Assessing Leakiness in Australia's Dryland Farming Systems

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Abstract It is ironic that while many of Australia's farming systems are strongly water limited, our dryland agriculture is threatened by water excess. Deep drainage below crop and pasture root zones leads to rising water tables and salinisation in the wider landscape. There is widespread interest in exploring alternative management strategies and alternative farming systems that can make better use of rainfall, restrict deep drainage and limit salinisation. While the problem occurs at broad landscape scales, the primary cause is farming practice at the farm or field scale. Farming systems models, appropriately specified at the field scale, have an important role to play in exploring the impact of alternative crops, pastures and management practices on the deep drainage term of the water balance. This paper reports on application of the APSIM (Agricultural Production Systems Simulator) model to explore the interactions between farming systems design, management, soil and climate factors. A transect approach is used to analyse the interactions between farming system design and climate in the Murray-Darling Basin (MDB), Australia's largest drainage system in which agricultural land, water ways and natural environments are at risk from salinity. The transects allow the joint and separate examination of the influences of rainfall amount and its seasonal distribution on the components of the water balance for a diverse range of soil conditions and management practices. These broad water balance assessments form the starting point for more locally specified and interpreted water balance investigation and farming system design.

Keywords: APSIM; Farming systems; Water balance

1. INTRODUCTION

While many of Australia's farming systems are strongly water limited, one of the greatest threats our dryland agriculture faces is water excess. Deep drainage below crop and pasture root zones is leading to rising water tables and salinisation in the wider landscape [NLWRA, 2000]. The replacement of perennial trees, shrubs and grasses with annual based cropping systems is generally recognised as a primary driver for the altered water balance that is causing redistribution of both water and salts in the landscape. While the general principles are well established, there is limited appreciation of the extent to which alternative farming system designs differ in their influence on the water balance and on how climate patterns alter these effects.

In this paper we use a farming systems model, namely APSIM (Agricultural Production Systems Simulator) [McCown et al., 1996], to explore the effects of farming system design, management, soil and climate factors on both economic outputs and water balance terms. Our focus is on "leakiness" at a point-scale; this is primarily the drainage term in water balance models, but in some cases may also include the runoff term. Depending on catchment characteristics, runoff can be a positive, contributing to water quality and steam flows or a negative, causing erosion and exacerbating water table rise and salinisation. The impact of leakage below farming systems on salinity development and water quality outcomes will depend of catchment considerations that are outside the scope of this paper.

While the salinity problem manifests itself at broad landscape scales, the primary cause is farming practice at the farm or paddock scale, and hence the logic of examining comparative farming systems performance at this scale [Keating et al., 1995]. We recognise that solutions require landscape scale approaches and may involve time scales that are well beyond those normally thought about with respect to farm or paddock scale decision making. We also recognise that landuse change to limit leakage may not always be the most viable option.

Despite these caveats, we believe an understanding of tradeoffs between productivity/profitability and leakiness at a paddock scale to be an important element of any integrated effort towards solutions.

The paper focuses on the Murray-Darling Basin (MDB) which represents one of Australia's major drainage systems in which large areas of agricultural land and extensive areas of water ways and natural environments are at risk from salinity [NLWRA, 2000]. The MDB contains a diverse range of climatic zones, and we were particularly interested in examining how rainfall total and rainfall distribution influence the drainage and runoff terms in the water balance for alternative farming systems. We have approached this question via a series of transects, where the aim was to highlight system response to some single dimension of the climate, all other factors being held constant. Hence the paper focuses on identifying the shape and relativities of the system response to climate elements and does not attempt to define a specific leakage rate at a particular place in the MDB.

2. MODELLING TOOLS

A combination of measurement and modelling is essential for a sound assessment of water balance in complex farming systems exposed to highly variable weather patterns. Measurement is needed in model construction, parameterization and testing. Modelling enables us to extend the water balance calculations over periods of historical weather records and assess long term consequences of farming system design in ways that are very difficult if not impossible using experimental approaches alone.

APSIM is a farming systems modelling tool designed to address complex climate-soil-plant-vegetation-management systems. It has been developed in Australia over the last 10 years and has found widespread application in farming systems analysis and design studies around the world. APSIM enables different biological, environmental and management modules to be linked together to simulate agricultural, forestry or natural systems.

The validity of this approach depends on (i) the assumption that historical climate is a guide to future climate and (ii) the model provides a realistic representation of the biophysical processes operating in the systems under consideration.

While climate change processes are acknowledged (and capable of being examined with these modelling tools), the fact remains that future climate in a region is still strongly related to present or past climate within the 50-100 year time scales we are considering. It is also the weather record during which the problem has developed.

Ensuring model scope, construction methods, scientific algorithms, constants and parameters come together to provide a valid representation of system performance is not a trivial exercise. Complex models such as APSIM cannot be "validated" in the sense that they can be shown to provide unequivocally accurate simulations. However, we can develop confidence in them by comparison with observations from a diverse range of situations. The more often we can compare model performance with a set of intermediate and integrative components from systems studies, the greater can be our confidence that they are capturing key processes and interactions that determine systems outcomes. A recent review of APSIM testing identified 54 reports over the last 5 years comparing some aspect of model simulation with observed data. Key studies in which components of the water balance were compared with detailed observations can be found in reports from Asseng et al., [1998], Probert et al., [1998], Verburg, [1996], Paydar et al., [1999], Snow et al., [1999] and Huth et al., [2001].

3. MODELLING METHODS

3.1 Climate Transects

Interpolated long-term weather data was supplied by Queensland Department of Natural Resources and Bureau of Meteorology via the SILO database. Two transects of climate stations (Figure 1) were selected to provide a means of exploring climate effects on the water balance of alternative farming systems within the MDB. The N-S transect (24 stations) followed the 600 mm rainfall isohyet (+/- 40mm) and captured variation in rainfall patterns from 40% of annual rainfall in winter in the north to 70% winter dominant in the south. The E-W transect (19 stations) was located at latitude 33°S and sampled annual rainfall regimes from 300 to 850 mm (approximately 60% winter dominant).

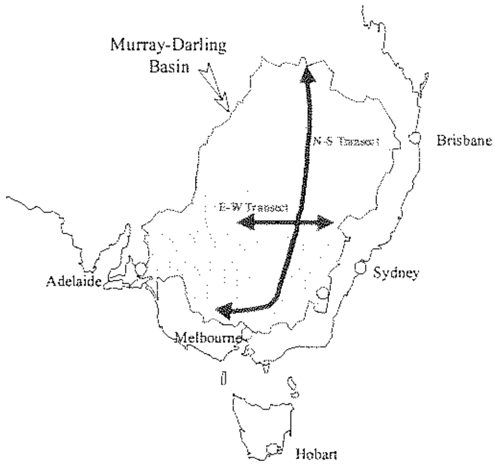

Figure 1. Map of the Murray Darling Basin in south-eastern Australia, showing the East-West and North-South transects.

3.2 Biophysical Analysis

Five farming systems were examined in these simulations, namely;

1. Annual wheat cropping, 80 kgN/ha (Annual wheat)
2. Wheat / sorghum rotations, with crops planned in response to rainfall events and soil water status (Opportunity cropping)
3. Three years of wheat followed by three years of lucerne (Phase farming)
4. A permanent lucerne stand, grazed down in May and oversown with wheat in the standard sowing window (Companion cropping)
5. A permanent lucerne stand, cut or grazed at flowering (Continuous lucerne)

The initial simulations used a single soil, namely a deep (3m) red earth capable of holding 167 mm of plant available water (PAW) to 1.1m (the assumed depth of the wheat root system) and 370 mm to 3.0m (the assumed depth of the lucerne root system). The nitrogen status of this soil was moderately low, but N fertiliser was applied in accordance with realistic farmer practice. Wheat crops (cv. Hartog) were sown on defined sowing rains (20 mm over a 10-day period) in a sowing window from the start of May to the end of July. Where appropriate, 75% of wheat and sorghum residues were removed (to mimic grazing) and the remainder left on the soil surface to decompose. In these initial scenarios, fallows were assumed to be completely free of weeds or regenerating annual crop or pasture species.

Two additional scenarios were examined to illustrate sensitivity of water balance terms to system parameterization. In one set of simulations, the soil type was changed to represent a high water holding capacity vertosol (Black earth) (355mm of PAW to the 1.8m rooting depth of wheat and 505mm PAW to the 3.0m rooting depth assumed for lucerne). In the second additional scenario, weeds were allowed to be present in the summer fallows. The rules for weed presence were based on the observations of Fischer et al., [1990], as interpreted for summer grass weeds in APSIM management logic. This logic allowed a cohort of weeds to establish between 1Dec and 29 April when rainfall over two days exceeded 25mm. Weeds were killed when their biomass exceeded 500kg/ha, and subsequent cohorts allowed to establish if rainfall conditions allowed.

4. ASSESSMENT OF ALTERNATIVE FARMING SYSTEMS

4.1 Measures of Water Balance

Estimates of drainage and runoff are highly episodic in these environments, as shown for one location in Figure 2. The E-W transect highlights the dominant effect rainfall total has on the long-term average drainage term in the water balance (Figure 3a). While not shown here, the evapotranspiration (ET) and runoff terms are also greater under the higher rainfall environments. The N-S transect illustrates how rainfall pattern modifies the water balance, over and above the rainfall total (Figure 3b). Concentration of rainfall in the winter months where potential ET is low exacerbates the water excess problem. Increasing the annual cropping intensity and/or increasing the presence of perennials in the simulated farming system, resulted in reductions in the drainage term of the water balance. For a given rainfall total and rainfall distribution, drainage was ranked: annual wheat > opportunity cropping > phase farming > companion cropping > perennial lucerne pasture.

4.2 Measures of Productivity

While this simulation study illustrates that farming system options exist that restrict drainage, these systems are not necessarily as profitable as the annual cropping systems that are currently widely practiced. Lower grain yields were simulated in systems that used pastures to maintain a drier soil profile (Figure 4). These lower grain yields were accompanied by varying levels of forage production, and economic evaluation of these alternative farming systems requires appropriate means of valuing both crop and forage elements.

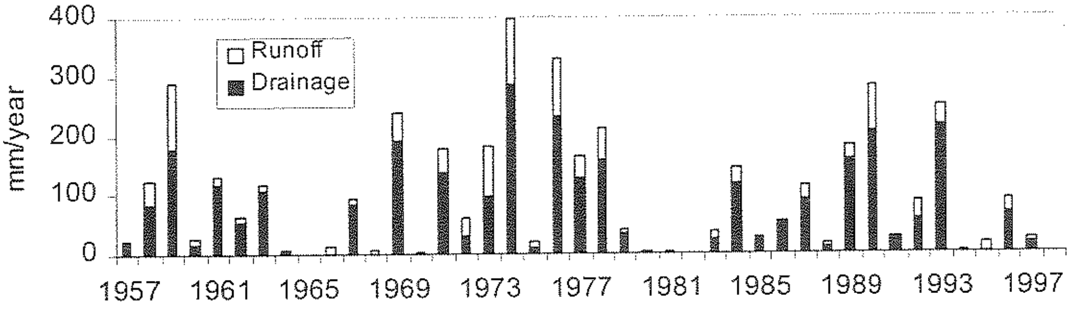

Figure 2. Time series of annual drainage and runoff simulated for annual wheat cropping at Parkes on the red earth soil.

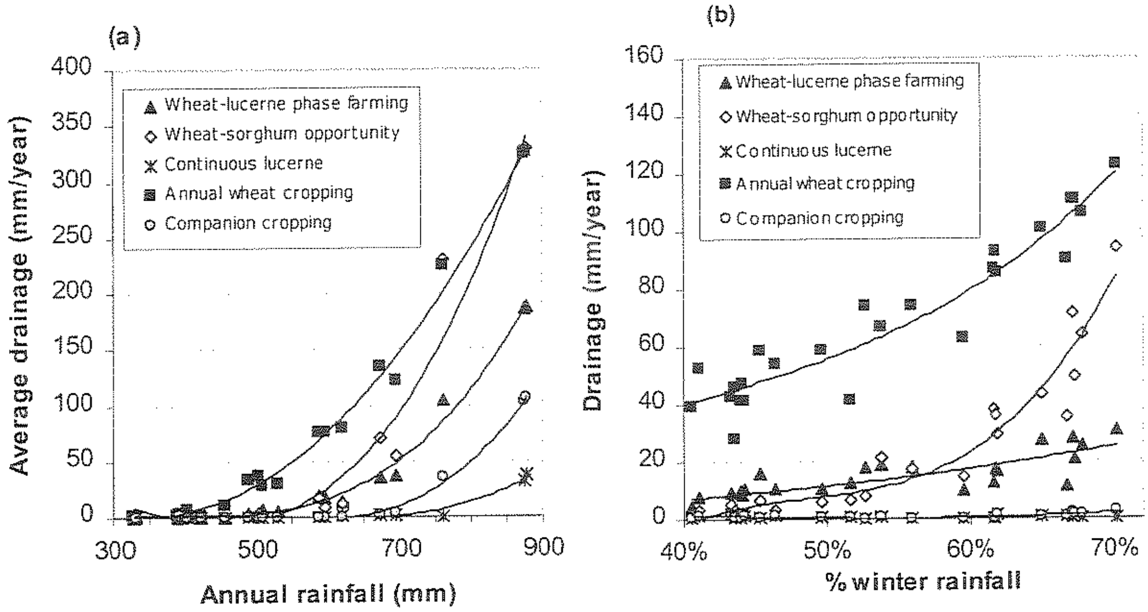

Figure 3. Simulated annual drainage for alternative farming systems (a) E-W transect and (b) N-S transect. Points show climate stations, lines regressions on climate variable. Red earth soil, no fallow weeds.

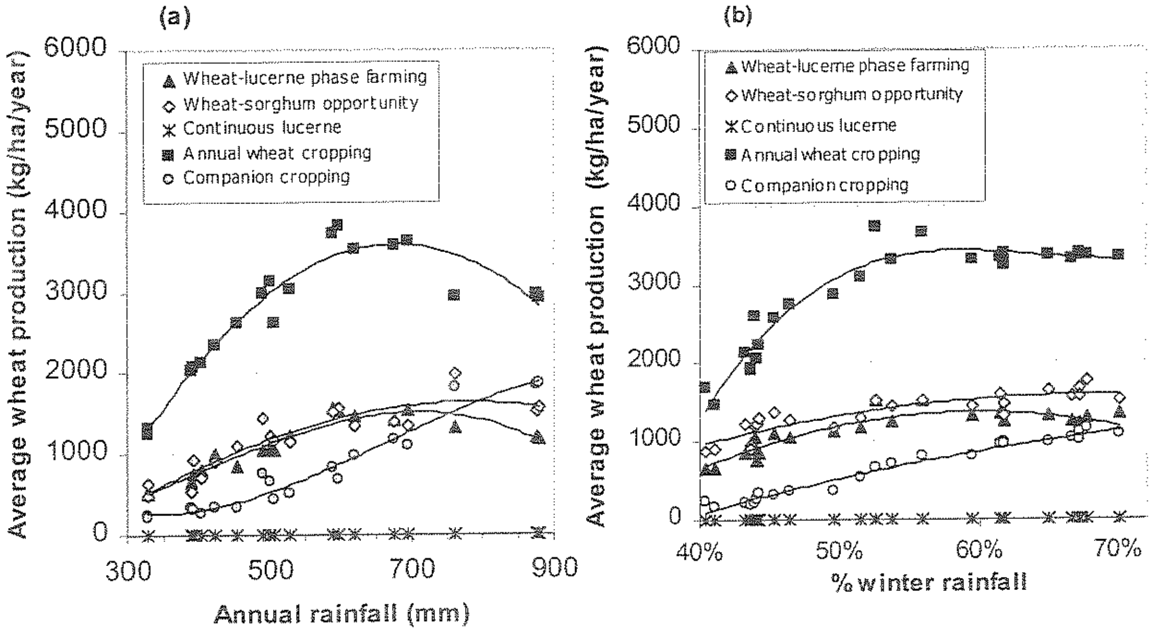

Figure 4. Simulated grain production for alternative farming systems along (a) E-W transect and (b) N-S transect. Symbols and lines as per Figure 2. Red earth soil with no fallow weeds.

4.3 Effects of Soil Type

The systems simulated in Figures 3 and 4 are not intended to represent the specific circumstances that apply along the different transects. For instance we know that water balance will be influenced by soil type and this varies greatly over the region of the transect. To illustrate the soil type effect, the simulations have been repeated for an alternative soil type (Figure 5). The higher PAW storage in the Black Earth resulted in a marked reduction in estimates of average drainage along the N-S transect.

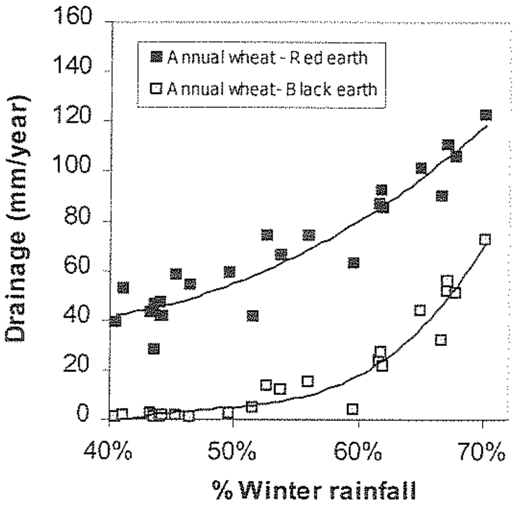

Figure 5. Effect of soil type on simulated drainage along the N-S transect for annual wheat cropping. Symbols and lines as per Figure 2. (Weed free fallows)

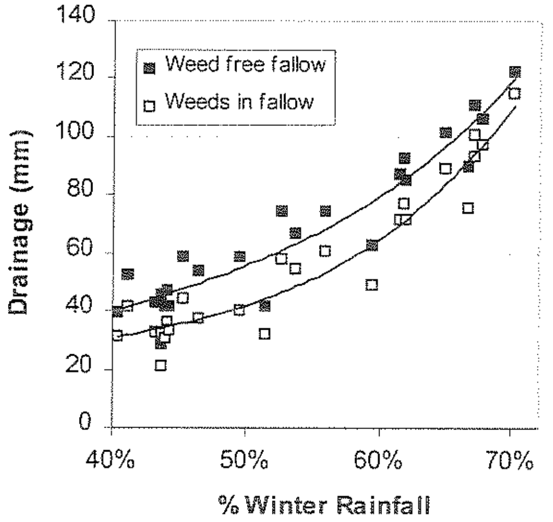

Figure 6. Effect of fallow weed control on simulated drainage along the N-S transect for annual wheat cropping. Symbols and lines as per Figure 2. (Red earth soil)

4.4 Effect of Fallow Weed Management

Many of the simulations included in this study include a summer fallow. In practice, differences exist in the extent to which weeds or self-regenerating annual crop or pasture plants are controlled by grazing or tillage. Sensitivity of drainage estimates to weed control in the fallow is examined in Figure 6.

5. CONCLUSIONS

Climate is a primary driver of water balance and this simulation study illustrates how both rainfall total and rainfall distribution contribute to overall water balance components. Farming systems based on winter annuals with bare summer fallows are leaky, most strongly so as annual rainfall totals exceed 500mm. Concentration of annual rainfall in the winter period, when evapotranspiration rates are at their lowest, exacerbates the water excess problem

The drainage term in the water balance is sensitive to many factors. Soil properties, nutrient supply, residue management, tillage and weed management will modify the absolute drainage rates simulated in response to climate and farming system. This study demonstrated how two of these factors, namely soil type and weed management over the fallows influence water balance components.

While many factors determine the absolute magnitude of water balance components, the relativities between farming system options and climate remain valuable. This study highlights the effectiveness of systems that include either a component of perennial vegetation (eg. phase farming) or greater intensification of annual cropping to include summer and winter components (eg. opportunity cropping). These systems are both well established, with considerable experimental evaluation (e.g., Ridley et al., [2001] and practical application. On the other hand, companion cropping is still largely at the conceptual stage but this study suggests it could be very effective in raising water use and restricting deep drainage. Issues such as nutrient and disease management in companion cropping systems would need to be investigated.

The shifts in water balance modelled in this study bring with them changes in production and economic returns. The economics of perennial forages in mixed cropping/grazing enterprises will have a large bearing on overall profitability of farming systems that are effective in restricting deep drainage. We have found a drainage-profit matrix a simple and effective means of communicating these tradeoffs with both farmers and policy makers.

Extrapolation of point based models to landscape or drainage basin scale is fraught with difficulties. While map based representations are possible [Asseng et al., 2001], we have chosen the more limited transect approach to avoid conveying a spatially explicit representation that exceeds our confidence in the underlying data.

6. ACKNOWLEDGEMENTS

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