Comparative Modelling of Water Leakage Under a Lucerne or Annual Pasture. 1. Role of Initial Soil Water Content and Frequency of Rainfall Data

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Abstract The establishment of perennial pastures such as lucerne (*Medicago sativa* L.) is currently one of the options proposed to help to control dryland salinity in southern Australia. The SWIM (Soil Water Infiltration and Movement) model was calibrated using trial results from a site near Katanning, Western Australia, which compared water use of established lucerne and an annual clover-based pasture. Both monthly and daily rainfall records from Katanning for May to December for 1970-1995 were used to assess long-term average water leakage during the period May 1 to December 31 from both the lucerne and annual clover-based pastures. Using monthly rainfall figures, water leakage was related to the initial difference in soil water content between the two pasture types, which was measured at 57 mm to a soil depth of 1.2 m. In years where leakage under the annual pasture was greater than 57 mm (42% of years), leakage under the lucerne pasture was approximately 57 mm less. Where leakage under the annual pasture was less than 57 mm, leakage under the lucerne was close to 0 mm. Average annual water leakage was 54 mm under annual pasture and 18 mm under lucerne pasture. When daily rainfall figures were used, the difference in leakage between clover and lucerne pastures was maintained at about 57 mm. However, average modelled leakage was higher under both pasture types (82 mm under annual pasture and 32 mm under lucerne), indicating that daily rainfall records are essential to obtain a clear picture of water leakage responses.

Keywords: Leakage, Drainage, Lucerne, Salinity

1. INTRODUCTION

Dryland salinity is recognised as one of the major forms of land degradation in southern Australia, affecting agricultural productivity as well as rural infrastructure. It is caused by excess water (ie water that cannot be stored within the soil matrix) leaking below the shallow root zone of annual agricultural crops and pastures, leading to rising groundwater levels. This process will be referred to as leakage throughout this paper. The deep-rooted perennial pasture, lucerne (*Medicago sativa* L.) has been proposed as a possible means to redress, at least partially, the hydrological imbalance caused by extensive clearing of native vegetation. Lucerne's deep roots, and perennial growth, allow it to withdraw water from deeper soil layers than those accessed by traditional agricultural crops and pastures. The band of dry soil formed by lucerne below the normal agricultural root zone acts as a buffer against future water leakage, creating a storage zone for excess water than can accumulate during the cool wet winters characteristic of the Mediterranean climatic zone of southern Australia.

Many studies [eg Crawford and Macfarlane, 1995; Latta et al., 2001; Angus et al., 2001; Ward et al., 2001] have shown that lucerne can create a buffer against water leakage in many regions and soil types of southern Australia. However, these studies have necessarily been short term in nature, whereas recent hydrological research has suggested that water leakage is episodic in nature in many locations, and the long-term average could be dominated by infrequent extreme climatic conditions [Zhang et al., 1999]. Modelling is therefore necessary in order to gain an insight into the role of lucerne in long-term reduction of water leakage.

Several models of soil water movement and/or storage are available. At the basic level, AgET [Argent, 1999] uses average climatic and ET data, 'tipping bucket' type models [eg WATBAL: Starr, 1999] solve the water balance equation for various soil layers, and the more mechanistic models, such as SWIM [Ross, 1990] solve the Richards' equation to determine flow rates between soil layers. The ready availability of monthly rainfall data, through such programs as Rainman, allows long-term modelling to be performed with little difficulty. However, monthly rainfall totals may be misleading, because rainfall seldom falls evenly during a month, but is usually concentrated within a few days. Excess water may therefore be generated for a few days of a month, but this may not be apparent from monthly rainfall totals.

In this paper, the mechanistic SWIM model is used, firstly to compare long-term modelled water leakage from lucerne pasture with that from an annual subterranean clover (*Trifolium subterraneum* L.) pasture using monthly rainfall data; and secondly, to compare water leakage generated from monthly with that from daily rainfall data.

2. METHODS

2.1. Model Calibration

Soil hydraulic properties required to run the SWIM model were obtained by calibration using data generated during the 1996 growing season from a site near Katanning, Western Australia, described by Hodgson et al. [2001] and Ward et al. [2001]. In this trial, a clover pasture and a lucerne pasture were compared with respect to their patterns of water extraction from a sandy duplex soil (Typic Palexerult by USDA Soil Taxonomy). The model was run from 1 May to 31 December 1996, with hourly rainfall data, and the water increment (the maximum water flux, excluding transpiration, in one time step) was set at 0.5 cm. Initial soil water contents for each vegetation type at each of the modelled depths were taken directly from soil water contents measured on May 1. Soil water contents at this time were at their lowest and most divergent for the lucerne and clover plots, as rainfall for the period January 1 to April 30 1996 was 9 mm. Daily potential evaporation was calculated according to Priestley and Taylor [1972] from meteorological variables measured on site. The drainage condition was set to drain under gravity.

The soil consisted of loamy sand to a depth of 45 cm, overlying a massively structured light clay to a depth of 70cm, in turn overlying a more blocky medium clay to a depth of about 1.5 m. Soil water contents were measured (by TDR at 15 minute intervals) at 0-10, 15, 25, 35, 50, 70, 90 and 110 cm. In the model, the soil was divided into layers at depths of 0.05, 5, 15, 25, 35, 44.5, 45.5, 50, 70, 90 and 110 cm, corresponding to depths of soil water measurement and horizon changes. Of the Campbell parameters for the $\Psi(\theta)$ relationship, θ_s (water content at saturation) was determined from maximum measured water contents, and Ψ_e (the air entry potential) and b (the negative slope of the straight line approximating the water retention curve on a log-log plot) were determined by iteration (within reasonable values) until modelled soil water contents at field capacity and at the end of the season matched measured soil water contents for all modelled depths. K_s was adjusted so that total modelled leakage matched total leakage determined from a water balance [Ward et al., 2001] for both the lucerne and clover plots. Silberstein et al. [1999] used similar values for K_s in their modelling at the same site.

Vegetation parameters were set according to above- and below-ground productivity measured in October, 1996. The annual pasture increased in relative coverage from 0.2 to 0.9 from day 30 (May 30) to day 150 (September 27), had a maximum root length density of 3.0 cm cm^{-3}, and the depth constant (the soil depth where root length density falls to 37% of the maximum value) was set at 10 cm. The lucerne pasture increased in relative coverage from 0.1 at day 1 (May 1) to 0.9 at day 90 (July 29), reflecting its greater early growth pattern than annual pasture. The maximum root length density was 3.8 cm cm^{-3}, and the depth constant was set at 20 cm, to simulate the greater depth of lucerne roots relative to annual pasture.

2.2. Model Application

Monthly (May to December) rainfall data for each year from 1970 to 1995 was used as model input, using the same initial soil water contents, Campbell soil parameters and vegetation parameters as for the 1996 calibration season. In other words, all parameters were re-set to standard values on May 1 for every simulation, and each simulation ran for a period of 8 months. Average monthly potential evaporation was used for all simulations. Using these parameters, leakage from annual pasture was compared with leakage from a lucerne pasture.

Daily rainfall (also May to December) was used as model input for the same years and with the same parameters as for monthly rainfall data, in order to ascertain the effect of frequency of rainfall data on modelled water leakage.

3. RESULTS

3.1. Model Calibration

Modelled and measured leakage for the lucerne matched well, in both quantity and timing (Figure 1). The downward trend in October was due to water uptake by lucerne from soil depths greater than 1.2 m, which was the limit for the water balance calculations. For the clover, SWIM modelled the quantity of leakage well, but could not accurately simulate the timing. Measured leakage began about 6 weeks earlier than modelled leakage, possibly due to macropore flow through the soil. However, the inclusion of macropores in the model resulted in much greater leakage under both vegetation types. Silberstein et al. [1999] also noticed this discrepancy using the TOPOG-Dynamic model at the same site, and concluded that K_s may have varied within the season, becoming smaller in magnitude as the clay B horizon swelled, reducing the impact of macropores.

3.2. Lucerne Versus Clover

Using monthly rainfall records, total ET for the period May 1 to September 31 was within the range 183-227 mm, and the maximum difference in ET between the lucerne and clover pastures in any specific year was of the order of 5 mm (data not shown).Therefore, differences in leakage between clover and lucerne pastures cannot be ascribed to differences in ET for the May-September period.

The modelled difference between clover and lucerne pastures in terms of leakage (Figure 2) was related to the difference in initial water storage, which was always set at 57 mm. In years where the leakage under clover was greater than 57 mm (11 out of the 26 years), leakage under the lucerne was approximately 57 mm less. In all other years, leakage under the lucerne was approximately zero. Average annual leakage was 54 mm for the clover and 18 mm under lucerne

The probability distribution function (Figure 3) indicates that average annual leakage under both clover and lucerne is heavily influenced by a few wet years. In contrast to the average water leakage, median leakage was 41 mm under clover and 0 mm under lucerne.

3.3. Daily Versus Monthly Rainfall

With daily rainfall input, the difference between modelled leakage under clover and lucerne followed the same pattern as observed with monthly rainfall input (Figure 2). However, modelled leakage under both pasture types tended to be higher when daily rainfall was used (Figure 4). Where leakage based on daily rainfall data was greater than about 30 mm, leakage based on monthly data was about 30 mm less. Where leakage based on daily rainfall data was less than 30 mm, leakage based on monthly data was approximately zero.

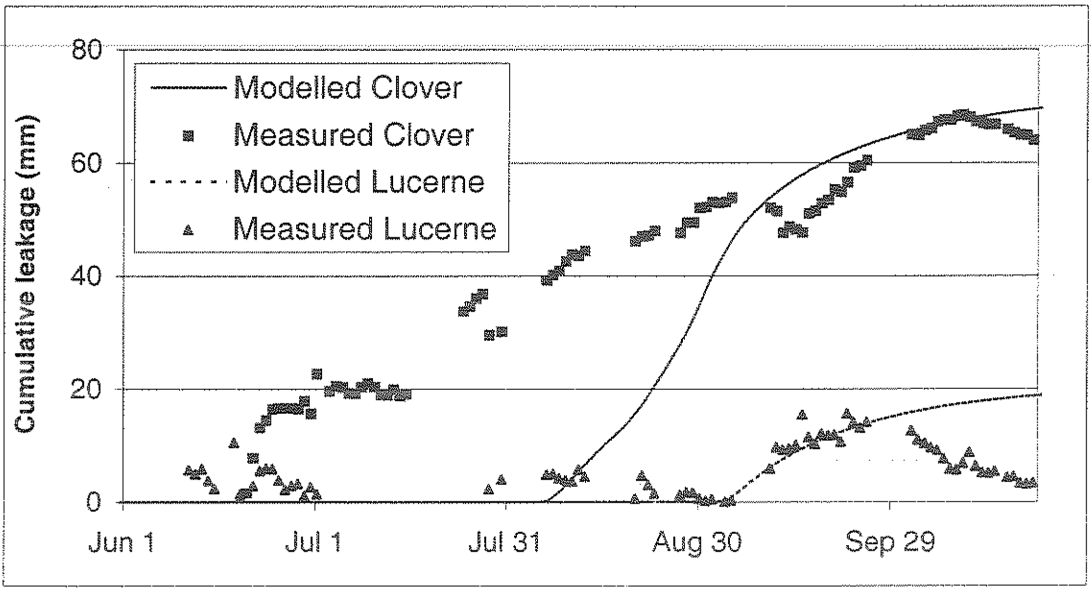

Figure 1. Comparison of modelled and measured leakage under clover and lucerne at Katanning in 1996.

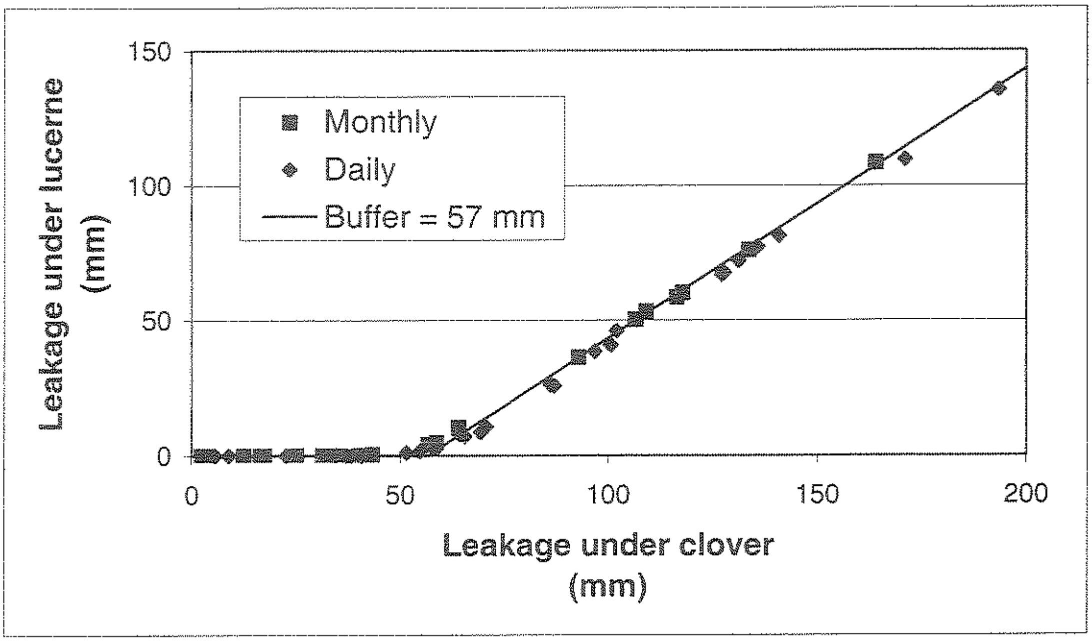

Figure 2. Modelled leakage for the period May 1 to December 31 under clover and lucerne pastures for daily and monthly rainfall data.

Average leakage using daily data was 82 mm under clover and 32 mm under lucerne, compared with 54 mm and 18 mm when using monthly data. APSIM [McCown et al., 1996] simulations using daily data gave average leakage values of 86 mm for clover and 31 mm for lucerne (P. Dolling, personal communication). Median leakage was 70 mm for clover and 10 mm for lucerne (figure 4), compared with 41 mm and 0 mm for monthly rainfall data.

4. DISCUSSION

Despite different vegetation characteristics for both above- and below-ground production, there was little difference in total ET between the lucerne and clover pastures. Therefore, the difference in leakage was almost entirely due to the difference in initial soil water storage, which was set at 57 mm on May 1 each year. The insensitivity of ET to changes in vegetation parameters has also been modelled by Asseng et al [2001]. Similarly, Ward and Dunin [2001]

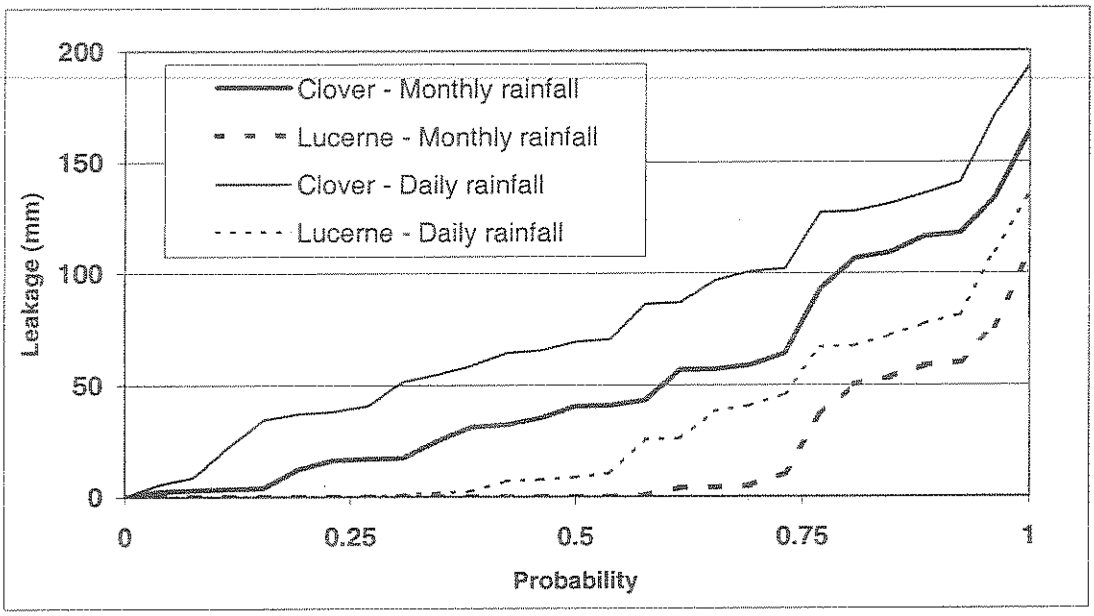

Figure 3. Cumulative probability distribution function for leakage under clover or lucerne modelled for the period May 1 to December 31 with monthly or daily rainfall as input.

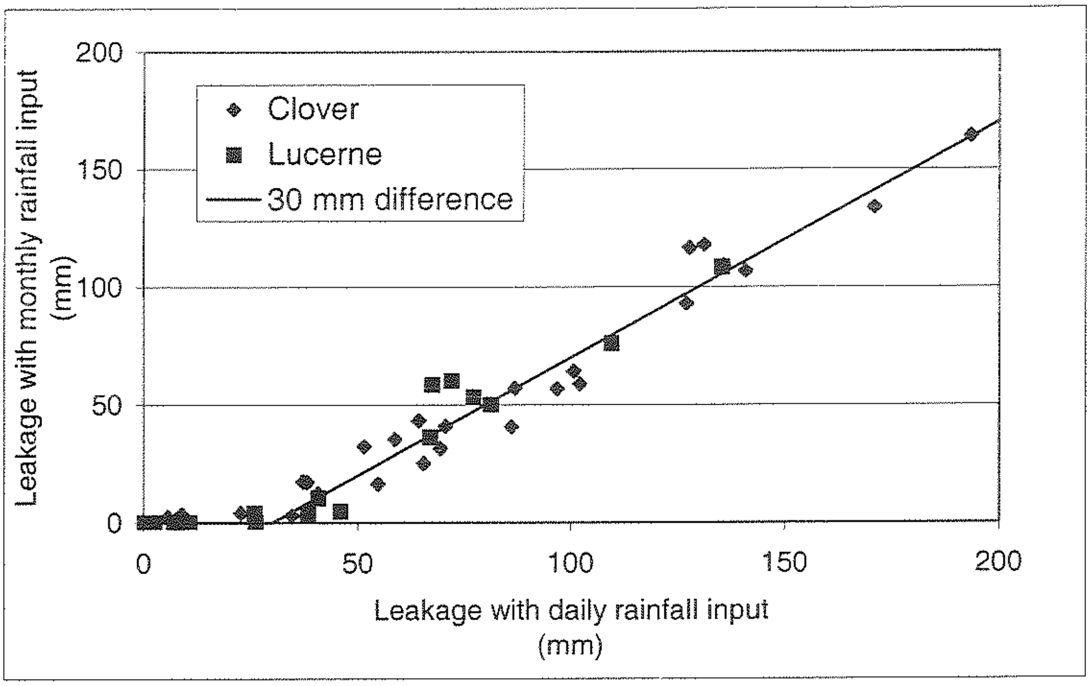

Figure 4. Influence of rainfall data frequency on modelled leakage from clover and lucerne pastures for the period May 1 to December 31.

showed that May-September ET is restricted by available energy, and is largely independent of plant type in many Mediterranean-style environments. Under this scenario, vegetation type is unlikely to influence leakage unless the initial soil water storage term varies, as observed in this modelling investigation. Any rainfall resulting in changes in soil water storage between January 1 and April 30 (implicitly, but not accurately, assumed to be zero in this paper) would tend to increase the initial soil water storage difference, and therefore would tend to increase the difference in water leakage between clover and lucerne pastures.

In this environment, continuous lucerne reduced leakage to approximately 33% of the average value modelled for annual pasture. This compares with 30% as modelled by Zhang et al. [1999], for a similar environment in eastern Australia. In drier regions, this relationship may break down, as the buffer provided by lucerne becomes larger relative to the average annual recharge [Ward, 2001].

The difference between using daily and monthly rainfall was due to periods of excess water identified from daily records but not from monthly records. For example, if the total July rainfall was 40 mm, this is approximately equal to potential evapotranspiration. Because SWIM interpolates to estimate rainfall intensity, it would assume rainfall of 1.3 mm per day throughout the whole month, and so gradients in soil moisture potential (and therefore leakage) would be minimal. However, if the rain actually fell in three days, substantial gradients in soil moisture potential would be generated, and leakage would be much larger.

The difference in leakage between daily and monthly rainfall records (30 mm) was remarkably consistent. With further research, this consistency may allow scaling of modelled leakage using monthly records to gain a more quantitative estimate of leakage. However, as estimates of daily rainfall records become more available, through programs such as patched point and gridded data sets, further research in this area is probably not warranted.

5. CONCLUSIONS

1. Differences in modelled water leakage for the period May 1 to December 31 between annual and lucerne pastures in south-western Australia are due almost entirely to differences in the soil water storage on May 1. Different growth patterns, and water use characteristics, during winter and spring have a negligible impact.

2. Use of monthly rainfall figures as input for SWIM resulted in a consistent underestimate of water leakage compared with daily rainfall figures.

6. ACKNOWLEDGEMENTS

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