Modelling Deep Drainage Under Different Land Use Systems.
1. Verification and Systems Comparison

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Abstract Drainage beyond the root zone contributes to water table rise and salinity in some parts of the Liverpool Plains catchment in northern NSW. The effect of land use on deep drainage was investigated by comparing the traditional long fallow system with more intense 'opportunity cropping'. Long fallowing (two crops in three years) is used to store rainfall in the soil profile but risks substantial deep drainage. Opportunity cropping seeks to lessen this risk by sowing whenever there is sufficient soil moisture. Elements of the water balance and productivity were measured under various farming systems in a field experiment in the southern part of the Liverpool Plains. The APSIM (Agricultural Production Systems Simulator) model was parameterised for the site using soil and water data (soil moisture, runoff, climate), and crop data (phenology, biomass, leaf area). Model performance was tested against four years of measured data on the site. Good agreement between model predictions and measurements indicated that the model captures the main hydrological and biological processes. The verified model was used in long-term (41 years) simulations to predict deep drainage under different systems and extrapolate experimental results. The results showed large differences between agricultural systems mostly because differences in evapotranspiration caused different profile moisture at the time of rain. Opportunity cropping resulted in greater water use, significantly reduced deep drainage and increased production compared to long fallowing. Modelling also indicated that continuous sorghum might be a better alternative for reducing deep drainage, than continuous wheat.

1. INTRODUCTION

Dryland salinity caused by shallow water tables is a major concern in the Liverpool Plains catchment in northern NSW, one of the most fertile agricultural areas in Australia. The catchment has a total area of 1.2 million ha which is predominantly under agricultural production. Large areas of the alluvial plains within the catchment are at risk of production loss due to high water tables and salinity [Broughton, 1994]. Deep drainage, which is the amount of water draining below the root zone, can potentially become recharge and contribute to rising water tables and salinity. The effect of farm scale management strategies on long-term deep drainage was investigated using both field experimentation and modelling. The APSIM (Agricultural Production Systems Simulator) model was parameterised with data measured on the experimental site. This paper describes model verification using measured and simulated results. The verified model was used in long-term simulations to extrapolate the results of the water balance and productivity in time to examine the capacity of alternative cropping systems to reduce deep drainage. It builds on previous studies [eg. Keating et al., 1995] by using more extensively tested and more accurately parameterised modelling tools. A second paper in these proceedings [Ringrose-Voase et al., 1999] describes how the model can be applied over the whole catchment taking into account soil and climate variability.

2. METHODS

2.1. Site Description

The experimental site was established in the foothills of the Liverpool Ranges on the 'Hudson' property in 1993 and is typical of the highly productive farming country in the catchment. The average annual rainfall is 678 mm, with most falling during summer. Average annual potential evapotranspiration is 1718 mm. The site is representative of areas previously identified as being significant contributors to groundwater recharge. The site is situated across two contour bays on a slope of approximately 2%. The soil is a Self-mulching Black Vertosol [Isbell, 1996], with a clay content of about 75% of which 90% is smectite. This gives the soil marked shrink/swell potential (linear shrinkage coefficient of 0.21) and a self-mulching surface. The available moisture holding capacity of the soil is large (505 mm to 3 m depth). Groundwater occurs 15 m below the surface above basalt bedrock.

The experiments were designed to compare water balance and production of cropping systems with varying lengths of fallow and perennial pastures. Only the cropping systems results are discussed here. The 'long fallow' system of one wheat and one sorghum crop in three years (see Table 1) is

Table 1. Agronomic treatments at the Hudson site.

Year	1994		1995		1996		1997		1998
Season	**Winter**	**Summer**	**Winter**	**Summer**	**Winter**	**Summer**	**Winter**	**Summer**	**Winter**
LF1	Wheat(fail)			Sorghum			Wheat		
LF2		Sorghum			Wheat			Sorghum	
LF3			Wheat			Sorghum			Wheat
W1	Wheat(fail)		Wheat		Barley		Wheat		Barley
OP1	Wheat(fail)	Mungbean	Wheat	Mungbean	Barley	Mungbean		Mungbean	Barley
OP2		Sorghum	Chickpea	Sorghum	Fieldpeas (fail)	Sorghum		Sorghum	Fieldpeas (fail)

traditionally used on soils with high moisture holding capacity to store rainfall over long periods of fallow. This guarantees sufficient moisture for reasonable yields even in the absence of growing season rainfall. However, much of the water will become runoff and/or deep drainage if rain falls on an already full profile. In a more flexible system of 'opportunity cropping' sowing is more closely matched with the amount of profile moisture so that more water is used by crops and deep drainage is reduced. This involves setting a 'sowing rule' that defines the minimum depth of wet soil for sowing to take place. The depth of 'wet' soil is monitored during a sowing window to determine whether or not sowing should take place according to the rule.

The experimental design comprised 9 treatments (Table 1): a wheat-sorghum-long fallow rotation (LF, 3 phased treatments), continuous winter cereal (W1), opportunity cropping with winter cereal and a summer pulse (OP1), opportunity cropping with sorghum and a winter pulse (OP2) and three types of perennial pasture (not reported here). OP treatments used a sowing rule of 0.5 m of wet soil. Treatment plots were 40 × 15 m with 4 replicate blocks of the 9 treatments.

2.2. Measurements

The measurements made on crops within each cropping cycle included dry matter, leaf area, phenology and grain yield. Soil water storage was measured monthly, or more frequently, using a neutron moisture probe. Surface runoff was measured from 100 m^2 subplots in at least one replicate of each treatment. Meteorological data were recorded on site with an automatic weather station.

The neutron moisture meter was calibrated by gravimetric soil water sampling in a number of calibration bays. The calibration data was also used to construct a relationship between bulk density and volumetric water content. This was used with material coordinate theory to correct water content measurements of each layer for changes in soil volume due to shrink/swell [Ringrose-Voase et al., 1998].

The soil moisture contents at saturation (SAT), field capacity (or drained upper limit, DUL) and wilting point (or lower limit, LL) were estimated from corrected moisture content profiles at various times.

2.3. The APSIM Model

APSIM is a software environment which consists of modules that can be 'plugged-in' or 'pulled-out' and a communications system (engine and module interfaces) that allows modules to share information. [McCown et al., 1996].

The model operates at a paddock scale (1-D) with a daily time step so it can capture the episodic deep drainage events. The MANAGER module allows flexible management rules to be included so that complex or conditional management scenarios, including rotations and sowing rules based on soil moisture, can be modelled. The RESIDUE module tracks water and N dynamics of crop/pasture residues. Using climate data, the water balance part of the model (SoilWat2) simulates runoff, evaporation and deep drainage and provides water to the crop modules for transpiration. The SoilWat2 module is a 'cascading bucket' water balance model that owes much to its precursors in CERES [Jones and Kiniry, 1986] and PERFECT [Littleboy et al., 1992]. The water characteristics of the soil are specified by the lower limit (wilting point), drained upper limit (field capacity) and saturated volumetric water contents. Runoff from rainfall is calculated using the USDA-Soil Conservation Service [1972] procedure known as the curve number technique. The procedure uses total precipitation on a given day to estimate runoff. Runoff curve numbers (CN, ie. runoff as a function of total daily rainfall) are specified by numbers from 0 (no runoff) to 100 (all runoff). The model also reduces CN according to the amount of crop cover and surface residues.

Soil evaporation is assumed to take place in two stages: the constant (potential) and the falling rate (less than potential) stages [Ritchie, 1972]. Water redistribution in the profile is calculated by allowing a fraction of the drainable water in each layer to drain to the next layer each day [Jones and Kiniry, 1986]. For water contents below DUL, water movement depends upon the water content gradient between adjacent layers and the average water contents of the two layers.

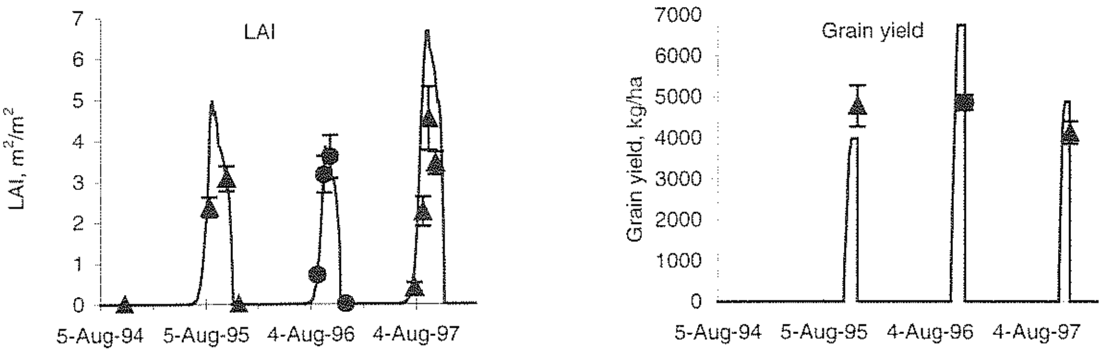

Figure 1. Predicted (lines) and measured crop growth data for treatment W1: ▲ wheat; ● barley. Error bars are ±1 standard deviation across replicates. (LAI: Leaf area index)

2.3.1.Model Verification

Data measured at the experimental site were used to verify that the model was able to accurately simulate plant production and soil water conditions. To do this, APSIM was parameterised using a combination of measured site specific data and known 'standard' parameter values from earlier model applications. Soil profile was divided into 16 layers of 100 mm thickness for surface and 200mm for other layers. Deep drainage was considered as the amount of water draining from the bottom of the soil profile. Using climate, soil plant and management inputs, simulations were run for each treatment over 4 years of the field experiment. Simulated water content profiles, phenological development, green biomass, leaf area index (LAI) and crop yield were compared with those observed at the site. Some phenological parameters relating to day length and temperature responses in the sorghum module were revised to suit the northern NSW conditions and local cultivars. The amount of simulated soil evaporation was increased because it was believed that soil cracking had caused greater evaporation than in non-cracking soils. Some site management issues such as spraying out sorghum after harvest and dealing with viral disease in field peas and sulphur deficiency in mungbeans were simulated by modifying the controlling parameters in the model.

2.3.2.Long-term Simulation Runs

Following the verification phase the APSIM model was used to extrapolate the water balance estimates and crop production for the 41-year period 1957-1998. The simulated cropping treatments were as above except that the opportunity cropping system consisted of wheat and sorghum due to its proven success in the region. A continuous sorghum system was also added as an alternative for comparison.

A sowing rule was implemented via APSIM's MANAGER module, which allowed wheat to be sown only if the top 50 cm of soil was wet enough (at least 75% of moisture holding capacity, 91mm of water present). For sorghum, the depth considered was 70 cm of wet soil (125mm of water) during a sowing window. With these rules there will be years when the required conditions are not met and so crops will not be sown.

Historical climate data for the 41 year period was generated using 'Data Drill' [Queensland Centre for Climate Applications, 1998] which is interpolated from recorded data.

3. RESULTS AND DISCUSSION

Model predictions of crops and pastures were compared with the field observations for verification of model performance. The calibrated simulations generally gave good description of the main biological and hydrological processes. For example, the prediction of LAI, yield and water contents in the profile were in close agreement with the measured values for the continuous wheat treatment (Figures 1 and 2). A good agreement between measured and predicted crop and water balance data for other treatments was also apparent. Runoff predictions were more variable across treatments and replicates. Figure 3 shows a comparison of the cumulative runoff for the OP2 treatment.

Model verification gives confidence in model predictions and results. Table 2 shows the deep drainage predicted by the calibrated model at Hudson experimental site. Large differences occur between treatments and years. The long fallow and wheat systems produced the most deep drainage. Opportunity cropping significantly reduced the amount of drainage below the root zone mainly because of increased plant water use. Winter 1998 was an exceptionally wet year (250 mm rain in July) and disproportionately influenced the average of the 4 year results. In order to make some conclusions about the episodic drainage on different systems, the long-term simulation results were analysed to give predictions beyond the 4 years of the experiment.

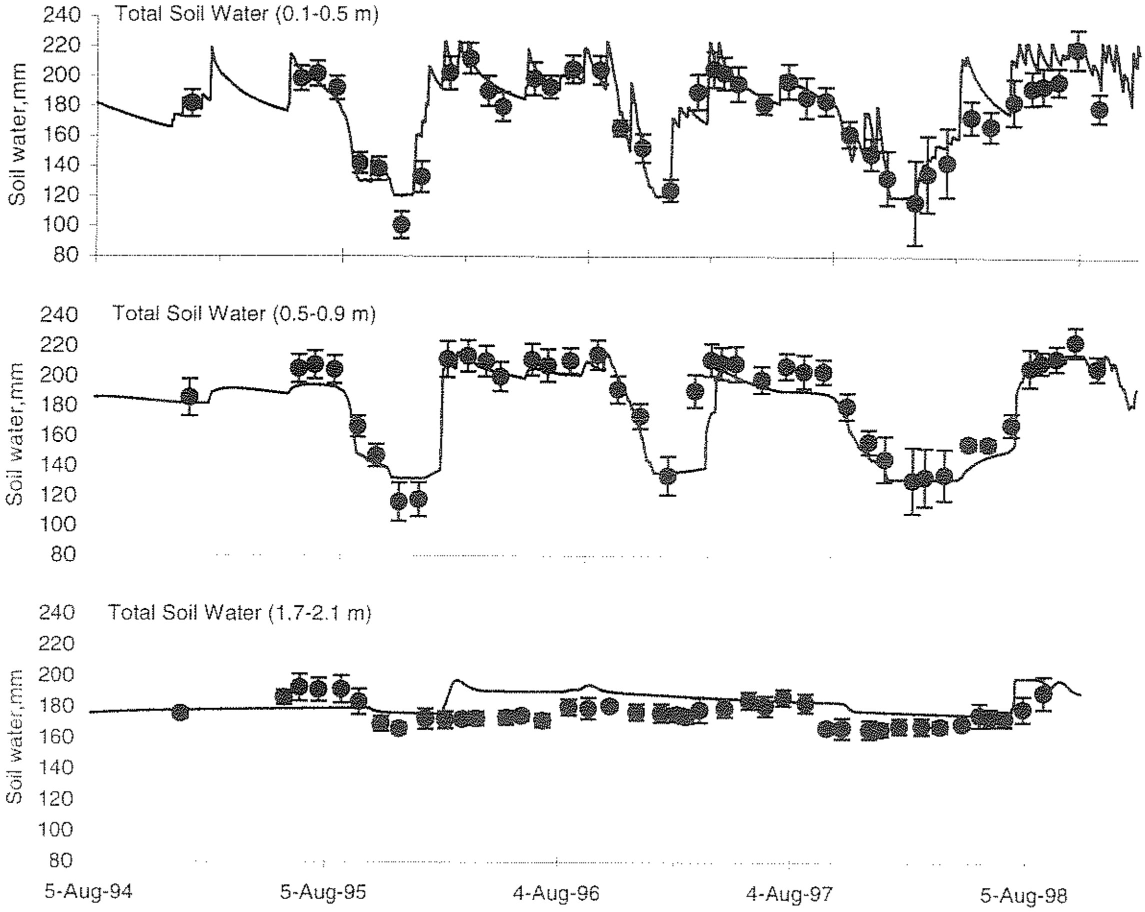

Figure 2. Predicted (lines) and measured (symbols) soil water of various layers under treatment W1.

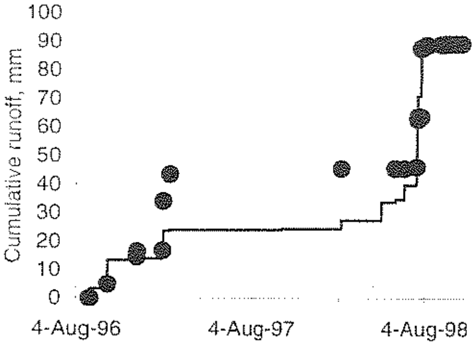

Figure 3. Cumulative predicted (line) and measured (symbols) runoff for treatment OP2 (opportunity cropping).

Table 2. Predicted deep drainage (mm) for treatments at the Hudson site (note that the 1998 period was 1/1/98 to 29/10/98

Treatment	1995	1996	1997	1998	Mean
W1	0	46	6	236	65
LF1	0	0	75	227	69
LF2	0	26	4	153	41
LF3	0	144	13	112	65
OP1	0	0	1	11	3
OP2	0	0	0	82	18

Table 3 summarizes the results of the long-term simulations in terms of predictions of the water balance terms and production. The results for long fallowing are the means of the 3 offset LF phases. Long fallow and continuous wheat produced much greater drainage than the opportunity cropping and continuous sorghum systems (Figure 4). These differences are explained by the mean monthly evapotranspiration and soil moisture deficit (Figures 5 and 6). The latter is the difference between amount of water in the profile and the amount when it is at field capacity (when it is considered 'full'). A low *mean* monthly deficit means the soil profile is more likely to be full on any one occasion and therefore prone to drainage after rainfall.

Crop water uptake by continuous sorghum coincides with the period of maximum rainfall in summer. This results in the soil water deficit increasing during December to March when rainfall is also greatest. From April to November the deficit decreases with winter rain and lower evaporative demand, reaching its minimum after winter. In contrast, under continuous wheat, the deficit increases from July to November. Lack of a crop during summer means summer rainfall decreases the deficit so that the profile is almost

Table 3. Long-term mean predicted values of water balance and crop production for cropping systems on the Hudson site (mean annual rain 678mm).

	Long fallow	**Opportunity cropping**	**Continuous wheat**	**Continuous sorghum**
Evapotranspiration, mm/yr	610	648	618	635
Drainage, mm/yr	29	2	36	3
Runoff, mm/yr	39	28	24	40
Wheat production, t/ha/yr	1.7	2.2	4.0	-
Wheat yield, t/ha/crop	5.0	3.2	4.4	-
Wheat cropping frequency, /yr	0.33	0.68	0.93	-
Sorghum production, t/ha/yr	1.9	1.9	-	3.9
Sorghum yield, t/ha/crop	5.7	4.4	-	4.7
Sorghum cropping frequency, /yr	0.33	0.44	-	0.85

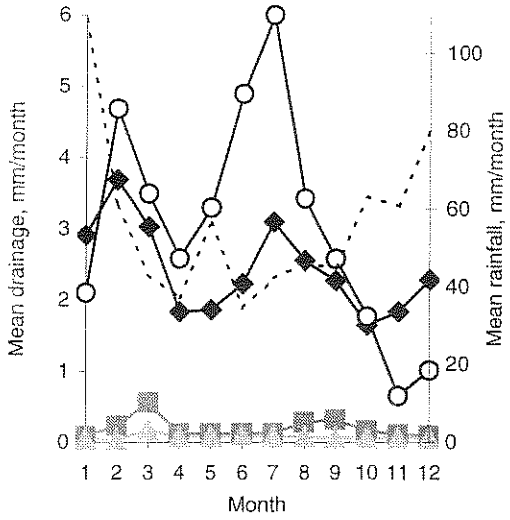

Figure 4. Predicted long-term (41 years) mean monthly deep drainage at the Hudson site for different cropping systems: ◆ long fallowing; ▩ opportunity cropping; ▲ continuous sorghum; ○ continuous wheat; and ---- mean monthly rainfall.

full at the start of winter. This means that winter rainfall is more likely to result in drainage (Figure 4).

Opportunity cropping resulted in large soil moisture deficit from October to April, because the pattern of uptake was a mixture of the two continuous cropping systems. Whilst long fallowing was also a mixture, its overall lower cropping frequency used less water resulting in smaller deficits.

The crop production data (Table 3) indicate that individual crop yields (t/ha/crop) were greatest in the long fallow system. However, the total production (t/ha/yr) from the long fallow was less than from any other system because cropping frequency was lower. Opportunity cropping had the greatest predicted grain production followed by the continuous wheat and continuous sorghum systems.

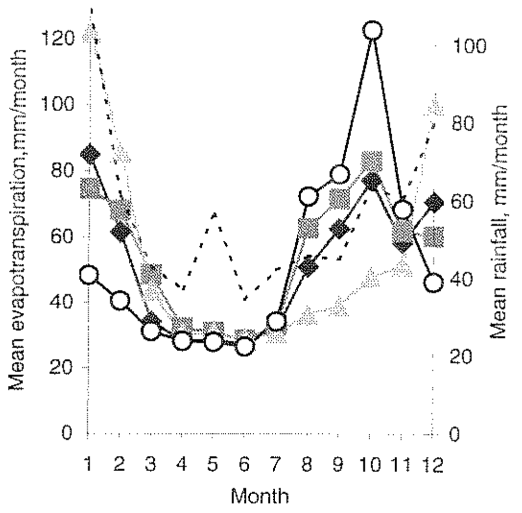

Figure 5. Predicted long-term (41 years) mean monthly evapotranspiration at the Hudson site for different cropping systems. Symbols as for Figure 4.

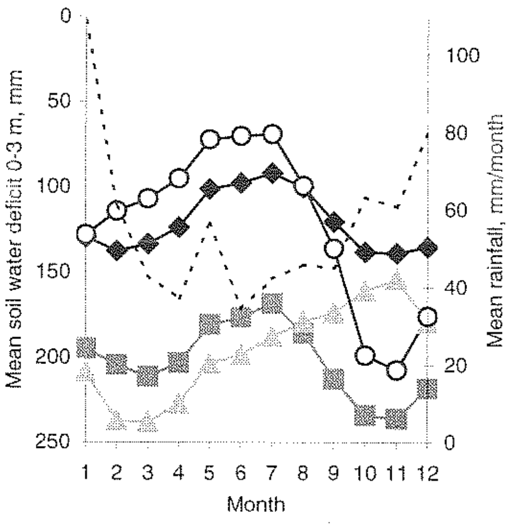

Figure 6. Predicted long-term (41 years) mean monthly soil water deficit at the Hudson site for different cropping systems. Symbols as for Figure 4.

Opportunity cropping and continuous sorghum systems seem to be most attractive options for the site both in terms of reducing deep drainage and increasing production.

4. CONCLUSIONS

The APSIM model, verified for the site, is capable of predicting water balance and productivity of complex agricultural systems in the Liverpool Plains catchment. With the episodic nature of the deep drainage events, the results from short-term experiments are not conclusive in terms of sustainability of the systems. Long-term simulation helps to identify best management options for the climate and soil at the site. Changing from long fallowing to opportunity cropping or continuous sorghum systems, which are better suited to this predominantly summer rainfall environment, can substantially reduce deep drainage, with an increase in productivity.

5. ACKNOWLEDGEMENTS

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