required to select the best irrigation practice. The maximum soil moisture stresses are expected to occur just before the start of each irrigation.

The soil moisture profiles for CIP, IPF100ET, IPF75ET and IPF50ET are shown in Figure 5.3. These profiles represent the soil moisture content on the day before each irrigation date for all irrigation events of the Maize crop. The wilting point and allowable depletion water content profiles also are shown in this Figure. The wilting point (WP) corresponds to the soil moisture at which the plants are no longer able to extract any moisture from the soil profile; at this point they

would die. The allowable depletion (AD) water content was assumed to be 0.5 of the total available (TA) water content, where the total available water is defined as the amount of water available between field capacity (FC) and wilting point (WP),

$$AD = FC - 0.5 (FC - WP).$$

Ideally, the irrigation practice should ensure that the soil moisture content does not decrease below AD.

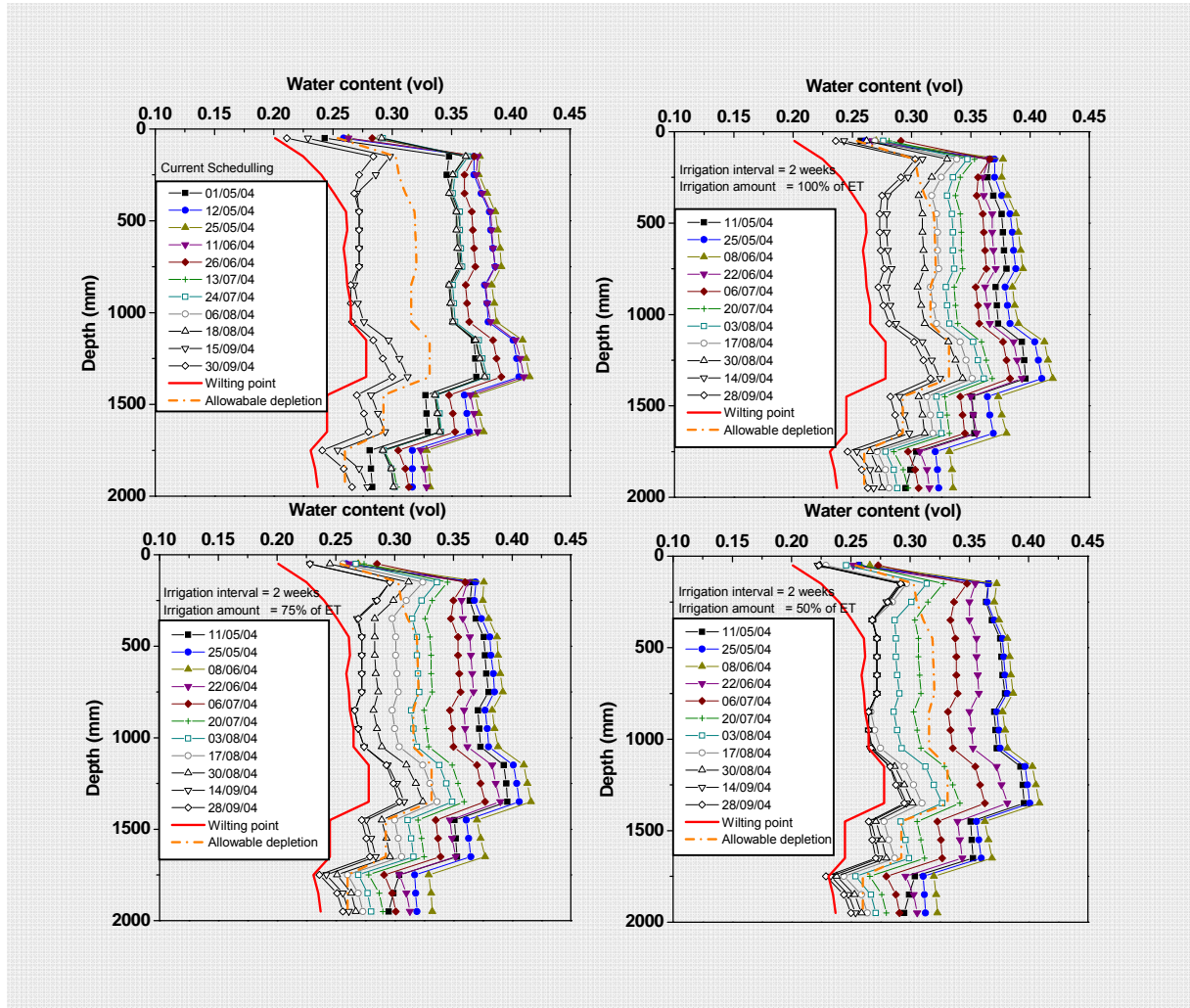


Figure 5.3. Soil moisture profiles the day before irrigations for the maize crop at KRS 7A; CIP (top left), IPF100ET (top right), IPF75ET (bot. left) and IPF50ET (bot. right)

The predicted soil moisture profiles for all irrigation strategies and monitoring dates remained always above the wilting point. Under CIP, the soil moisture content was less than the allowable depletion on 15/09/04 and 30/09/04 (Figure 5.3 (top left)). For IPF100ET, there were three occasions when soil moisture in middle parts of the soil profiles was less than the AD. For IPF75ET and IPF50ET there were four and five occasions, respectively, when the soil moisture profiles were lower than AD (Figure 5.3 (bottom left and right)). These results suggest that the maize crop would be under moisture stress for some time during the second half of the growing

season for all of the irrigation strategies. The soil moisture content was always above AD during first half of the growing season because of the ET demand was relatively less.

The predicted soil moisture profiles for the CIP were wetter than all other strategies, except at two occasions during September when these were drier than the IPF100ET in some parts of the soil profile. Most of the time, the predicted soil moisture profiles for the CIP varied within a relatively narrow range, whereas, in all the other strategies, the variation between various monitoring dates was relatively larger.

The soil moisture profiles of CIP were similar to IPF100ET with respect to the water availability for the crop. If it is assumed that the maize crop was already mature during the month of September and ready for harvest (no irrigation was applied during this month in CIP) then the impact of the last two soil moisture profiles on the crop water availability can be ignored; both of these were less than the AD. Accordingly, the CIP may appear to be the best irrigation practice with respect to soil water availability but, as discussed earlier, it caused the largest amount of wastage in the form of runoff and drainage. The predicted amount of water used as ET in the CIP also was less than in the IPF100ET. The best strategy with respect to both crop water availability and water saving was IPF100ET. It would require around 11 ML/ha (assuming 100% irrigation application efficiency) and deliver a net saving of 330 mm (23%) over one growing season without any crop water stress. The predicted water savings were achieved from reductions in the runoff and drainage. The IPF75ET would require around 8.4 ML/ha and deliver a net saving of around 40%; however, the crop would be under minor stress for a few days. The level of stress was reduced by decreasing the irrigation interval from fortnightly to weekly in last half of the growing season, as shown in Figure 5.4. The build up of soil salinity was not significant and remained similar to the EC profile shown in Figure 4.2. There were no significant differences in the predicted soil salinity profiles over time among the various irrigation strategies.

Based on the above model predictions, it is concluded that irrigation application equal to 100% of total fortnightly pan evaporation at 14 days interval is the best irrigation strategy and would save around 23% water. An irrigation application amount equal to 75% of total fortnightly and weekly pan evaporation at 14 day interval during the first half of the growing season and 7 day interval during the second half would be the best irrigation option if it is practicable to change the irrigation interval. This irrigation strategy would save around 40% water. A minor impact on the crop yield is predicted if the irrigation interval is not changed from fortnightly to weekly during the second half of the growing season.

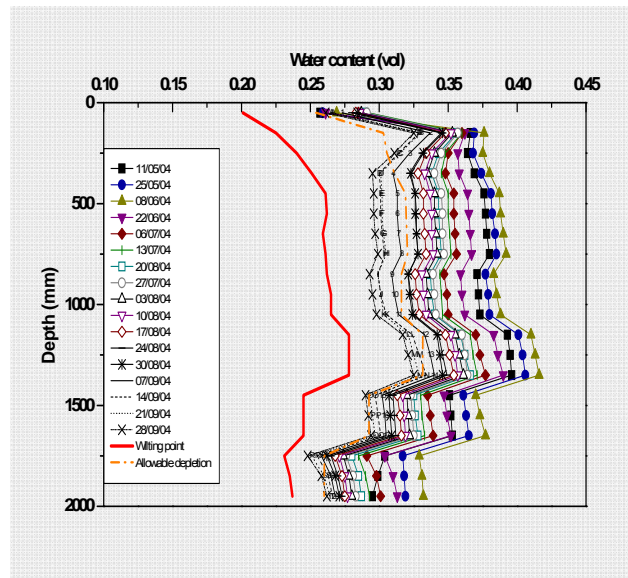


Figure 5.4. Soil moisture profiles the day before IPM75ET irrigations for the maize crop at KRS 7A

5.2. Irrigation Scheduling of Sugarcane Crop – Deep Water Table

The irrigation intervals and amounts used to irrigate the Sugarcane crop in the experimental block CUM 55 during 2004-05 were applied to simulate the current irrigation practice (CIP) and soil moisture profiles on the day before each irrigation. Five irrigation application strategies, in addition to the CIP, were simulated to determine an irrigation schedule that would produce the maximum soil moisture availability, minimum runoff and drainage, maximum ET, and minimum salinity accumulation in the soil profile. Total observed weekly and fortnightly pan evaporation (ET) was calculated for the whole simulation period.

In the first irrigation strategy (IPF100ET) an irrigation application amount equal to 100% of the total fortnightly pan evaporation (ET) from the past 14 days was applied every fortnight. In the second irrigation strategy (IPF75-100ET) an irrigation amount equal to 75% of the total fortnightly ET from previous two weeks was applied every fortnight for the first quarter of the growing season and 100% of total fortnightly ET was applied during the rest of the growing season. In the third irrigation strategy (IPF50-100ET) the irrigation amounts were 50% of the total fortnightly ET during first quarter of the growing season and 100% during rest. In the fourth irrigation strategy (IPM50-100ET), an irrigation application amount equal to 50% of total fortnightly ET was applied every fortnight during first quarter of the growing season and 100% of total weekly ET was applied every 7 days during remainder of the growing season. The fifth irrigation strategy (IPM50-75ET) was the same as the fourth, except the irrigation amount was 75% of total weekly ET during the final three-quarters of the growing season. Water balance, soil moisture profiles and salinity profiles were compared between these irrigation strategies to assess ET, runoff, drainage, soil moisture availability and salinity accumulation over time.

For the current irrigation practice a total of 2585 mm of water was applied as irrigation and rainfall to the sugarcane crop and about 190 mm was used from already available moisture in the soil profile. The model predicted that out of the 2775 mm total applied water, about 69% (1920 mm) was used as ET, 24% (670 mm) was lost as runoff and 7% (190 mm) drained below the soil profile (Table 5.2). For IPF100ET, the total applied as irrigation and rainfall, including the water which was available from the soil profile at start of the simulation, was around 3330 mm, of which about 71% (2375 mm) was used as ET, 19% (620 mm) was lost to runoff and 10% (340 mm) was lost to drainage. For IPF75-100ET, about 3150 mm of water was applied as irrigation and rainfall, 75% (2375 mm) was used as ET, 17% (530 mm) was runoff and 8% (270 mm) drained below the soil profile. For IPF50-100ET, about 2970 mm was applied as irrigation and rainfall, 78% (2317 mm) was used as ET, about 16% (470 mm) was lost to runoff and around 6% (190 mm) was lost to drainage. For IPM50-100ET, 2930 mm was applied as irrigation and rainfall, 78% (2300 mm) was used as ET, 12% (360 mm) was lost as runoff and 10% (280 mm) drained below the soil profile. Finally, for IPM50-75ET, about 2630 mm was applied as irrigation and rainfall, 86% (2265 mm) was used as ET, 7% (190 mm) was lost to runoff and around 7% (175 mm) was lost as drainage.

Table 5.2. Total irrigation amounts, ET, runoff and drainage for various irrigation strategies for the sugarcane crop at CUM 55

Irrigation Strategy	Total Applied	ET	Runoff	Drainage
	mm			
CIP	2585	1920	670	190
IPF100ET	3175	2375	620	340
IPF75-100ET	2995	2355	530	270
IPF50-100ET	2815	2317	470	190
IPM50-100ET	2840	2300	360	280
IPM50-75ET	2460	2265	190	175

The total irrigation and rainfall amount was smallest for IPM50-75ET, largest for IPF100ET, and was similar for IPF50-100ET and IPM50-100ET. The total ET was largest for IPF100ET, smallest for CIP, and was significantly larger in all irrigation strategies compared to the CIP (Figure 5.5). Variation of ET between the irrigation strategies, except CIP, was small (2375 – 2265 mm). Larger total ET usually results in greater crop productivity. The model predicted that the total runoff was the highest for CIP and lowest for IPM50-75ET. The second lowest total runoff resulted from IPM50-100ET. The total drainage was the highest for IPF100ET and lowest for IPM50-75ET. Considering total ET, runoff and drainage together, IPM50-100ET and IPM50-75ET gave the best results; both had comparable total ET and less runoff and drainage. Assessments of the soil moisture availability and salt accumulation in the root zone also are required to identify the best irrigation strategy.

The soil moisture profiles for CIP are shown in Figure 5.6. As discussed above, the soil moisture is usually at a minimum immediately before each irrigation. If the predicted soil moisture was less than the allowable depletion it was assumed that the sugarcane crop would be under some degree of water stress. There were only few dates when the soil moisture was above the allowable depletion level. At all other dates the predicted soil moisture was below the allowable depletion level, indicating that the sugarcane crop was under soil moisture stress. On some dates, the soil moisture was very close to the wilting point, and it is expected that the crop experienced moisture stress at least during these days. A small total ET under CIP also indicates that the crop was under moisture stress at least some days during the growing season. Neither the irrigation amounts nor the irrigation intervals were appropriate. The irrigation amounts were large, which resulted in excessive runoff; and the irrigation intervals were too long, which resulted in soil moisture stress.

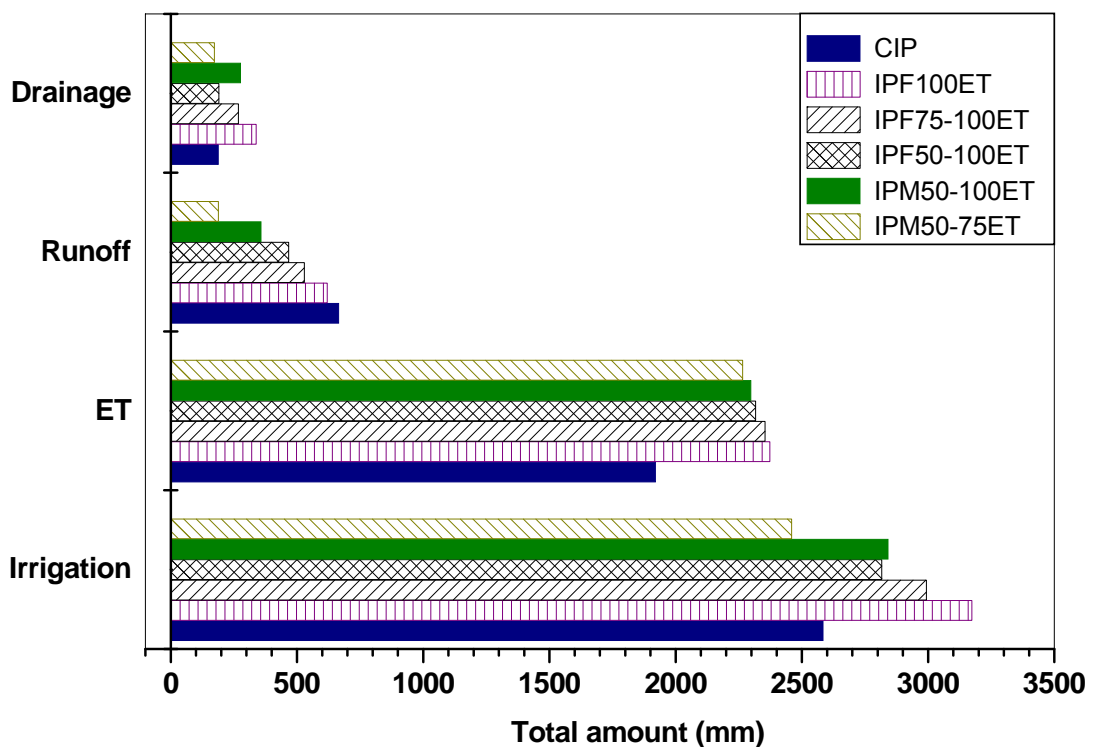


Figure 5.5. Water balances for the simulated irrigation options at CUM 55; total applied irrigation amount, ET, runoff and drainage

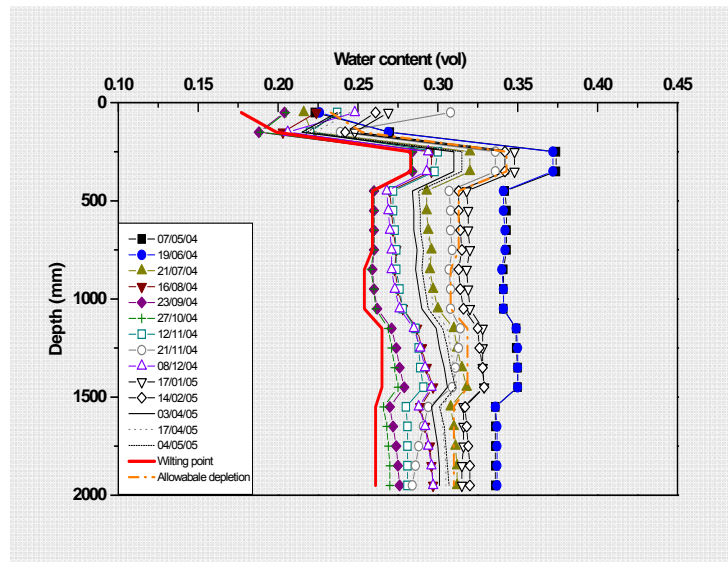


Figure 5.6. Soil moisture profiles the day before CIP irrigations for the sugarcane crop at CUM 55

The predicted soil moisture profiles for the IPF100ET are shown in Figure 5.7. The moisture profiles were above AD level during first quarter of the growing season, and below AD during rest of the growing season. This suggested moisture stress, although total ET was the largest for this irrigation strategy. The soil moisture profiles for IPF75-100ET and IPF50-100ET were above AD on most dates during first quarter of the growing season but less than AD during last three quarters of the growing season (Figure 5.8 and Figure 5.9). If these irrigation strategies were adopted, the model predicts that they would cause moisture stress and decrease crop productivity.

The soil moisture profiles for IPM50-100ET are shown in Figure 5.10. For this irrigation strategy the soil moisture profiles were always above the AD level, except one date when soil moisture was slightly less than AD. The soil moisture profiles for the IPM50-75ET also were below AD on some dates during the growing season (Figure 5.11) and were not ideal. The best irrigation strategy was IPM50-100ET, which was least likely to cause soil moisture depletion below the AD limit. There was salt accumulation over time in some parts of the soil profile (Figure 5.12); however, the accumulation was well below the threshold (170 mS/m) that would affect the productivity of the sugarcane crop.

The IPM50-100ET is recommended for the sugarcane crop grown on the Cununurra clay in the ORIA. A total of about 2200 mm of water will be required for irrigation where crops are irrigated after half the soil water supply is depleted. This amount equates to about 22 ML/ha (with 100% application efficiency). This is close to lower end of the range (22.7 to 23.8 ML/ha) estimated by Muchow and Keating (1998) using the APSIM-Sugarcane model. About 78% of the total applied water will be used as ET, 12% will be wasted as runoff, and around 10% will be lost to drainage.

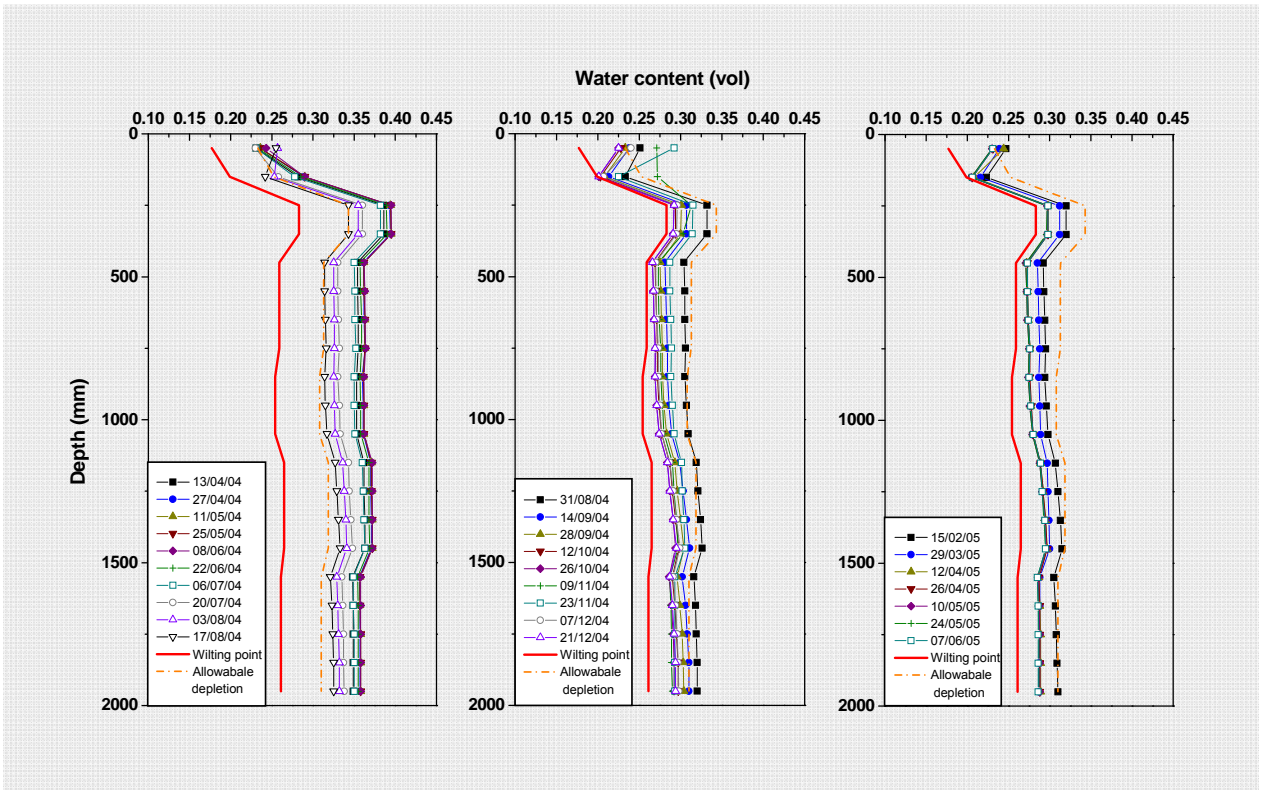


Figure 5.7. Soil moisture profiles the day before IPF100ET irrigations for the sugarcane crop at CUM 55; 13/04/04 (left) to 07/06/05 (right)

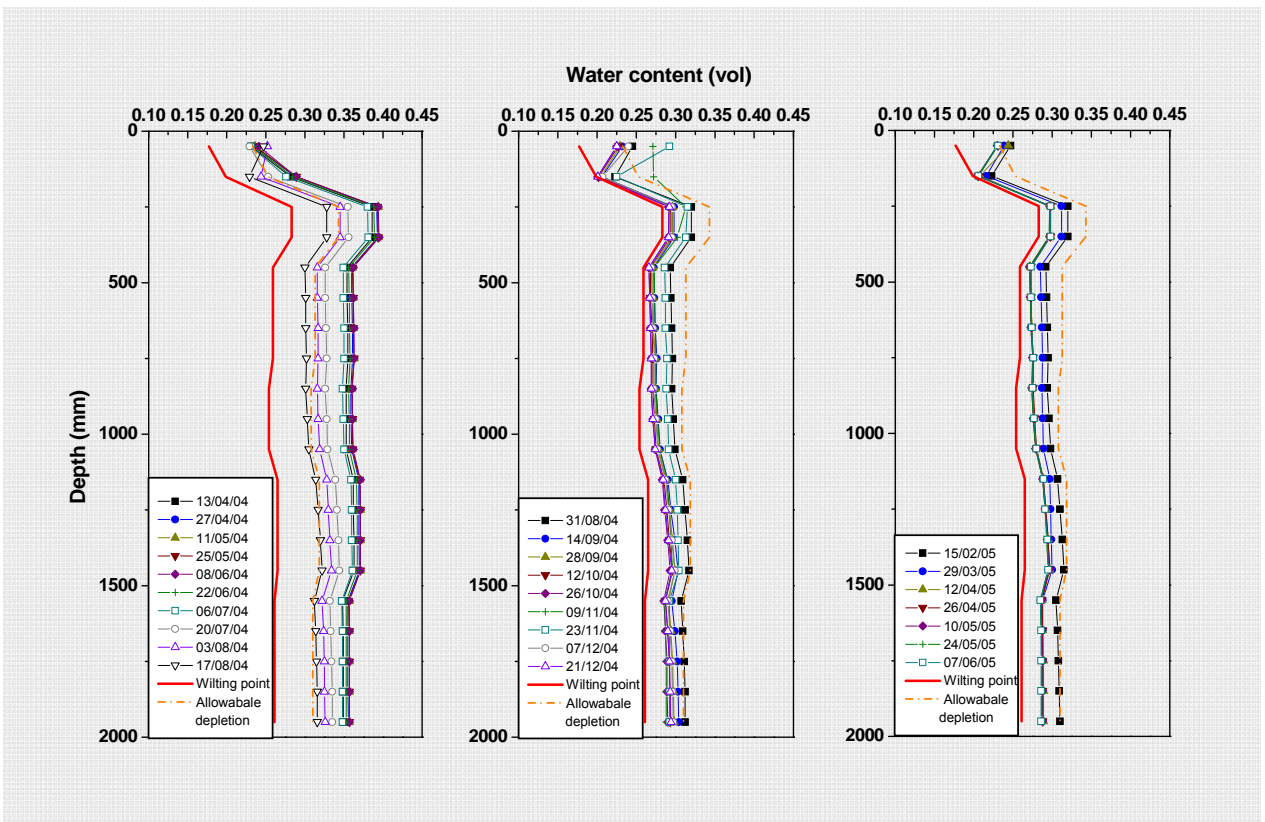


Figure 5.8. Soil moisture profiles the day before IPF75-100ET irrigations for the sugarcane crop at CUM 55; 13/04/04 (left) to 07/06/05 (right)

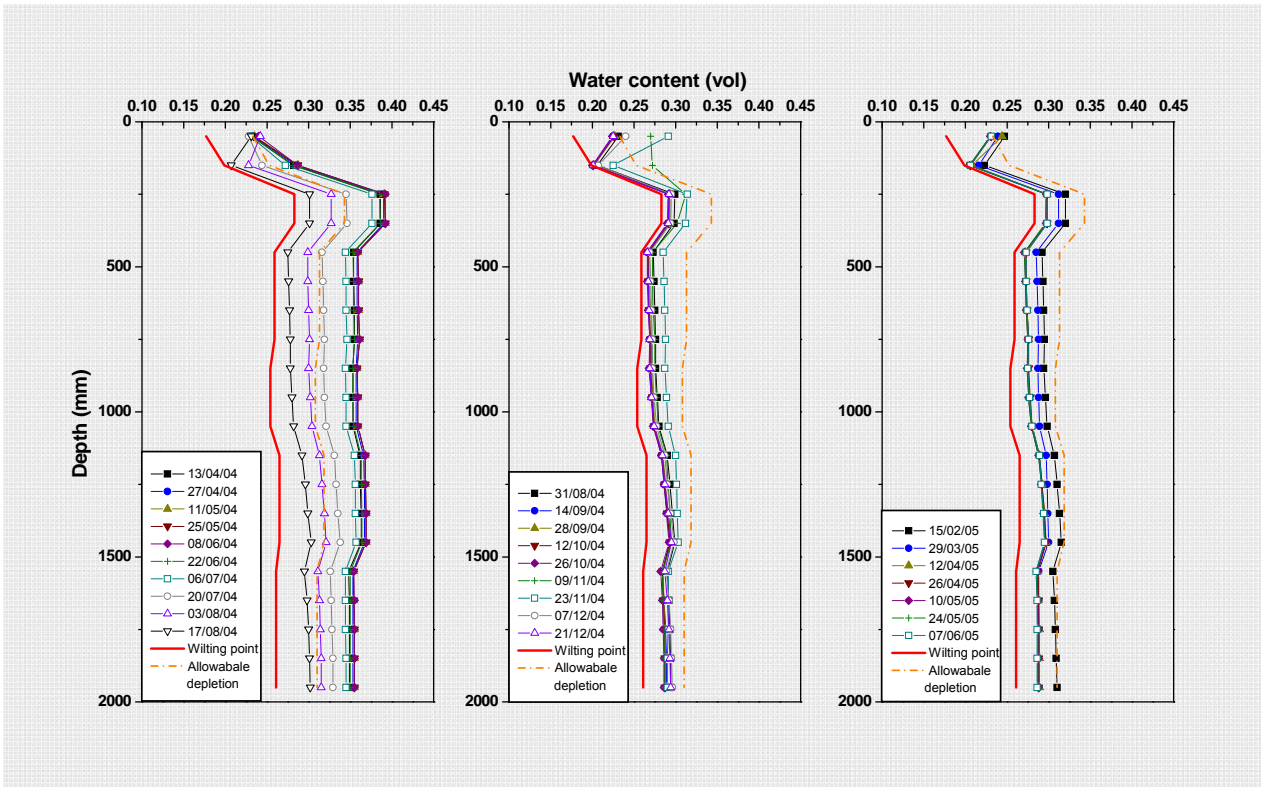


Figure 5.9. Soil moisture profiles the day before IPF50-100ET irrigations for the sugarcane crop at CUM 55; 13/04/04 (left) to 07/06/05 (right)

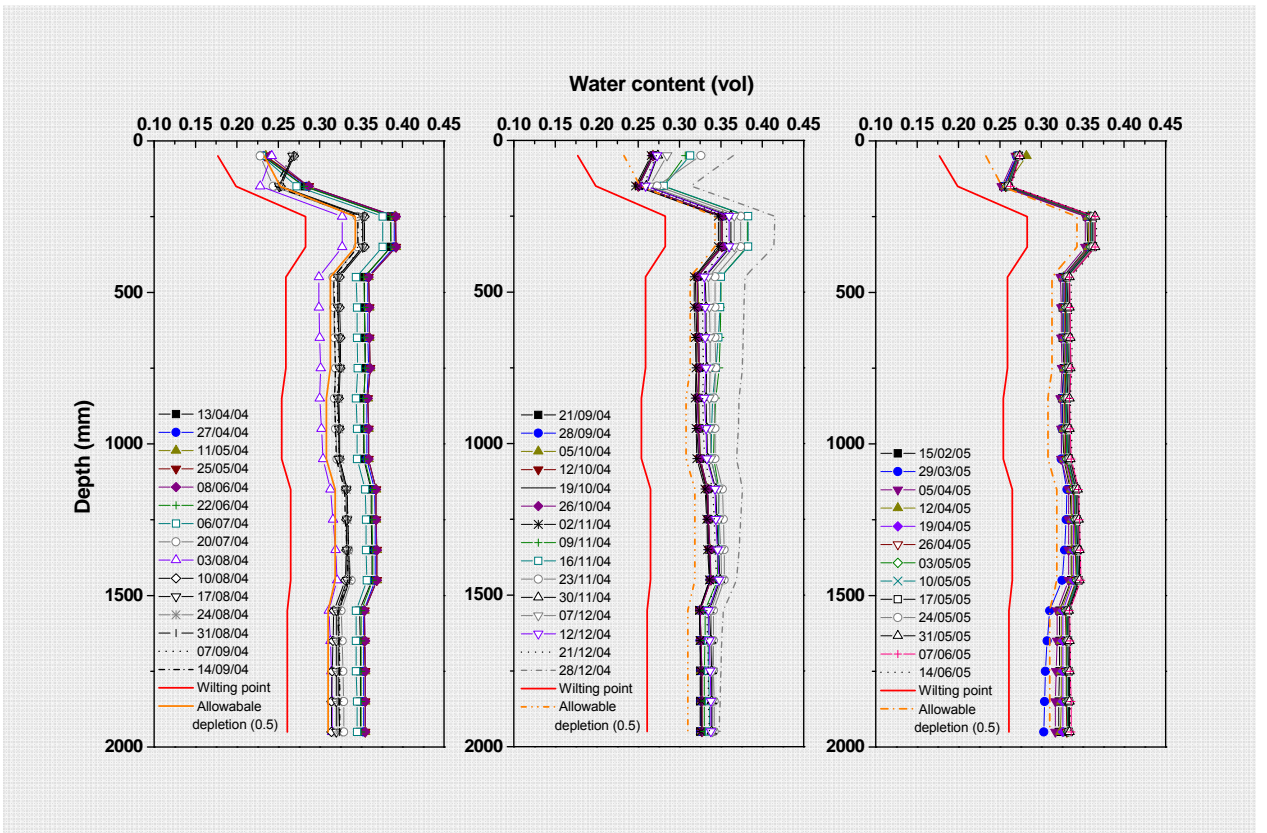


Figure 5.10. Soil water content profiles the day before IPM50-100ET irrigations for the sugarcane crop at CUM 55; 13/04/04 (left) to 07/06/05 (right)

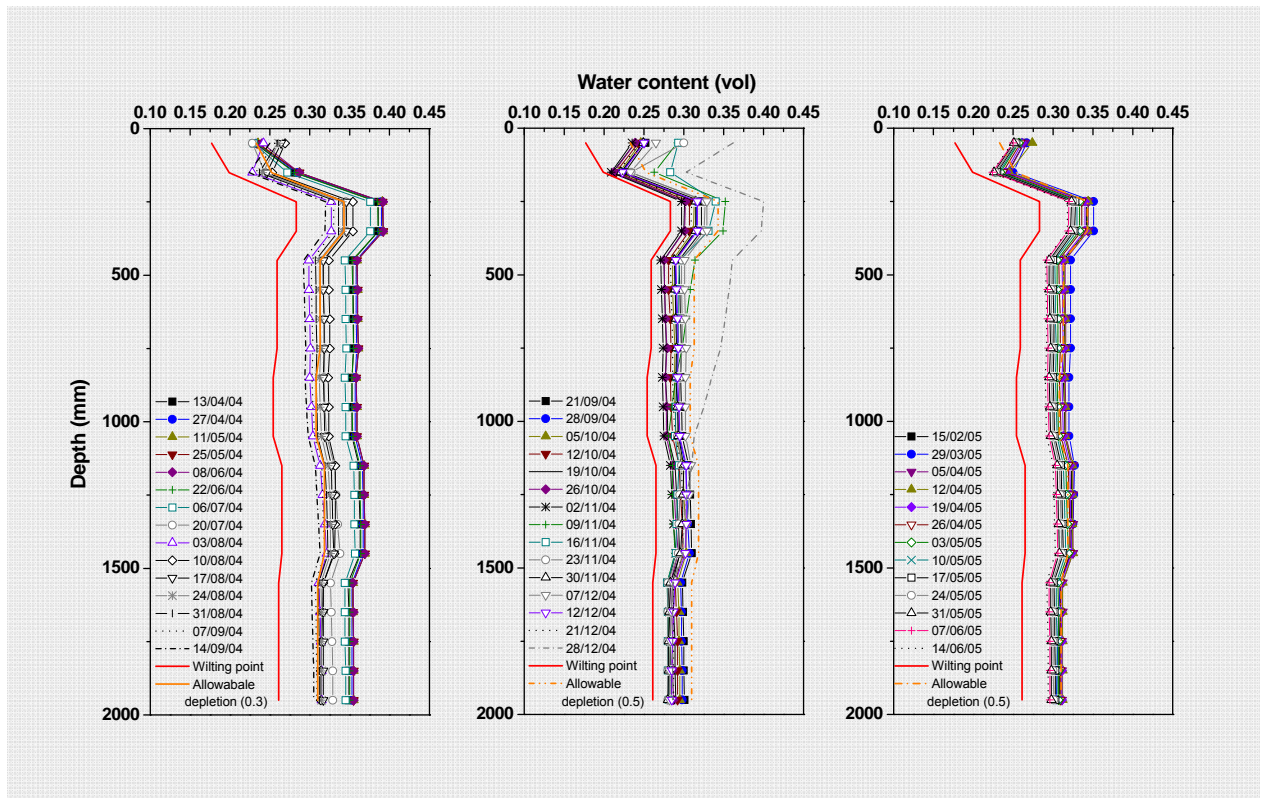


Figure 5.11. Soil moisture profiles the day before IPM50-75ET irrigations for the sugarcane crop at CUM 55; 13/04/04 (left) to 07/06/05 (right)

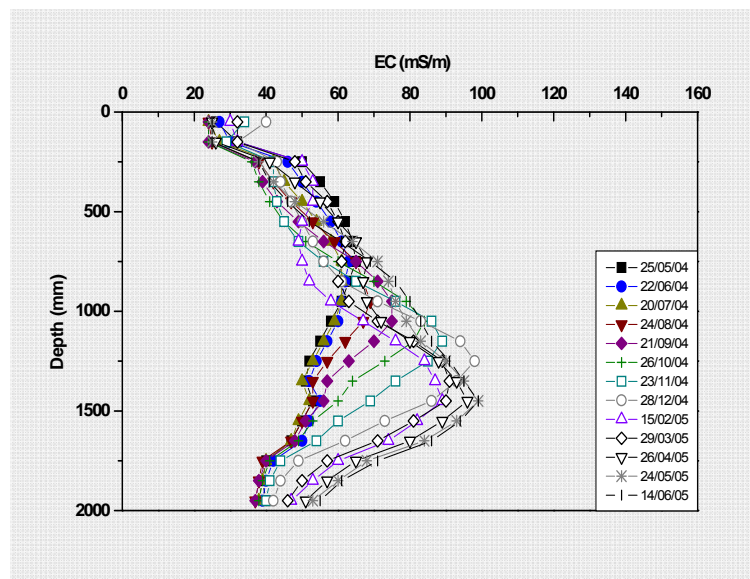


Figure 5.12. Soil profile EC during growing season of the sugarcane crop for IPM50-100ET at CUM 55 site

5.3. Irrigation Scheduling of Sugarcane Crop - Non-saline Shallow Water Tables

The calibrated LEACHC model was used to assess the impacts of non-saline shallow water tables on irrigation water requirements, irrigation scheduling and soil salinity risks. Two shallow water table depths (1 and 2 m) with EC of 50 mS/m were considered in the modelling. It was

assumed that a sugarcane crop was present throughout a total simulation period of three years. The soil type was Cununurra clay. The textural and physical properties of this soil, initial soil chemical profile, exchangeable cations, and cation exchange capacity were based on the data from CUM 55 site (Table 3.7 to Table 3.9). For each water table depth, four simulations were conducted; IPF75ET, IPF50ET, IPW75ET and IPW50ET, where F indicates a fortnightly irrigation interval, as above, and W indicates a weekly irrigation interval. Thus, IPW75ET denotes that the irrigation interval was 7 days and the irrigation application amount was 75% of total fortnightly pan evaporation (ET). One year (May 2004 to April 2005) of pan evaporation and temperature data were obtained from the KRS weather station and then processed to estimate the total weekly and fortnightly ET amounts, and the mean weekly temperatures and amplitude. These data were repeated in the subsequent two years so that the model could be run for three years.

The model predicted significant ET contributions from the two shallow water tables; the shallower the water table the greater the groundwater contribution to ET for a particular irrigation strategy (Figure 5.13). The groundwater contribution was maximum (60% of the total ET) from a 1 m deep water table for IPF50ET and was minimum (26% of total ET) from a 2 m water table for IPW75ET. Both the irrigation application amounts and intervals affected the ET contributions from shallow water tables. A large irrigation application amount (75% ET) and short irrigation interval (7 days) resulted in smaller ET contributions from groundwater, and vice versa. In general, if less irrigation water was applied then more water was drawn from the shallow water table to meet the ET requirements of the crop. The soil moisture availability always remained above the AD level for all eight irrigation strategies. On this basis, and provided it would not result in the accumulation of excessive salts in the soil root zone area, an irrigation strategy with small irrigation application amounts and long irrigation intervals is recommended in areas where a non-saline water table is within 2 m of ground surface (e.g., IPF50ET)

The predicted average soil EC profiles for both water table depths increased slightly over time (Figure 5.14 and Figure 5.15). The variation in the predicted average EC profiles among the simulated irrigation strategies was small. The water table depth did not have any significant impact on the build up of salinity and both water table depths resulted in similar average EC profiles over time. Although the average soil profile EC increased during the simulation period from the initial levels it remained well below the threshold for adverse impacts on the sugarcane crop.

Based on the simulated results, the irrigation strategy IPF50ET is recommended for sugarcane crops if grown over the Cununurra clay soil and non-saline shallow water tables of 1 to 2 m depth. The model predicted that this irrigation strategy will result in the maximum irrigation water use efficiency because a greater proportion of shallow groundwater is used for ET requirements. The model also predicted that this irrigation strategy will not cause the

accumulation of excessive salts in the root zone during the simulation period. It may also help to control water table rise by direct use of groundwater by the crop.

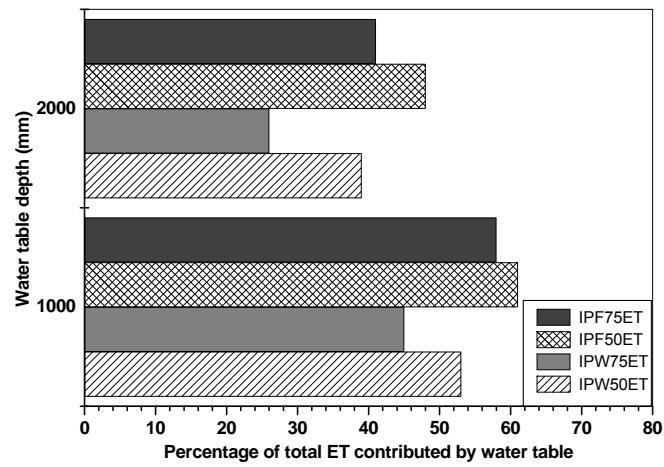


Figure 5.13. Predicted groundwater contributions to total ET for sugarcane crop grown over non-saline (50 mS/m) 1 and 2 m deep water tables

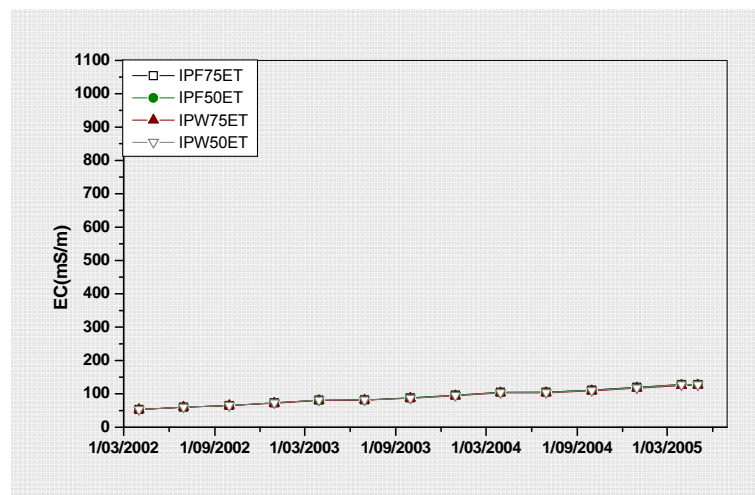


Figure 5.14. Predicted average soil profile EC for sugarcane crop grown over a non-saline (50 mS/m) 1 m deep water table

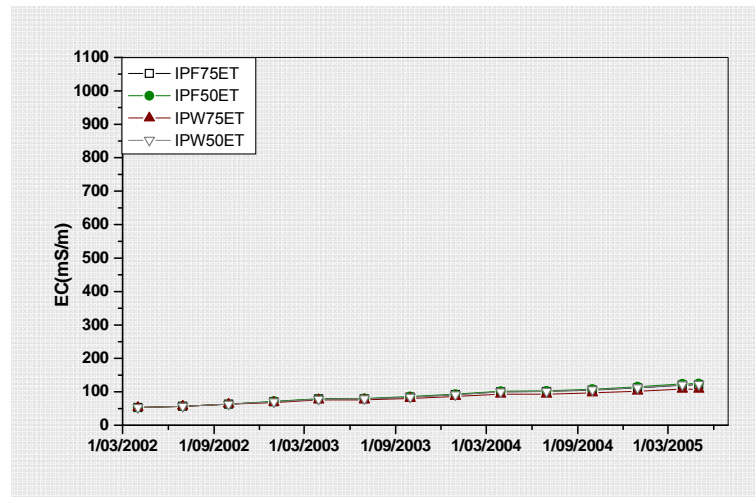


Figure 5.15. Predicted average soil profile EC for sugarcane crop grown over a non-saline (50 mS/m) 2 m deep water table

5.4. Irrigation Scheduling of Sugarcane Crop – Saline Shallow Water Tables

In these simulations, the calibrated LEACHC model was used to assess the amount of water that can be drawn from shallow water tables to meet ET requirements, impacts on the irrigation water requirements, and soil salinity risks. Eight simulations were conducted. In the first four, a saline water table with an EC of 200 mS/m was fixed at 1 m depth. In the second four, the watertable was fixed at 2 m depth with an EC of 300 mS/m. At both water table depths the following simulation were run: IPF75ET, IPF50ET, IPW75ET and IPW50ET. In all simulations a sugarcane crop was grown for three consecutive years on the Cununurra clay. The initial average soil profile EC was around 55 mS/m. The diversion dam water quality was used as the irrigation water quality. Other data about soil textural and physical properties, initial conditions, pan evaporation, temperature, etc., were the same as used above for irrigation scheduling of the sugarcane crop over non-saline shallow water tables.

The model predicted significant ET contributions from saline shallow water tables. There was no significant difference between groundwater contributions to ET for crops grown over saline (Figure 5.16) and non-saline water tables (Figure 5.11). Both the irrigation application amounts and intervals had an impact on the groundwater contribution to ET (Figure 5.16). A large irrigation application amount (75% ET) and short irrigation interval (7 days) resulted in smaller ET contributions from the shallow water table, and vice versa. As above, if more irrigation water was applied then less shallow groundwater was used by the crop. The model predicted that the ET contribution from the water table would be maximised (60%) if the water table was 1 m deep and the irrigation strategy was IPF50ET. This irrigation strategy would also have the lowest irrigation water requirements and the maximum water use efficiency. The predicted ET contribution from the water table was smallest (25%) if the water table was at 2 m depth and the irrigation strategy was IPW75ET.

The soil moisture availability between irrigations was similar in all irrigation strategies and was always above the AD level. If a particular irrigation strategy used less water from irrigation applications then the remainder of the ET requirements were met by drawing water from the shallow water table, thereby preventing the soil moisture content from decreasing below the AD. Nevertheless, more use of saline groundwater for ET requirements may result in the accumulation of excessive salts in the soil root zone area.

Figure 5.17 and Figure 5.18 show the predicted average soil profile EC over time for the simulated irrigation strategies. The average EC of the soil profile increased significantly over time for all irrigation strategies and water table depths. In general, the shallower the water table depth, the larger the average soil profile EC for a particular irrigation strategy. At both water table depths the predicted average soil profile EC over time was largest (> 900 mS/m) for irrigation strategy IPF50ET. Low irrigation application caused withdrawal of more water from the water table which resulted in the highest average soil profile EC over time. The lowest average soil profile EC (> 500 mS/m) resulted from IPW75ET at both water table depths but it was well above the level tolerable by the sugarcane crop.

In summary, the modelling suggests that the soil profile salinity risk will be high if a saline water table exists for long periods at or above 2 m depth. Over irrigations may reduce the build up of soil profile salinity through flushing but it will result in excessive accessions to the water table causing groundwater to rise even further. The recommended management strategy for a saline shallow water table is to lower its level below 2 m by artificial deep open or sub-surface drainage and applying regular leaching applications to flush excessive salts from the root zone area into the drainage system. Without this intervention, it is likely that high evaporative demands, extended fallow periods and low irrigation application will cause excessive accumulation of salts in the root zone area that will affect crop productivity.

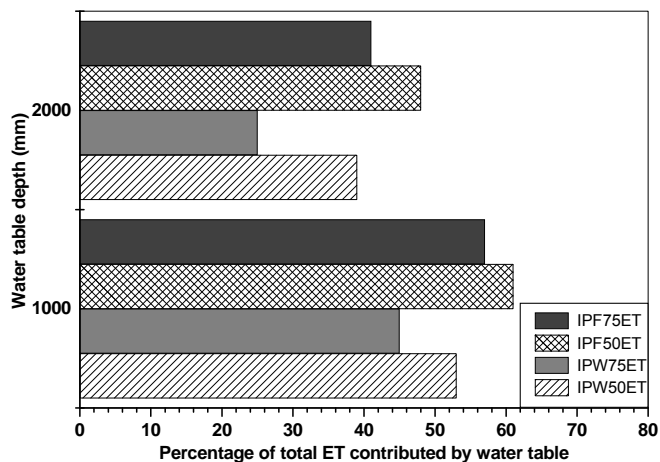


Figure 5.16. Predicted groundwater contributions to total ET for sugarcane crop grown over saline (200 and 300 mS/m) 1 and 2 m deep water table

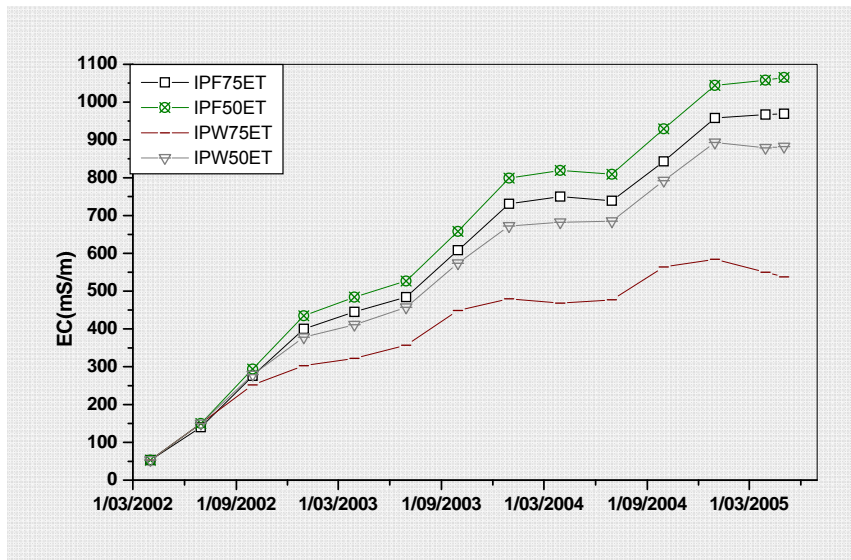


Figure 5.17. Predicted average soil profile EC for sugarcane crop grown over a saline (200 mS/m) 1 m deep water table

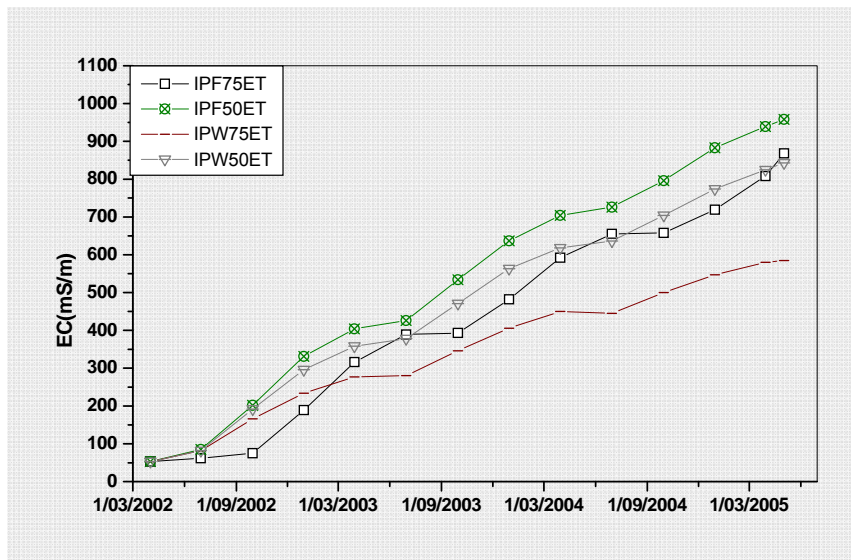


Figure 5.18. Predicted average soil profile EC for sugarcane crop grown over a saline (300 mS/m) 2 m deep water table

6. CONCLUSIONS

This research evaluated water and salinity management strategies for maize and sugarcane crops grown on Cununurra clay in the ORIA. The impacts of both fresh and saline shallow water tables on the water demands and soil root zone salinity were evaluated through modelling. The LEAHC model was used for irrigation scheduling and soil salinity prediction. This model was calibrated using soil, crop, irrigation and weather data from two sites, one at the Kimberley Research Station (KRS 7A maize crop) and the other in block 55 at Cummings Farm (CUM 55 sugarcane crop). The model was then applied to evaluate various irrigation strategies.

The simulation results indicated that irrigation application amounts equal to 100% of the total fortnightly pan evaporation, applied at 14 days interval, would be the best irrigation strategy for maize crop grown over a deep water table. The predicted irrigation water use would be around 23% less than the existing practice. Irrigation application amounts equal to 75% of the total fortnightly pan evaporation, applied every fortnight during first half of the growing season, and 75% of the total weekly pan evaporation, applied every week during the second half of the growing season, would be a better irrigation strategy if it is feasible and practicable to change the irrigation interval from 14 days to 7 days. The irrigation water use for this irrigation strategy was predicted to be around 40% less than the existing irrigation practice.

The study found that the best irrigation strategy for the sugarcane crop grown over a deep water table would be irrigation application amounts equal to 50% of the total fortnightly pan evaporation, applied every fortnight during first quarter of the growing season, and irrigation application amounts equal to 100% of total weekly pan evaporation, applied every week during rest of the season. This irrigation strategy would require around 22 ML/ha of irrigation water, with 100% application efficiency, for a single sugarcane crop.

The best irrigation strategy for the sugarcane crop grown over a non-saline shallow water table of ≤ 2 m depth would be irrigation application amounts equal to 50% of the total fortnightly pan evaporation, applied every 14 days. The model predicted that this irrigation strategy would result in the best water use efficiency by encouraging plants to use groundwater to meet the crop ET requirements. The modelling results indicated that the soil salinity risks would be high if the sugarcane crop was grown for long periods over a saline shallow water table (≤ 2 m). The best management strategy would be to lower the water table below 2 m depth by artificial drainage and apply regular leaching applications to flush excessive salts into the drainage system.

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