5.4 Quantifying Episodic Recharge Under Crop/Pasture/Fallow Rotations

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Submitted to *Agricultural Water Management*

Abstract

A field and modelling project to investigate episodic recharge in the Mallee region (Hillston and Walpeup) of Australia is described. More specifically, the project evaluates the impact of agronomic practices on recharge, and in particular episodic recharge. Episodic recharge is of concern because we anticipated that agronomic practices are not likely to affect it significantly.

Various crop and pasture rotations involving fallow, field pea, Indian mustard, wheat, oats, lucerne, and medic pastures were considered. A biophysically based model (WAVES) was calibrated with the field data and then used to simulate soil moisture content, plant growth, and recharge under these rotations.

Results showed that (1) recharge just below the root zone was episodic and that just 10 % of annual recharge events contributed over 85 % of long-term totals. Episodic recharge could therefore reduce the effectiveness of land management options in controlling recharge; (2) winter fallows can increase recharge significantly; (3) changes in land management may take a considerable period of time (> 10 years) to have any noticeable impacts on recharge; (4) recharge under lucerne was approximately 30 % of that under medic pasture.

5.4.1 Introduction

The rise of groundwater tables and associated dryland salinity have been identified as major land degradation problems in the Mallee region of southeastern Australia. This region is characterized by a semi-arid climate, and originally a low, sparse woodland of multi-stemmed individuals of the genus *Eucalyptus*. Much of the salinity problem is caused by massive clearing of native vegetation and the use of shallow-rooted annual crops and pastures (Clifton *et al.* 1995). These land use changes have significantly altered the water balance of the region and led to increased recharge to the groundwater system; recharge under native Mallee vegetation is less than 0.2 mm yr^{-1} (Allison *et al*. 1990), but following replacement by annual cropping increases by a factor of 100. It appears to be economically and sociably infeasible to restore the natural water balance/recharge rate/water table depth by replanting the native vegetation on a sufficient scale, but better management of agricultural practices may reduce the undesirable effects associated with dryland salinity.

The main emphasis of current salinity control strategies is to enhance plant water uptake to minimize groundwater recharge. For example Clifton and Taylor (1995) propose that land management include either improving the growth of existing annual crops and pastures, or replacing these with perennial vegetation. The traditional agricultural practice in the Mallee regions involves winter fallows in crop rotations and this has been shown to contribute to improved crop yield (French 1978; Fischer 1987). However, it has also been shown that winter fallows have caused increased recharge (O'Connell *et al.* 1995). It is desirable to evaluate recharge rates and their long term impact on regional water balance and salinity under different crop rotations.

A number of studies have been conducted to evaluate current rates of groundwater recharge and its relationship to environmental factors (Walker *et al.* 1991; Kennett-Smith *et al.* 1994). These have shown that a simple water balance model can be used to analyse the general factors which affect recharge in a region. However, the need for a more detailed physically based model to evaluate the effect of different agronomic practices on recharge has also been recogised. An important step in predicting groundwater recharge is to better understand its episodic nature, how it varies across the landscape, and how it is influenced by landuse and agricultural management. Physically based models (e.g. Dawes *et al*. 1997; Hauhs 1990) can help identify key processes and the most important factors controlling groundwater recharge, providing information that can be used to develop sustainable land management practices.

Recharge in the Mallee region is generally considered to be episodic in nature. Episodic recharge is infrequent significant recharge events. The word 'significant' refers to the relative magnitude of the recharge. While it is true that better agronomic practices can reduce mean annual recharge, it is anticipated that they are not likely to affect episodic recharge significantly. as a result of rare but very large rainfall events. Rainfall in the Australian arid zone is marked by extreme variability and that rare, very large rainfall events are important for recharge process. It is therefore the distribution of these events that determines the patterns of recharge.

During the period of 1991 to 1995, two field experiments were conducted at Hillston (New South Wales) and Walpeup (Victoria) to study the effectiveness of changing landuse and agronomic practices in reducing groundwater recharge (Hume and Mitchell 1996). The purpose of the study was to investigate episodic recharge in the Mallee region and to evaluate the impact of agronomic practices on recharge, and in particular episodic recharge.

5.4.2 Field experiments and data

An integrated program of field experimentation was established on the Mallee Research Station, Walpeup, Victoria (35°07′ S, 141°59′ E) and on a farm property near Hillston, NSW (33° 22′ S, 145° 51′ E).

The Hillston site was located on aeolian deposits of Devonian hills in the N.E. of the Murray Basin. The soil is a calcareous red earth (Stace *et al.*, 1968) with a Northcote classification Gn 2.13 (Northcote, 1979; Isbell, 1996). The Hillston experiment was established in a field that had been cleared of trees (mallee, bulloak and western red box) in 1988. Two dryland wheat crops were grown on the site during 1989 and 1990, and it was ploughed and leveled during 1991 in preparation for experiment. The site has a predominant northeasterly aspect and a uniform slope of less than 0.3%. The climate is semi-arid with mean annual rainfall of 371mm (1890–1992), of which 56–68 % falls in the growing season (May – November). The Hillston site was irrigated prior to the commencement of field measurements.

The Walpeup site was located in a swale within an east–west oriented dune system (Newell 1961; Rowan and Downes 1963). The soil is a solonised brown soil (Stace *et al.* 1968) with a Northcote classification Gc 2.22 (Northcote 1979) and has been used for agriculture since being cleared of native Mallee vegetation in 1914. The site has a westerly aspect with a uniform slope of 1%. The climate is semi-arid with mean annual rainfall of 340 mm (1957–94), of which 65–70% falls in the growing season (May – November) but with significant variation in quantity and distribution. The mean potential evaporation is approximately 2000 mm yr^{-1}.

Experimental design

A common experimental methodology was used at both locations although the cropping treatments differed to reflect local cropping practice. Two perennial plantings; one traditional, and one modified rotational cropping treatments were established at each location. The rotational cropping treatments were established as a cyclical rotational experiment (Patterson 1963). Each phase of each rotation is expressed in each year of the experiment providing an efficient means of replication in both time and space. The spatial variability of soil properties was assessed by electromagnetic survey (Geonics EM38). Experimental treatments were randomly allocated to account for these spatial patterns in the 'blocking' of the experiment.

Experimental layout

The Walpeup experimental site rotational treatments were allocated to 18 plots, each 21 m by 20 m, and separated from its neighbour by a 5–10 m buffer. Two PVC neutron moisture meter (NMM) access tubes were installed 5.5 m deep and 10 m apart in each plot to monitor soil water. A fallow rotation treatment (fallow/wheat/field pea) and a continuous crop rotation treatment (Indian mustard/wheat/field pea) were established in June 1993. Three years of biomass, soil moisture, and climate measurements were made, ending in December 1995.

Soil data

The relationships between volumetric water content, hydraulic conductivity, and soil water potential were described with the Broadbridge and White (1988) soil model. The parameters of the soil model were estimated by inverse modelling (Hume and Mitchell 1996). Soil water beneath each treatment was measured at intervals of two to four weeks. Measurements at Hillston started in November 1991 and continued until December 1995, while the period of measurements at Walpeup was from June 1993 to December 1995.

Meteorological data

At each site, meteorological data were recorded hourly by automatic weather stations. Wet and dry bulb temperatures were measured using temperature sensors with a standard muslin wick at Walpeup, and relative humidity measured at Hillston. A tipping bucket rain gauge recorded rainfall amount and intensity. Radiation sensors with a uniform spectral response from 500 to 1000 nm were used to record solar radiation. Missing rainfall data were taken from a manual rain gauge on site. Other missing meteorological data were interpolated using measurements from neighbouring weather stations.

Plant growth data

Plant biomass was sampled several times throughout each growing season, approximately 3 weeks apart at Walpeup, and one harvest was conducted at Hillston. At each biomass harvest, 5 × 2 m drill row above-ground samples were dried at 80°C. The date of sowing, emergence, anthesis, and grain harvest was recorded for all traditional crops. The percentage green foliage was deduced from photographs of each plot at each biomass sampling. Biomass production of cereal crops was assessed at anthesis, by measuring the dry weight of all above ground plant material after drying at 45°C for 24 h.

To compare simulated plant growth with the measurements, we first calculated dry weight of green material based on the total dry weight and percentage green foliage. The dry weight of green material was converted into leaf area index using specific leaf area values from samples at each site or from values of Armstrong and Pate (1994) for field pea, Sharma and Kumar (1989) for Indian mustard, and Dawes *et al.* (1997) for oats and wheat.

5.4.3 Model implementation

The saturated and air-dry moisture contents for each soil horizon were estimated from soil moisture measurements (Hume *et al*. 1996). Initial estimates of saturated hydraulic conductivity were measured using disc permeameters (White *et al.* 1992). The Broadbridge–White soil parameters λ_c and C were initially estimated from an evaluation of the soil texture profiles at each plot. Finally the soil parameters were adjusted using inverse modelling (Hume and Mitchell, 1996) (Table 5.7). Four plots were selected from the two experimental sites to compare WAVES with measurements. Information on vegetation parameters appears in Table 5.8. Some of the vegetation parameters (*e.g*. maximum rooting depth) were estimated based on field measurements, while others were obtained from literature (Sharma and Kumar 1989, Whitfield *et al.* 1986; Hodges 1992; Hatton and Dawes 1993; Armstrong and Pate 1994; Dawes *et al.* 1997).

WAVES was run using daily values of maximum and minimum air temperatures, precipitation, vapour pressure deficit, and solar radiation. The simulation commenced at 1 January 1992 for Hillston, at 1 January 1993 for Walpeup, and ended on 31 December 1995 for both sites.

The ability to control recharge, especially episodic recharge, by agronomic means was evaluated in four modelling scenarios. These crop rotations are typical farming practices in NSW and Victorian Mallee. The first two scenarios compared the effectiveness of annual and perennial pastures in controlling recharge. Two crop rotations were modelled; the first was an 8-year sequence of fallow/oat/wheat/wheat/(lucerne × 4) (RT1) and the second was the same as RT1 except with four year of medic pasture (RT2). WAVES was used to simulate 32 years (1957–89) of deep drainage beneath these rotations using inputs of meteorological data measured at Hillston. The soil hydraulic properties at plot 10 and vegetation parameters listed in Table 5.8 were used in the simulations. The effect of fallowing on recharge was evaluated in two further modelling scenarios in which WAVES simulated recharge beneath a fallow rotation, medic/fallow/wheat (RT3), and one without fallow, medic/medic/wheat (RT4). These two scenarios ran for 33 years (1957–90) using meteorological data measured at Walpeup with soil hydraulic properties listed in Table 5.7 and vegetation parameters in Table 5.8. To further evaluate the impact of rooting depth on recharge, the second two scenarios were run using deep rooting depth of 100 cm (RT3d and RT4d). In these simulations all the model parameters were kept constant, except maximum rooting depth at Walpeup, which varied from 50 to 100 cm.

Table 5.7 Broadbridge–White soil parameters for each soil layer used in WAVES simulations at Hillston and Walpeup

Plot	Soil layer	Depth (cm)	K_s (m/d)	θ_s (cm^3/cm^3)	θ_d (cm^3/cm^3)	λ_c (m)	C
			Hillston				
1	1 (sandy clay loam)	0 – 52	0.05	0.30	0.05	0.60	1.10
10	2 (sandy clay)	52 – 375	0.05	0.35	0.10	0.42	1.01
	1 (sandy clay loam)	0 – 52	0.05	0.30	0.05	0.30	1.50
	2 (sandy clay)	52 – 375	0.01	0.35	0.10	0.35	1.05
			Walpeup				
3 & 10	1 (sandy loam)	0 – 10	0.10	0.40	0.20	0.10	2.00
	2 (sandy clay loam)	10 – 18	0.10	0.40	0.05	0.10	1.07
	3 (sandy clay)	18 – 187	0.01	0.35	0.10	0.30	1.05
	4 (light clay)	187 – 487	0.001	0.35	0.10	0.40	1.10

Table 5.8. Vegetation parameters used to simulate crop and pasture growth at Hillston and Walpeup

Parameter	Oats	Wheat	Mustard	Field pea	Medic	Lucerne
IRM weighting factor for water	0.2	0.2	0.2	0.2	0.2	0.2
IRM weighting factor for nutrients	0.5	0.5	0.5	0.5	0.5	0.5
Specific leaf area (m^2 kg leaf dry weight)	12.0	12.0	7.5	10.5	12	12.0
Slope in conductance model	0.70	0.70	0.70	0.70	0.90	0.70
Maximum carbon assimilation rate (kg C m^{-2} d^{-1})	0.015	0.015	0.012	0.015	0.012	0.01
Light extinction coefficient	0.65	0.65	0.65	0.65	0.65	0.85
Temp. for optimum growth (°C)	20	25	21	25	20	20
Temp. for half optimum growth (°C)	5.0	5.0	7.0	5.0	10.0	10.0
Degree daylight hours (°C hours)	15000	15000	13000	13500	16000	—
Saturation light intensity (µmols m^{-2} s^{-1})	1000	1000	1000	1000	1200	1000
Maximum rooting depth (m)	1.0	1.5	0.3	0.3	1.0	3.0
Leaf respiration coefficient (kg kg^{-1} d^{-1})	0.0015	0.0045	0.0065	0.0025	0.0002	0.0002
Root respiration coefficient (kg kg^{-1} d^{-1})	0.00012	0.00012	0.00012	0.00008	0.0001	0.0001

5.4.4 Results and discussion

Simulated plant growth

Fig. 5.24 shows a comparison of simulated leaf area index and the measured values for six selected plant types. The model results are in good agreement with the measurements. The predicted leaf area index followed the measurements reasonably well for wheat, Indian mustard, and field pea. The model captured the peak leaf area index well in terms of timing and its magnitude. However, it slightly overestimated leaf area index during the first month of the growing season. For medic pasture, WAVES predicted the leaf area index very well. The simulated leaf area index for lucerne showed reasonable agreement with the observed values. There was only one measurement available for oats at Hillston, however it is not unreasonable to assume that the leaf area index pattern is realistic for the site given that the simulated peak leaf area index was in good agreement with the measurement.

The peak LAI of Indian mustard grown at Walpeup in 1993 was only 0.5. Wheat grown after this mustard crop in the drought in 1994 reached a maximum LAI of 1.5, while wheat grown in the same year on land fallowed during 1993 reached LAI of 2.5. There was no difference in the LAI of field peas grown during 1995 suggesting that the soil moisture at sowing was similar beneath both the fallow and non-fallow treatments. The wheat grown during the 1994 drought explored all available soil water and the effect of fallowing on crop growth was only apparent in the year immediately after the fallow. WAVES faithfully reproduced this behaviour without the need to adjust the parameters that characterise plant growth. This shows WAVES' ability to accurately model the effect of different levels of moisture availability on growth.

WAVES is primarily concerned with the responses and feedbacks of plants on water balance under different climatic conditions. It uses a generic plant growth model incorporating the integrated rate methodology (IRM) of Wu et al. (1994). It explicitly considers the effect of light, temperature, available water, and nutrients on plant growth on a daily time step. The IRM framework provides an explicit means of combining these factors into a single response function. It also provides a means of taking into account not only the relative availability of resources, but also other possible factors such as salinity. IRM retains a mechanistic representation of relative plant growth response to resources availability in the form of its enzyme kinetics origins. The treatment of plant stomatal functioning, transpiration, carbon allocation, and respiration in WAVES is based on well-established relationships with some simplification. The canopy conductance model of WAVES is adapted from Ball et al. (1987) as modified by Leuning (1995) and it provides the key linkage between the transport of water and carbon in the system. It is well understood that the amount of transpiration by a plant is directly related to its leaf area and therefore, it is important to be able to accurately simulate plant leaf area index.

WAVES uses a number of parameters to describe canopy carbon balance and plant growth (see Table 5.8). A necessary step in applying the model is to determine the values of these parameters or constants for the site under consideration. Parameter estimation may have at least as great an effect on the accuracy of the model results as the intrinsic accuracy of the model itself. In this study, most of the parameter values were obtained from literature as discussed previously, while the growing season length (degree daylight hours) and the leaf and root respiration coefficients (which are very difficult to measure) were obtained by trial and error methods for the first growing season. The results shown in Fig. 5.24 represent the following growing seasons with the fitted parameter values. It is encouraging to note that WAVES performed well in simulating leaf area index for six plant types under different rotation systems, given different soils at the two sites, and that annual rainfall was quite variable during the period of experiments.

Maximum rooting depth was found to play an important role in plant growth and soil moisture distribution. At Walpeup the maximum rooting depth was set to 30 cm for wheat and medic (Table 5.8), which is much smaller than the values reported in the literature (Gajri and Prihar, 1985). Field measurements showed that pH was 9.6 and exchangeable sodium percentage (ESP) was 18 % between 18 and 50 cm at the site. These factors indicate that the soil is highly sodic and provides very unfavourable conditions for root growth. This restriction in rooting depth allowed more accurate modelling of both leaf area development, and soil moisture profiles. Shallow rooting depth in the Victorian Mallee has serious implications for plant growth and recharge control because rooting zone acts as a buffer in reducing recharge and shallow rooting depth means little recharge control. Incerti and O'Leary (1990) suggested that one of the options is to introduce varies which are more tolerant to high pH.

The simulations presented here provided thorough tests for the plant growth component of WAVES. It was shown that the model performed well under a range of land use and climatic conditions and this suggests that WAVES is robust for simulating plant growth.

Temporal and vertical variation of soil moisture

The simulated soil water agrees very well with the measured values at both sites throughout the study period (Figs. 5.25 and 5.26). These particular depths were chosen to represent different soil layer (see Table 5.7) and root zone (Table 5.8) at the two sites. The model was able to reproduce seasonal variations in soil moisture for different soil types under various cropping rotations. These results support the findings of Dawes *et al.* (1997) and Zhang *et al.* (1999c) for two dryland catchments at Wagga Wagga, NSW.

To further evaluate the performance of the model in simulating soil water dynamics, we compared calculated and measured soil moisture profiles for different periods. At both sites, the model agrees very well with the measurements throughout the soil profile (Figs 5.27 and 5.28). A drying front associated with maximum rooting density at approximately 1 m was observed throughout the study period at Hillston, below which the soil water remained relatively constant.

The maximum rooting depth used at Walpeup had a significant effect on modelled soil moisture. As mentioned already, soil physical and chemical measurements supported using a shallow rooting depth. Also, soil moisture measurements indicated that any drying front penetrated to a depth of only about 30 cm. When we used a rooting depth of 100 cm, WAVES was unable to reproduce the moisture profiles in the top 100 cm of soil, or the peak LAI of the crops.

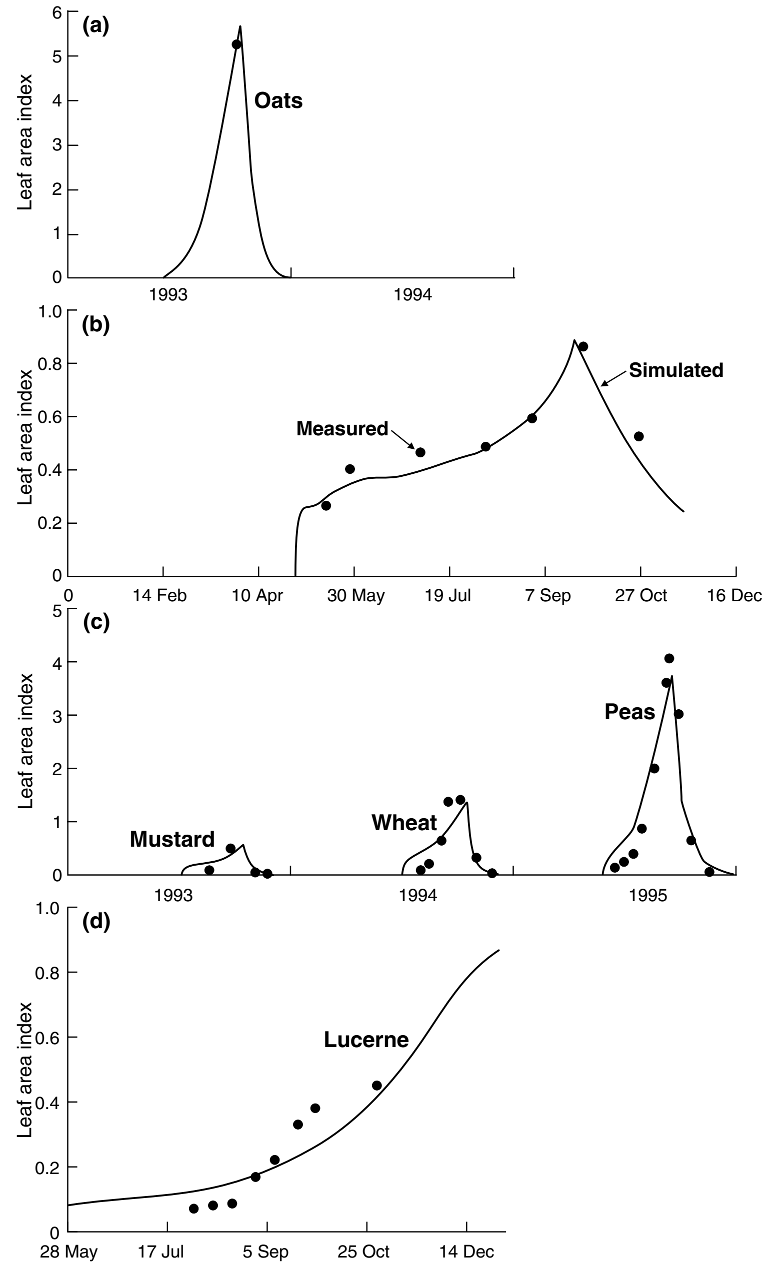

Fig. 5.24. Comparison between simulated (—) and measured (•••) leaf area index (LAI) at Hillston and Walpeup.

Table 5.9. Annual rainfall and estimates of annual recharge at 1.5 m and 4.0 m depths, using the WAVES model.

Plot	1992			1993			1994			1995		
	Rainfall (mm)	Drainage at 1.5 m (mm)	Drainage at 4.0 m (mm)	Rainfall (mm)	Drainage at 1.5 m (mm)	Drainage at 4.0 m (mm)	Rainfall (mm)	Drainage at 1.5 m (mm)	Drainage at 4.0 m (mm)	Rainfall (mm)	Drainage at 1.5 m (mm)	Drainage at 4.0 m (mm)
Hillston												
1	471	24	13	581	10	12	212	3	13	365	0	13
10	471	23	27	581	6	33	212	0	29	365	0	25
Walpeup												
3	—	—	—	348	18	10	153	11	10	382	30	10
10	—	—	—	348	21	10	153	5	10	382	40	10

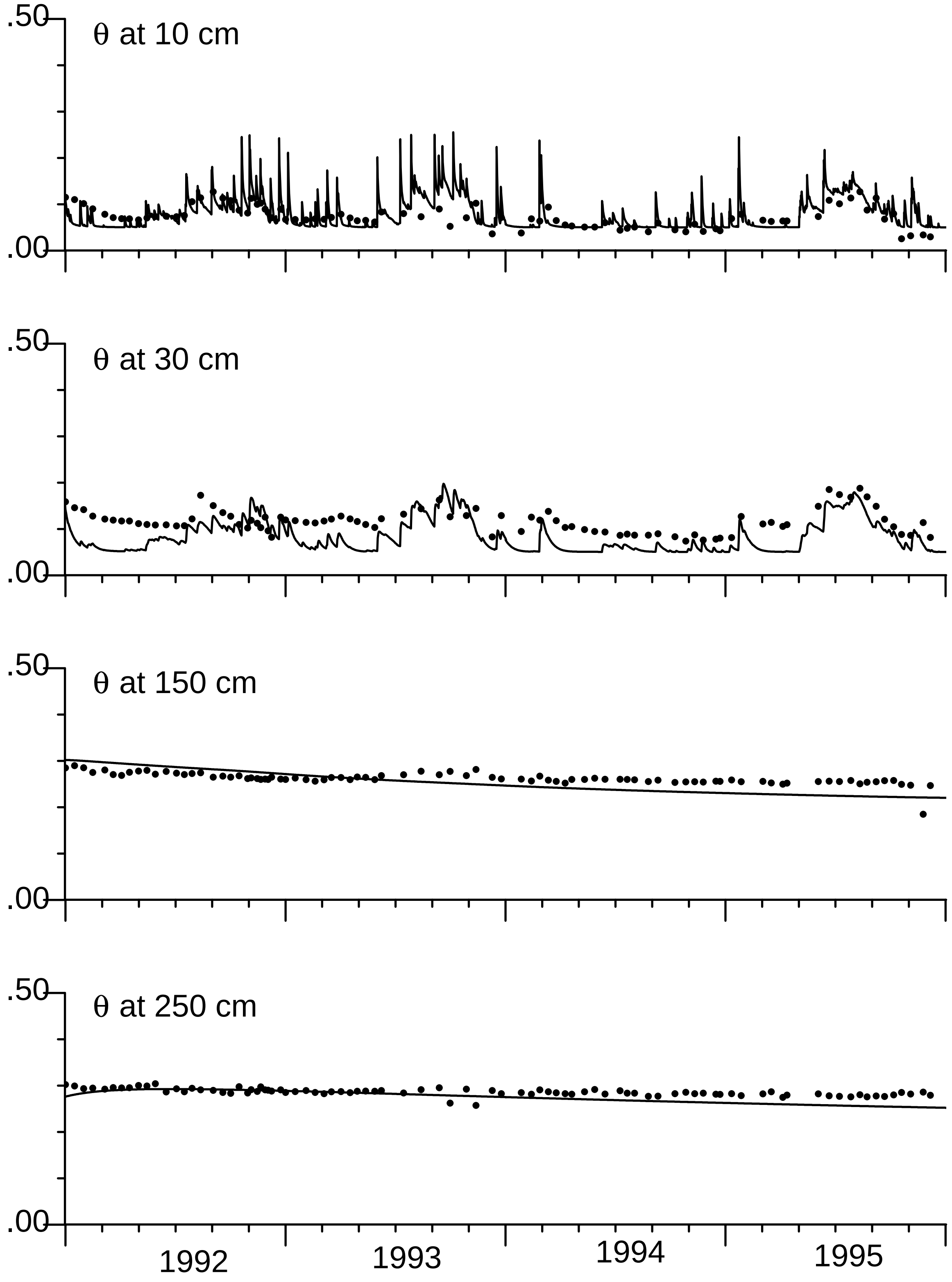

Fig. 5.25. Comparison between predicted (—) and measured soil water content (•••) at Hillston (plot 10).

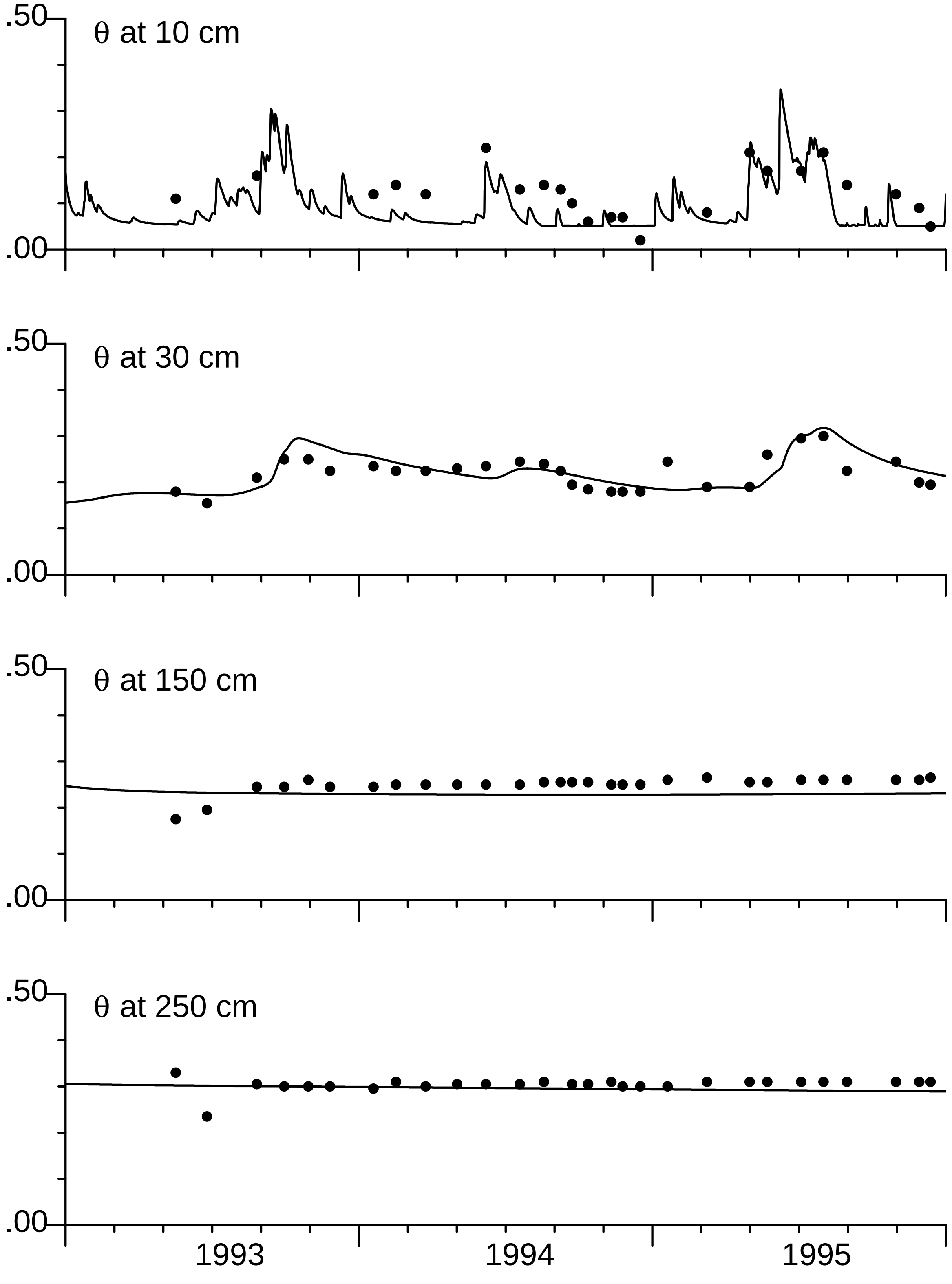

Fig. 5.26. Comparison between predicted (—) and measured soil moisture content (•••) at Walpeup.

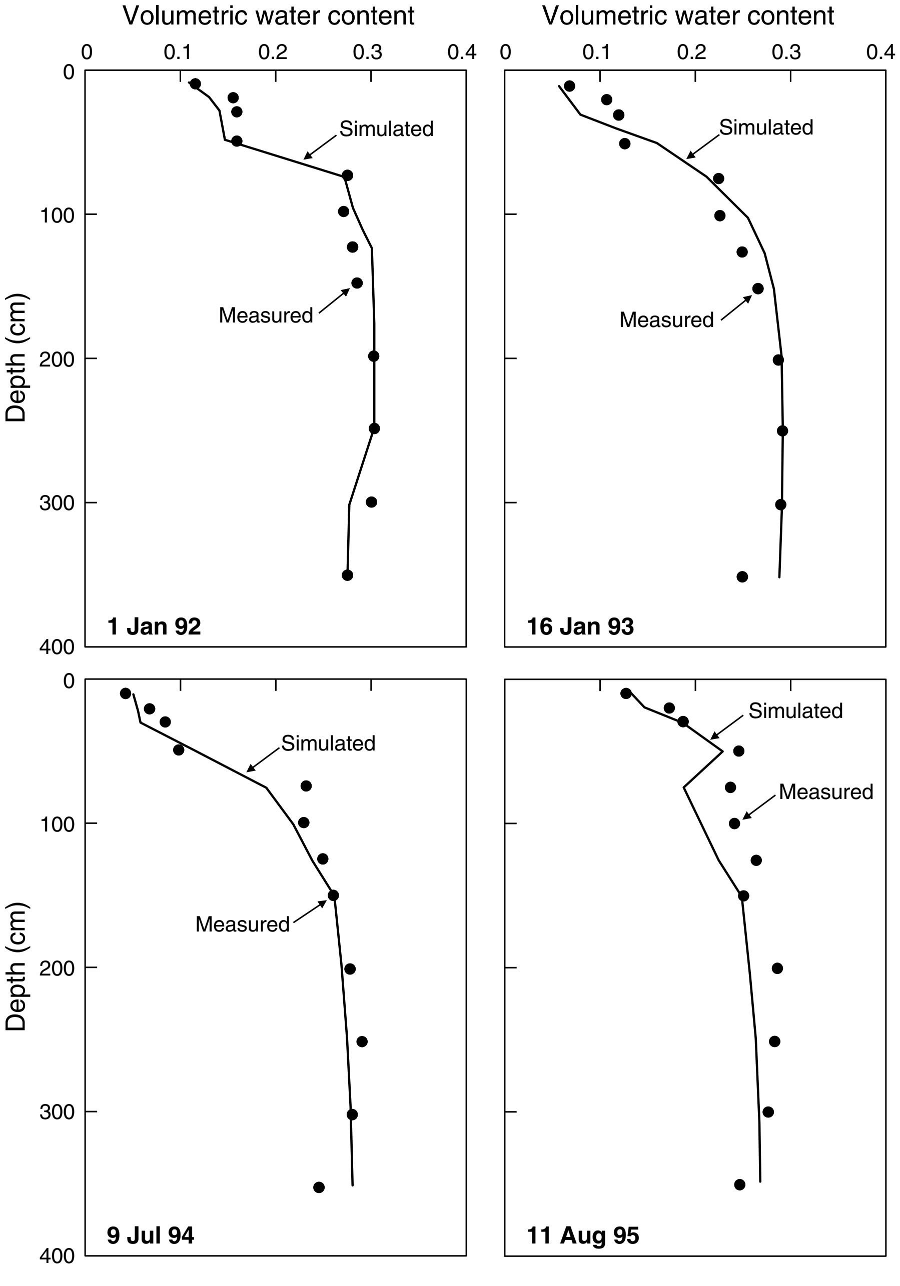

Fig. 5.27. Simulated (—) and measured (•) soil moisture profiles at Hillston for the selected dates.

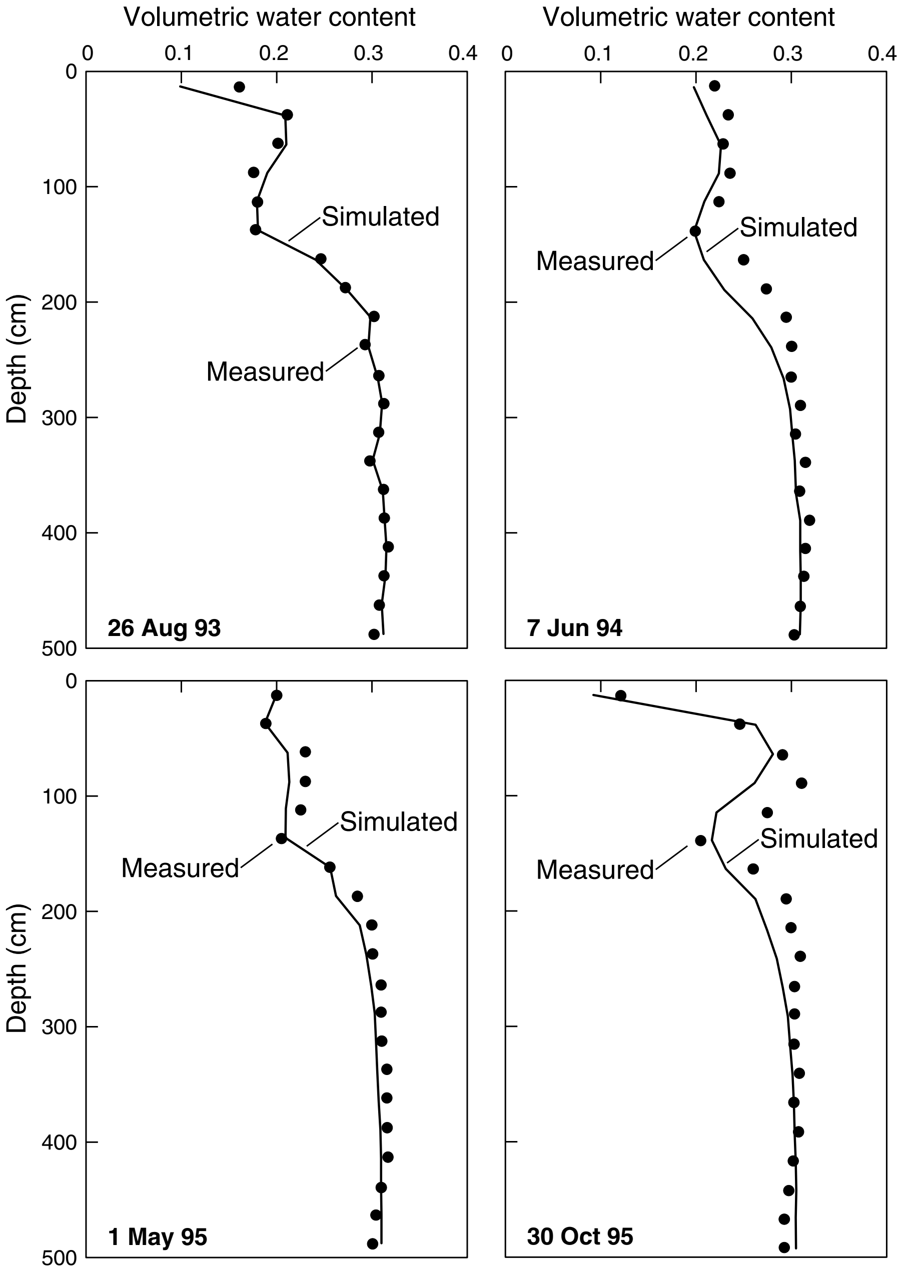

Fig. 5.28. Simulated (—) and measured (•) soil moisture profiles at Walpeup for the selected dates (plot 3).

Groundwater recharge

Modelled groundwater recharge (deep drainage) rates range from 9 to 33 mm per year (Table 5.9). The highest recharge occurred under plot 10 at Hillston, while the two cropping systems at Walpeup showed consistently lower recharge rates. The high recharge rate under plot 10 at Hillston may well be attributed to the fact that the bottom soil layer of the plot 10 was about 15% wetter than the other plots at the site.

As a result, the unsaturated hydraulic conductivity for plot 10 was twice that of plot 1, despite the lower saturated hydraulic conductivity. Given that the Hillston site was flood irrigated before the experiment started and the deep soil layer of plot 10 was always above field capacity, the cropping rotations had little impact on recharge to groundwater. These results are consistent with our understanding of the processes controlling recharge, and the measured soil moisture data.

Deep drainage is affected by a number of factors, such as rainfall, soil hydraulic properties, and vegetation. The annual recharge simulated at 4 m depth for the both sites showed no obvious relationship to the annual rainfall (Table 5.9). We have included the net flux modelled passing 1.5 m depth, this depth being the common maximum rooting depth of wheat (Incerti and O'Leary, 1990). The Hillston results show the impact of the first year irrigation, then subsequent cropping water use accounted for stored water and eliminating any deep drainage passing 1.5 m. The Walpeup data, with a much shallower rooting depth, deep drainage followed, generally, the annual rainfall, with actual crop rotation having little effect.

During the period of the study, the deep soil layers were relatively wet and deep drainage occurred mainly as a result of antecedent soil moisture content. Therefore, potential groundwater recharge showed little response to annual rainfall or crop rotations. It can be argued that for deep soil layers with low hydraulic conductivity it takes a long time for surface management to have noticeable impacts on recharge. However, over a long enough period of time the effects of vegetation changes may then be quite significant in terms of rising groundwater tables. The unsaturated hydraulic conductivity of the soil at the base of plot 10 was estimated to be 0.8 mm/d based on the Broadbridge–White soil model. At that rate, it would take nearly 13 years for water from the surface to reach the bottom of the soil column. This estimate is likely to be an upper limit, but places the time scale of recharge control in context.

Fallow soil water storage

At Walpeup in June 1993 the soil water storage was similar between fallow and continuous cropping systems (Fig. 5.29). By sowing in 1994 an additional 44 mm of water was stored in the upper 1.5 m soil profile due to fallowing. The additional soil water content at sowing due to fallowing (Fig. 5.29) resulted in the higher leaf area index of fallow wheat in the 1994 drought. At Hillston in 1992 similar soil water profiles occurred under each cropping system (Fig. 5.29). By sowing 1993, fallowing had stored an additional 25 mm of soil water.

On average, an additional 22 to 37 mm of soil water is stored in Mallee environments due to fallowing (French 1978; Incerti *et al.* 1993; O'Leary and Connor, 1997) and the stored water can be used to increase crop yield (French, 1978). However, the effect of fallowing, especially long fallowing, should not be overlooked because only part of increases in crop yield after fallowing could be ascribed to additional water supply (French, 1978). Furthermore, the distribution of additional soil water from fallowing has been observed in the lower portion of the root zone or below the root zone, potentially leading to deep drainage (Incerti *et al.* 1993; O'Leary and Connor 1997). This has implications for recharge control under dryland conditions as highlighted by O'Connell *et al.* 1995. Incerti *et al.* (1993) argued that the use of long fallows to increase soil water supply for crop yield can not be justified. This was because it is likely to increase drainage below the root zone, and crops could only use a fraction of the stored water due to relative shallow rooting depth and sandy soil texture in the Mallee.

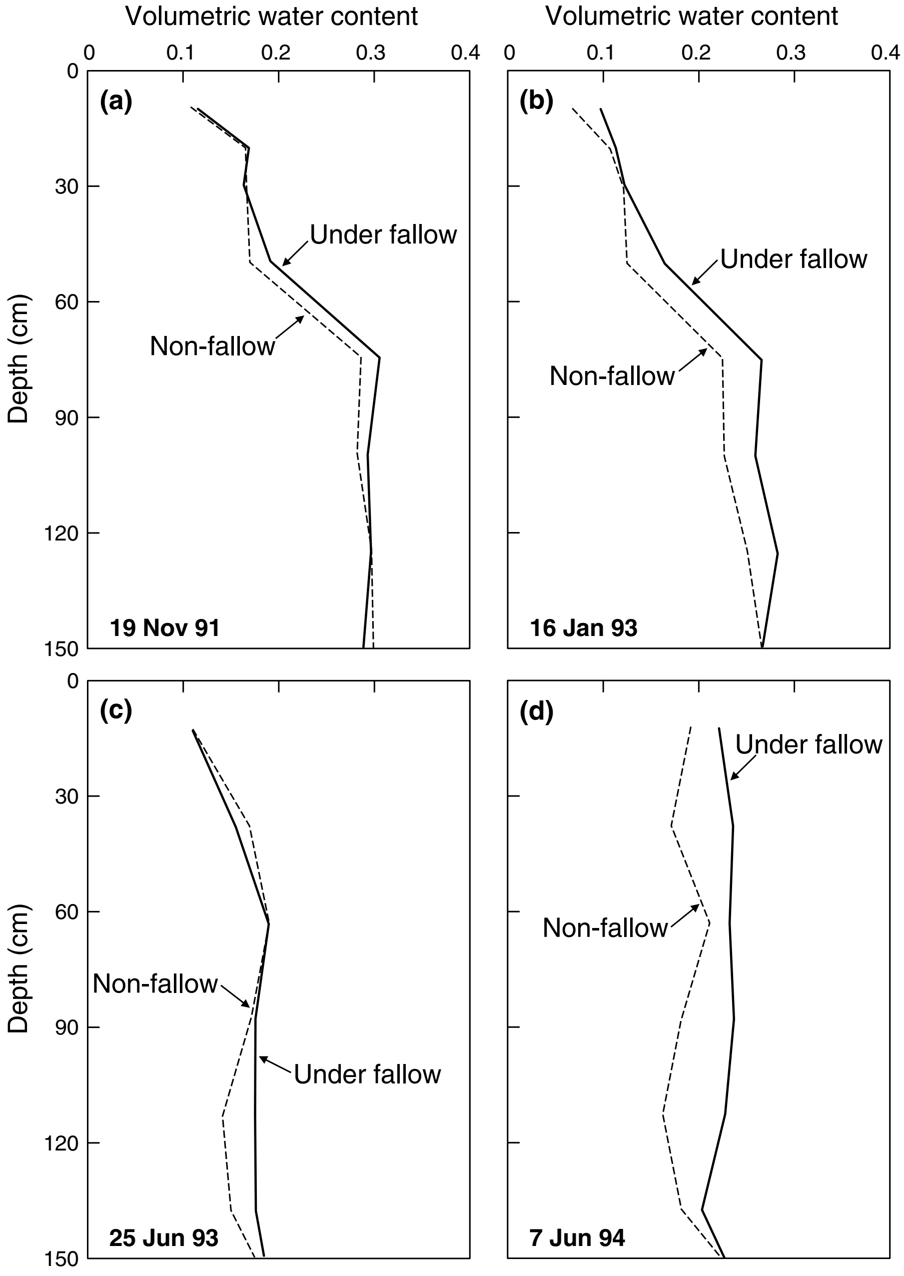

Fig. 5.29. Measured soil moisture profiles prior to (a) and after (b) fallowing at Hillston and Walpeup under fallow (—) and non-fallow (•••) crop rotations.

Long-term modelling

Recharge in the Mallee region is generally considered to be episodic as a result of infrequent large rainfall events. Rainfall at the two study sites showed extreme variability, especially at Hillston (Fig. 5.30). More than 20% of total rainfall occurred in less than 5% of total time (Fig. 5.30). Because these rainfall events are infrequent in time and significant in magnitude, they can cause large episodic recharge. As a result, it is anticipated that any agronomic practices are not likely to affect episodic recharge significantly.

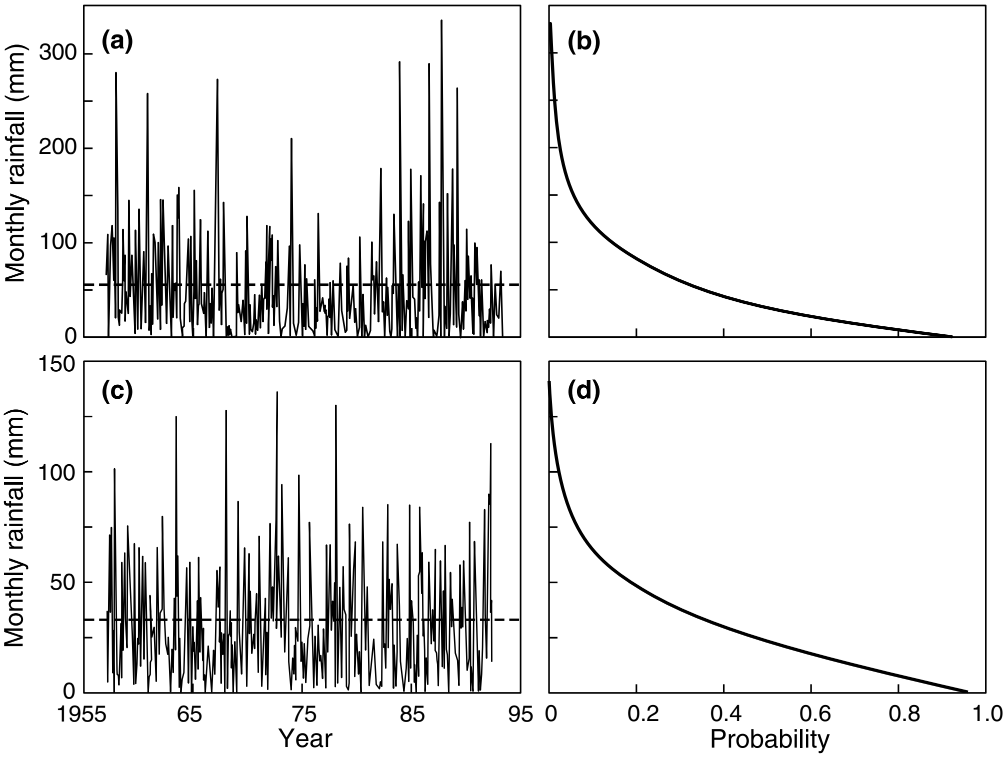

Fig. 5.30. Monthly rainfall and frequency distribution at Hillston (a,b), and at Waleup (c,d) during the period of 1957 to 1992. The horizontal lines indicate the mean rainfall.

The long-term scenario modelling at both Hillston and Walpeup is summarised in Table 5.10. Average recharge at 4 m under the lucerne rotation (RT1) was approximately 30% of that under medic rotation (RT2) and this suggests that on average lucerne has better control on recharge than medic pasture. For shallow rooted plants (*i.e.* 0.5 m rooting depth), average recharge at 4 m under the fallow rotation was 26 mm year^{-1} compared to 19 mm year^{-1} from the non-fallow rotation. This difference in recharge due to fallowing is 7 mm year^{-1} which equates to 35% extra deep drainage. The difference in average recharge between fallow and non-fallow rotations is 9 mm year^{-1} with rooting depth of 1 m (Table 5.10). Fallowing was found to cause similar deep drainage increases at Walpeup by O'Connell *et al.* (1995) using chloride profile analysis.

Table 5. 10. Summary of long-term scenario simulations

Site	Hillston		Walpeup			
Rotation[a]	RT1	RT2	RT3	RT4	RT3d	RT4d
Average rainfall (mm)	564		351		351	
Rooting depth (m)	1.5	1.5	0.5	0.5	1.0	1.0
Min. recharge (mm/yr)	0	4	8	8	5	7
Max. recharge (mm/yr)	15	34	37	37	10	25
Average recharge (mm/yr)	4	13	19	26	7	12

a:

RT1: fallow/oat/wheat/wheat/(lucerne × 4)
RT2: fallow/oat/wheat/wheat/(medic × 4)
RT3: medic/medic/wheat
RT4: medic/fallow/wheat
RT3d: medic/medic/wheat (deep roots)
RT4d: medic/fallow/wheat (deep roots).

The impact of fallowing on recharge depends on soil hydraulic properties and maximum rooting depth of successive crops. The impact, and risk of recharge, is much greater on sandy soils than on clay soils because they are inherently more conductive, have lower water holding capacity, and higher infiltration rates. Rooting depth and total soil depth play important roles in controlling recharge. The deep-rooted crops can utilize more soil water and hence offer greater control on recharge. It is generally understood that the soil volume acts as a buffer zone in reducing recharge, the deeper the rooting system, the greater the recharge control.

The annual recharge just below the root zone (*i.e.* 100 cm depth) was episodic and showed significant temporal variations (Fig. 5.31). At Hillston, 10% of annual recharge events accounted for 50 to 75% of the totals; this ratio was increased from 20 to 85% for Walpeup conditions by changing the rooting depth from 50 to 100 cm and the magnitude of these annual recharge events was as high as 130 mm year^{-1}; it is clear that the rooting depth has significant impact on episodic recharge because it determines the size of the buffer zone.

The episodicity of the recharge events can be described by the cumulative distribution function shown in Fig. 5.32. It is clear that the use of the lucerne and non-fallow rotations could reduce average recharge, but it also makes recharge more episodic in the sense that recharge occurs much less frequently but its magnitude can still be significant (see Fig. 5.31). As a result, better agronomic practices are not likely to control episodic recharge significantly. For example, annual rainfall in 1973 was 538 mm (*i.e*. 58% higher than the long-term average) and the annual recharge at 1.0 m depth under the non-fallow rotation (RT4) even exceed that under the fallow rotation (RT3). This was because the soil profile under RT4 was wetter than that under RT3, which lad to substantial more surface runoff and hence less infiltration. However, this was only observed to occur under wet years and the fallow rotations generally produced more recharge at 1.0 m depth.

The recharge rate at 4.0 m was much less variable compared to drainage rate at 1.5 m (Fig. 5.33). At Hillston, the recharge rate at 4.0 m depth increased dramatically after 10 years for the medic rotation (RT2) but not for the lucerne rotation (RT1), which continues to decrease. The recharge under RT2 appears to respond to the cumulative rainfall anomaly. At Walpeup, a similar trend was observed for the fallow rotation with shallow rooting depth (RT4). However, an increase in recharge occurred after 20 years with deep-rooted plants (RT4d) (Fig. 5.33).

It is interesting to note that the fallow rotation (RT4d) was insensitive to the cumulative rainfall anomaly. These results suggest that changes in land management (e.g. fallowing, crop rotation) may take a considerable period of time (>10 years) to have any noticeable impacts on recharge; the difference in recharge under fallow and non-fallow rotations is significant (Table 5.10).

Annual recharge at 4 m depth under the fallow rotations responded to cumulative rainfall anomaly (Fig. 5.33). It is also shown that deep-rooted plants have better control on recharge, but the degree of control is modified by soil characteristics and the prevailing weather conditions.

Results from this study showed that the recharge just below the root zone is episodic in the sense that it occurs infrequently and its magnitude is significant. Given the fact that plants can only use water in root zone, the effect of current agronomic practices on episodic recharge is limited. During these events, the root zone, generally considered as a buffer zone, became saturated and significant recharge occurred. As a result, episodic recharge can substantially reduce the effectiveness of land management options in controlling recharge. This is more so for sandy soils than for clay soils because of low water holding capacity and high infiltration rates.

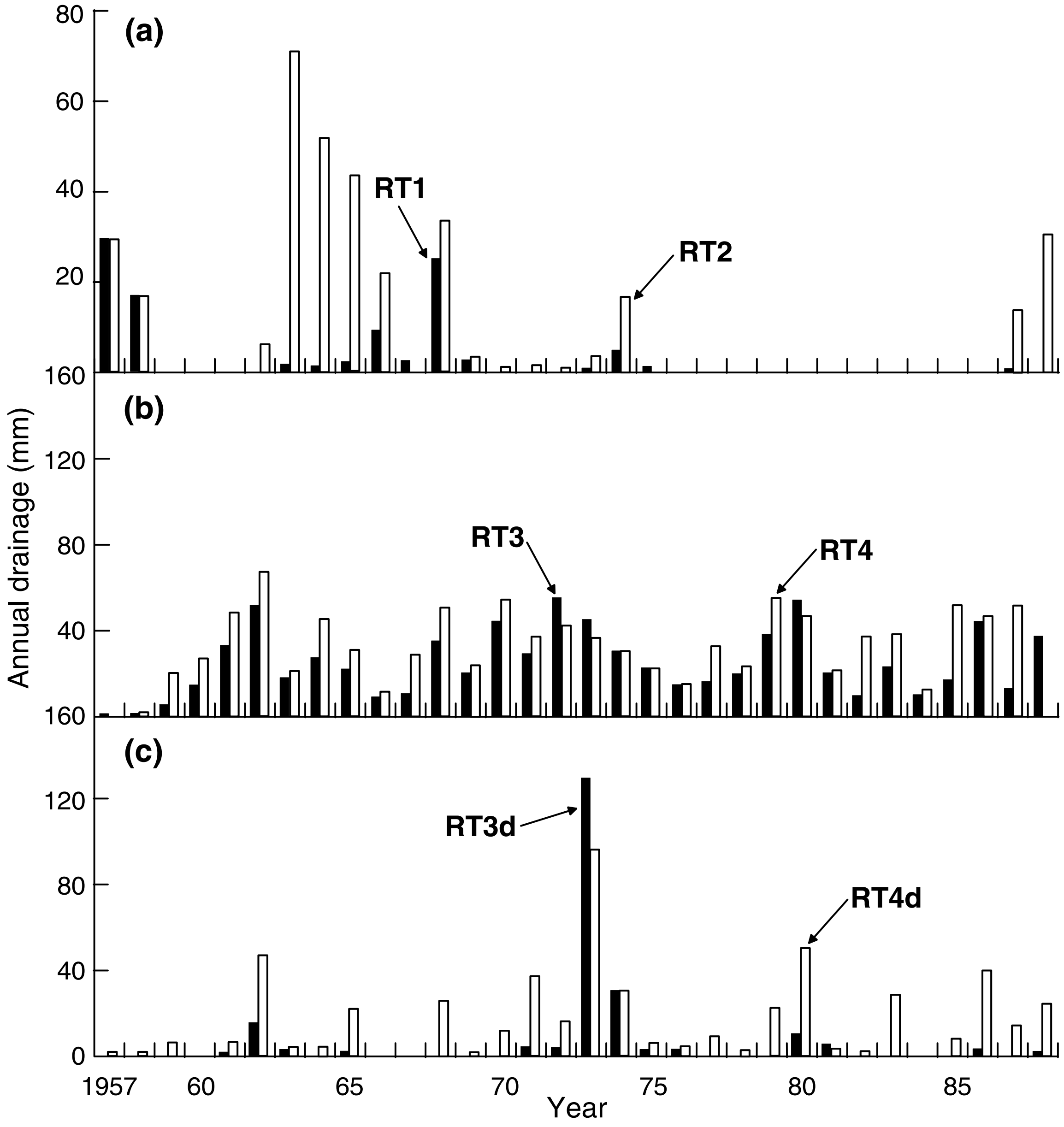

Fig. 5.31. Simulated recharge rates at 1.0 m depth for (a) Hillston under lucerne rotation (RT1) (▮) and medic rotation (RT2) (☐), (b) Waleup under non-fallow (RT3) (▮) and fallow rotation (RT4) (☐) with rooting depth of 0.5 m, and (c) Waleup under non-fallow (RT3d) (▮) and fallow rotation (RT4d) (☐) with rooting depth of 1.0 m.

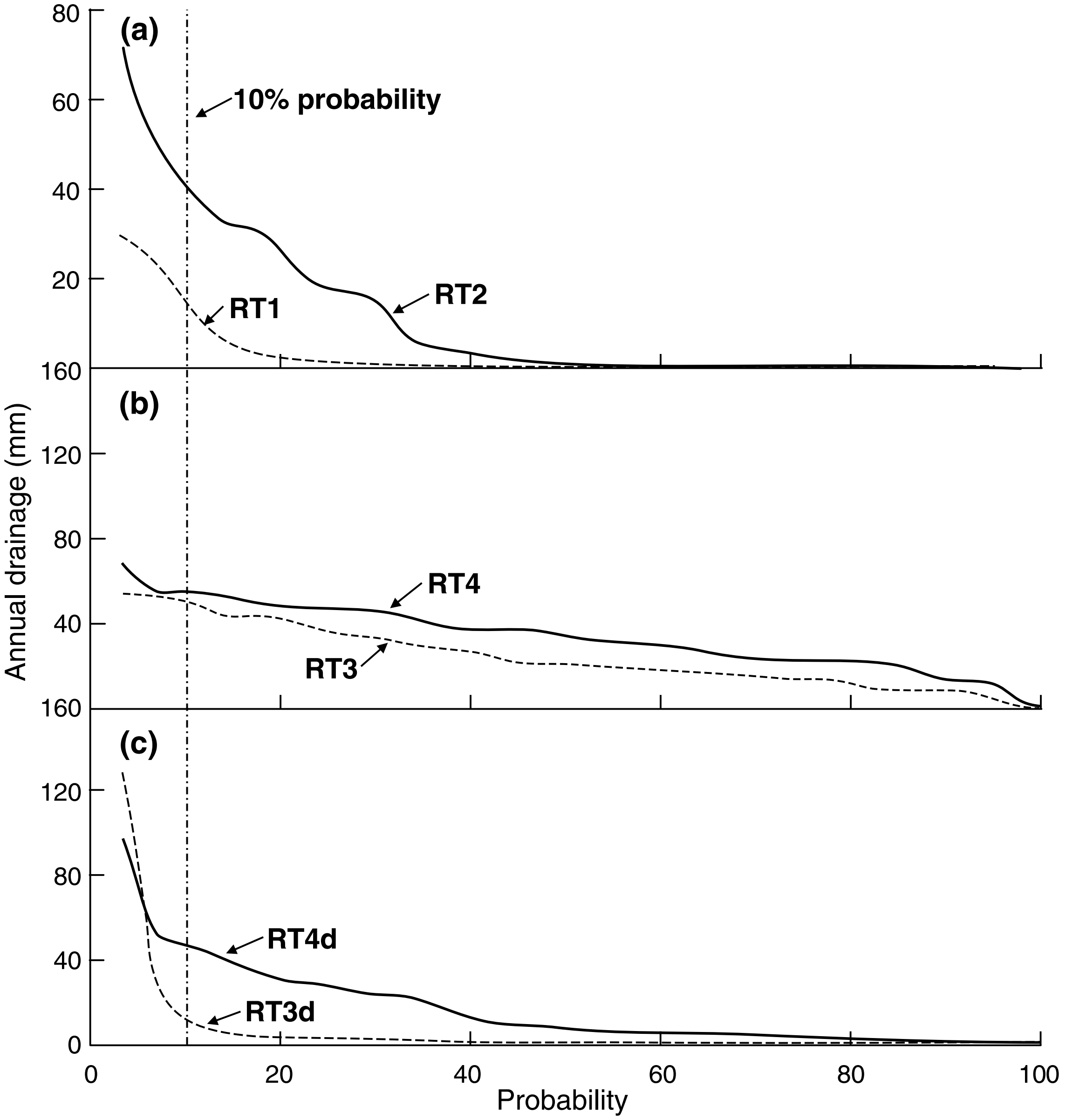

Fig. 5.32. Frequency distribution of annual recharge at 1.0 m depth for (a) Hillston under lucerne rotation (RT1) and medic rotation (RT2), (b) Waleup under non-fallow (RT3) and fallow rotation (RT4) with rooting depth of 50 cm, (c) Walpeup under non-fallow (RT3d) and fallow rotation (RT4d) with rooting depth of 100 cm. The vertical line indicates 10% probability.

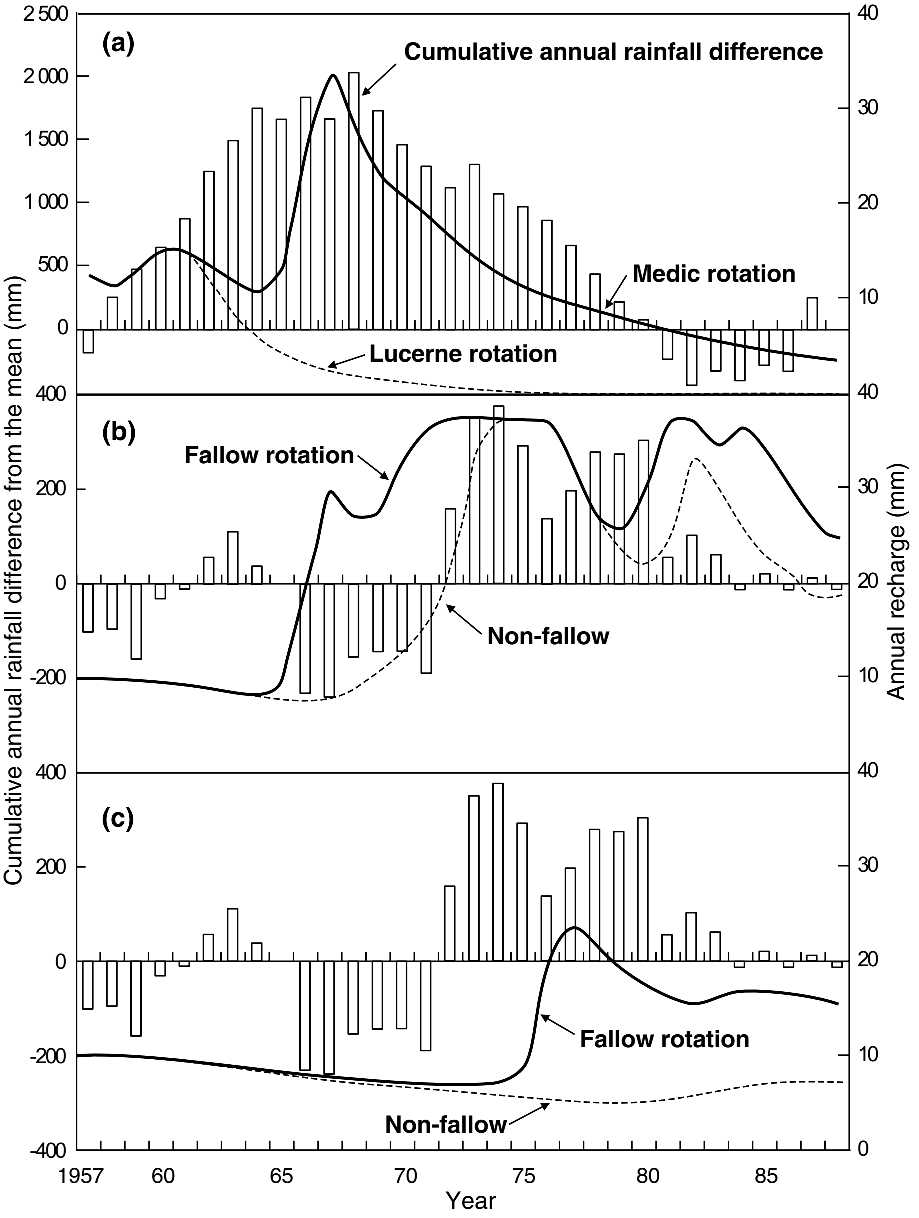

Fig. 5.33. **Cumulative annual rainfall differences from the mean (☐) and annual recharge rates at 400 cm depth for (a) Hillston under lucerne rotation and medic rotation, (b) Waleup with rooting depth of 50 cm, and (c) Waleup with rooting depth of 100 cm under non-fallow and fallow rotation.**

Conclusions

Recharge just below the root zone is episodic and 10% of the annual recharge events accounted for 25 to 85% of the long-term totals under the Mallee conditions. The magnitude of these annual recharge events can be up to 130 mm year^{-1} and it is these events that contribute largely to groundwater recharge. Given the episodic nature of recharge in the Mallee region, better agronomic practice is not likely to affect episodic recharge significantly although it can reduce mean annual recharge.

Changes in surface management (*e.g.* fallowing, crop rotation) may take a considerable period of time (>10 years) to have any noticeable impacts on recharge as observed in the above scenario modelling. It is important to recognize the long term impacts of any agronomic practices on recharge because the effects of these changes may not be apparent for a short period of time, but may then be devastating in terms of rising groundwater table. Lucerne appeared to have better control on recharge than medic pasture and average recharge under lucerne was only 30% of that under medic pasture.

One of the advantages of physical models such as WAVES is the ability to simulate the hydrological effects of various land management options and to identify key factors controlling the processes. An attempt was made in this study to evaluate the effects of winter fallowing in crop rotations on groundwater recharge. The results showed clearly the long term benefit of non-fallowing in reducing recharge and this has implications for dryland salinity control. The traditional practice of winter fallow significantly increased soil moisture storage, groundwater recharge, and the risk of salinity. We argue that winter fallowing has contributed to dryland salinity in the Mallee regions, and more areas could be affected in the future unless improved agronomic practices are implemented. O'Connell *et al.* (1995) suggest that fallowing may be eliminated, provided its alternative encourages vigorous vegetative growth (e.g. replacement with grass-free pasture, grain legume, oilseed phase) as reported by Griffiths and Walsgott (1987) and Incerti *et al.* (1993).

Acknowledgements

This work was partially funded by the Murray–Darling Basin Commission through its Natural Resources Management Strategy Investigation and Education Program (Grant No. M4025). Technical assistance in site maintenance and data collection was provided by S.D. Blandthorn, A.J. Corbett, S. Wisneske, M.C. Brown, M.J. Ferguson, J.L. Latta, M.W. Ferguson. We are grateful to Mr. W. Milthorpe for the use of his farm at Hillston. We are grateful to V. Snow and F. Lewis for comments on a draft of this paper.