Application of APSIM 'multi-paddock' to estimate whole-of-farm water-use efficiency, system water balance and crop production for a rice-based operation in the Coleambally Irrigation District, NSW

Donald Gaydon[1], Shaun Lisson[2], and Emmanuel Xevi[3]

[1] CSIRO Sustainable Ecosystems, 306 Carmody Rd, St Lucia Q 4067, Email don.gaydon@csiro.au
[2] CSIRO Sustainable Ecosystems, University of Tasmania, Hobart Tas 7001, Email shaun.lisson@csiro.au
[3] CSIRO Land & Water, Private Bag No.3, Griffith NSW 2680, Email emmanuel.xevi@csiro.au

Abstract

Apart from being amongst the world's most efficient rice producers, with average yields exceeding 9 tonnes/ha, rice-based operations in Australia's Riverina region are also unusual in that rice is grown in rotation with other crops, including wheat, soybeans and maize. Because these businesses rely almost completely on irrigation, the current extended drought and recent legislative requirements relating to minimum environmental river flows have resulted in an increased focus on improving water-use efficiency. A whole-of-farm systems model is a valuable tool for exploring the impact of potential farm management responses to increased variability in irrigation water supplies. Irrigation water is a whole-of-farm resource and simulation of its utilisation must necessarily be performed in a multi-paddock modelling environment. Using the APSIM farming systems model with new multi-paddock feature and WaterSupply module, this paper presents the benchmarking of a case-study farm in the Coleambally Irrigation District, NSW, with emphasis on whole-of-farm water-use efficiency, production and deep drainage. The case-study farm consisted of seventeen (17) paddocks under several different cropping rotations, all sharing available water resources. A comparison of simulated outputs with farmer records and district averages is made.

Key Words

Rice, water-use efficiency, irrigation, APSIM

Introduction

There are around 2,000 family operated farm businesses growing rice in the Murrumbidgee valleys of NSW and the Murray valleys of NSW and Victoria. The average size of an Australian rice farm is around 400 hectares. Such crops as wheat, barley, soybean, maize, mungbean, as well as various pastures, are grown in rotation with rice. From the perspectives of both gross margin and water-use efficiency (Table 1), the farmer seeks to maximise their planted rice area. Strict industry-regulated standards govern the area of rice which may be grown on any farm, limiting annual rice area to one third of the farm's *rice-suitable* soils or 300 ha – whichever is greater. This is for the purposes of limiting regional drainage that leads to rising watertables. (further info: RiceGrowers Association of Australia http://www.rga.org.au)

Table 1. Murrumbidgee Valley average figures for 2005/2006 (source :NSW Department of Primary Industries "Farm Enterprise Budget Series" http://www.agric.nsw.gov.au/reader/budget **)**

Crop	Gross Margin ($/ha)	Water Use Efficiency ($/ML)
Aerial-sown long-grain rice	1500	115
Irrigated Soybeans	636	79

Irrigated Wheat	263	75

Modelling Framework

Because a farm's irrigation water supplies are generally shared between two or more paddocks, modelling of on-farm water-resources requires the combination of a multi-paddock simulation environment and a dynamic water supply model. Such capacity is provided by the APSIM modelling framework. For more information, refer to **http://www.apsim.info**. Figure 1 schematically illustrates this framework. APSIM multi-paddock provides a *multi single-point* simulation capability, in which individual points (representing paddocks) can share farm resources (such as water, livestock etc). This is clearly differentiated from a 2 or 3-dimensional landscape model, where water and solutes may move between points in either overland or sub-surface lateral flows. In APSIM, the points do not interact other than to share the same climate, time clock, and irrigation water (if appropriate). Each simulation point possesses a *crop area(ha)*, allowing calculation of irrigation volumes drawn from shared water resources, but otherwise possesses the characteristics of a typical APSIM simulation – allowing simulation of crop sequences, intercropping, complex soil and crop management,

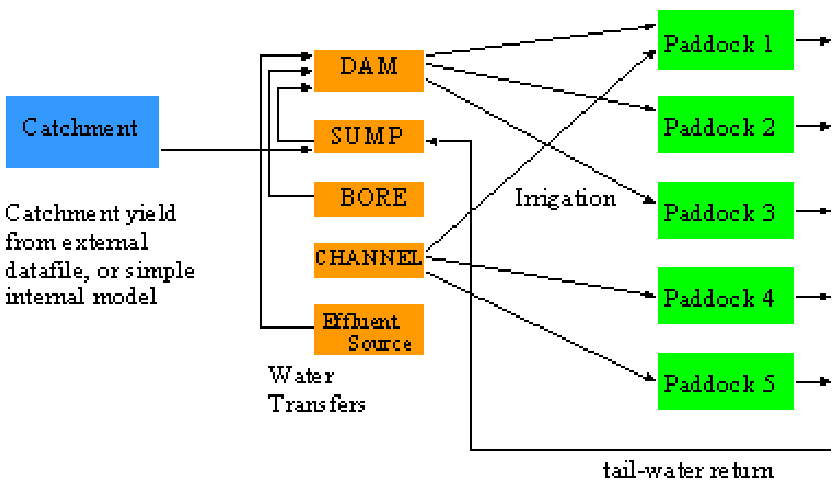


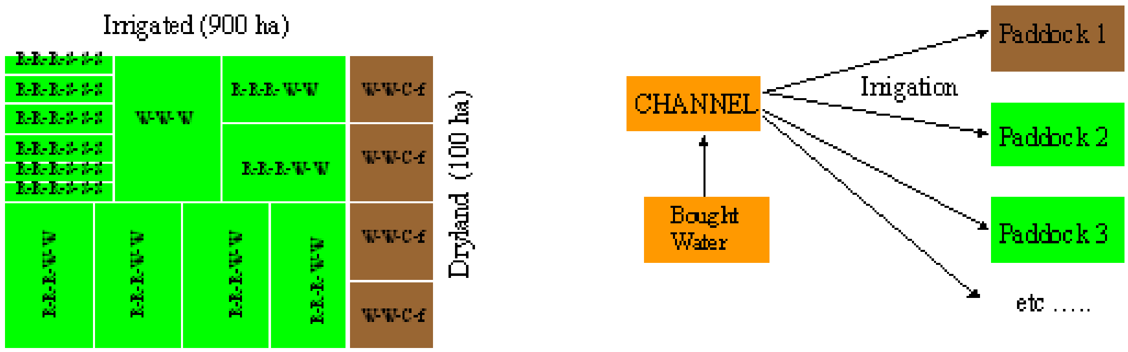
Figure 1. APSIM multi-paddock modelling framework. Some potential elements shown; configuration can vary depending on user requirements.

dynamic balances of soil nitrogen, phosphorus, water, crop residues etc. (Keating *et al* 2003). The APSIM WaterSupply module (Gaydon & Lisson 2005) is an instantiable module, capable of performing the role of multiple water-sources for the APSIM Irrigate module. The rice model *Oryza* (Boumann *et al* (2006)) was incorporated into APSIM as part of a joint collaboration with the developers at Wageningen University, Holland. APSIM-Oryza has been successfully used in simulation of rice-based operations in Korea (Zhang *et al* (2006)), and its initial use in a temperate Australian environment in rotation with other crops is detailed in Gaydon *et al* (2006), including parameterisation of Australian cultivars.

This paper presents the benchmarking of a case-study farm in the Coleambally Irrigation District, and represents the first application of APSIM multi-paddock in conjunction with the Water Supply module. The validated model was subsequently used as part of a modelling study investigating the use of irrigation allocation forecasts in farm management (Gaydon *et al* 2006).

Methods

Simulations using APSIM v4.1 were performed for the case-study farm over a twenty year period (1957-1976) assuming that full licensed allocation was available each year, and further water was available for purchase on the open market without limit, if required. Through several rounds of discussions with the farmer, the layout shown in figure 2 was configured. Detailed information on water-infrastructure, agronomic management, soils and irrigation licence details were obtained and incorporated into APSIM. Output files were produced for each paddock, before being combined externally to provide total annual production, gross margin, irrigation water use, and other water-balance terms for the whole farm. Figures were then compared with district historical figures and the farmers own records to validate model setup.

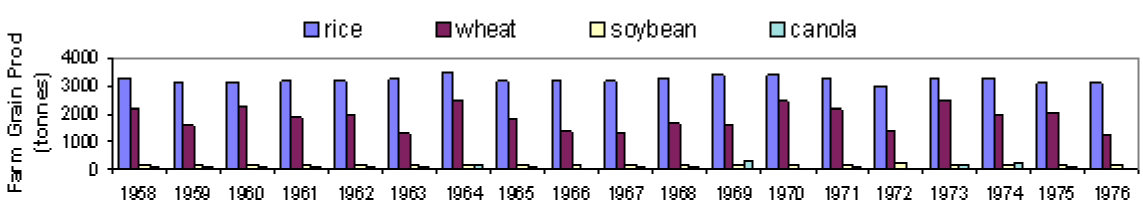


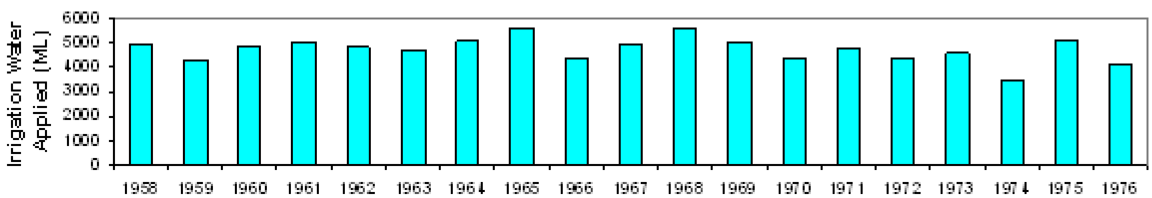
(a) **(b)**

Figure 2. Schematic layout for case-study farm. (a) plan (not to scale) showing paddock rotations. R – rice, W – wheat, S – soybean, C – canola, f – fallow. (b) simplified simulation setup – 13 irrigated paddocks, 4 dryland paddocks, 2 irrigation water sources.

Results

Using a spreadsheet, output files for each paddock were then combined to provide average annual production, irrigation water use, and other water-balance terms for the whole farm (see figures 3 & 4).





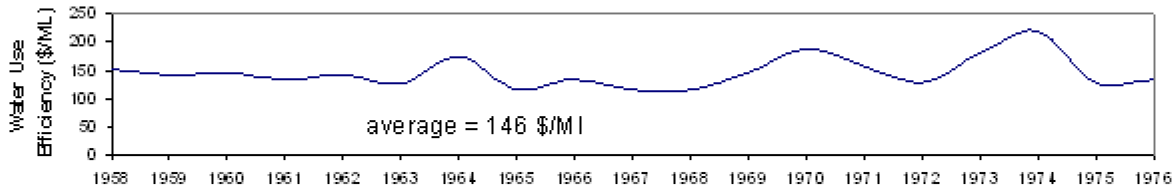


Figure 3. Scaling-up paddocks to whole-of-farm figures for benchmark runs. (top) Total farm grain production (tonnes) , (middle) Irrigation water applied (Ml), and (bottom) Water-Use Efficiency for the whole farm ($/ML)

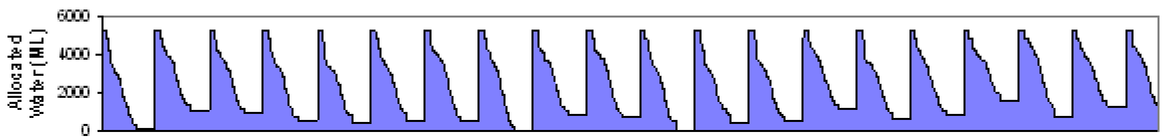


Figure 4. Whole-of-farm usage of allocation water for benchmark simulations (1957-1976) (X-axis as for figure 3). The second supplementary water source 'bought water' was required only in 1965 and 1968.

Tables 2 and 3 compare benchmark simulation outputs for average grain yields and irrigation water-use with the farmer's estimates and local averages.

Table 2. Grain Yield comparison for benchmark simulations

Crop	*Simulated (t/ha)*			*Farmer's Estimates (t/ha)*	*District Averages (t/ha)*
	Max.	*Min.*	*Ave.*		
Rice	11.65	10.0	10.7	10+	9[1]
Soybean	3.39	2.4	2.86	2.5 - 3	3[1], 2.6[3]
Irrigated Wheat	6.03	2.4	4.8	5	5.5[1]
Dryland Wheat	4.5	1.0	2.7	3	1.8[1]
Dryland Canola	2.8	0.65	1.73	2.5 - 3	1.8 – 2.0[1]

Simulated average in-crop drainage, Et, and Ep figures (in mm) were 253, 930,573 for rice; 164, 357, 198 for wheat; and 177, 557, and 376 for soybeans respectively.

Table 3. Irrigation water-use comparison for benchmark simulations

Crop	*Simulated (Ml/ha)*			*Farmer's Estimates (Ml/ha)*	*District Averages (Ml/ha)*
	Max.	*Min.*	*Ave.*		
Rice	14.6	8.8	11.4	12	13[1], 14[2]
Irrigated Soybean	7.5	4.5	6.7	7	8 [1,2]
Irrigated Wheat	4.5	1.5	3.3	1.5 – 4.5	2.5[2], 3.5[1]

[1] NSW DPI "Farm Enterprise Budget Series" 2005/2006" http://www.agric.nsw.gov.au/reader/budget)
[2] Khan et al (2004)
[3] WfHC "Off- and On-farm Savings of Irrigation Water" report (2005) http://www.csiro.au\healthycountry/

Discussion

Benchmark simulation outputs showed acceptably good correlations with the farmer's own estimates for crop yields and water-usage figures. Water-use efficiency figures simulated were higher than local averages for rice. However the case-study farm routinely records higher than district average water-use efficiency figures (10 tonne/ha production from 12 Ml/ha, compared with district averages of 9 tonne/ha from 14 Ml/ha). Cai et al (1994) reported details of simulated drainage under three successive ponded summers on a similar soil to the case-study farm, using the Hydrus model. Simulated in-crop drainage in the first summer was 254mm, increasing to 296mm in each of the following two summers. Lehane (1983) estimated that 25% water applied to rice crops bypasses the crop root zone. For an average of 12 Ml/ha, this would translate to a drainage of 300mm. Given the fact that rice water-use efficiency has probably improved since the time of Lehane's work, due largely to varietal improvement, the APSIM figure of 253mm for average rice drainage is considered to be "ballpark". Simpson et al (1992) found that, on average, 40% of total rice Et is due to evaporation from the paddy water surface, and the remaining 60% from the rice plants themselves. Early in the season all of the evaporative loss was from the water surface. In mid-December two thirds was via the plants, increasing to 90% in mid-January. The simulated APSIM average figures for the case-study farm were 930mm total rice Et, and 573mm for Ep (rice transpiration), giving a percentage of 61% of total Et from the plants. This is in close agreement with the field measurements of Simpson (1992).

Comparison of simulated figures with published data on measured rice evapotranspiration indicates that APSIM Oryza may be underestimating rice Et. Humphreys et al (2003), referring to a consultancy report by the author in 1997, reported 1200mm rice Et for Wakool and Denimein Irrigation Districts of southern NSW, whilst Bethune et al. (2001) reported 1250mm rice Et in Shepparton. The simulated average Et using APSIM was 930mm. Humphreys and Meyer (1996), however, showed that variation between seasons in total ETo, rainfall and net evaporation is very large. Over the 32 years from 1962/63 to 1993/94 ETo at Griffith ranged from 920 to 1360 mm (mean 1160 mm). Given this large variability, the simulated figure for 1957-76 may be within the acceptable range, however further investigation is warranted.

Conclusions

APSIM proved an effective and flexible platform for simulation of shared, on-farm water resources in conjunction with multiple, independent paddocks. The benchmarked setup described in this paper provides a platform for subsequent investigation into the impact of potential agronomic and management changes on water resources, or conversely, the effect of changes in water resources on farm production, WUE, and drainage. This work also presents the first use of APSIM-Oryza in rotations involving other crops. Whereas good correlations were obtained between simulated and historical figures, some modelling issues in relation to rice require further investigation.

References

Bethune, M., Austin, N., Maher, S. (2001), *Irrigation Science,* Vol 20, pp 99-105.

Bouman, B.A.M. and van Laar, H.H. (2006) “Description and evaluation of the rice growth model ORYZA2000 under nitrogen-limited conditions”, *Agricultural Systems*, 2006, Vol 87, pp 249–273.

Cai, L., Prathapar, S. A., and Beecher, H.G., (1994), “Modelling leaching and recharge in a bare transitional red-brown earth ponded with low salinity water in summer”, *Australian Journal of Experimental Agriculture*, 1994, Vol 34.

Gaydon DS & Lisson SN (2005) *APSIM WaterSupply,* chapter in “Inventory of Australian Software tools for Best Use of Water On-Farm” – Final Report for Project 3.08, CRC for Irrigation Futures, G Inman-Bamber, S Attard - eds.

Gaydon DS, Lisson SN, Xevi E, and Dassanayake D. (2006) “Value Assessment of Irrigation Allocation Forecasts for a Rice-based Operation in the Coleambally Irrigation District – in terms of water-use efficiency, production, and drainage” – Final Report, CSIRO Water for a Healthy Country Flagship, Project No. T4.S2.P1 Murray Region Irrigation.

Humphreys, E. & Meyer, W.S. (1996), *Farmers’ Newsletter*, Large area no.148, 1996, pp.39-41.

Humphreys, E., Edraki, M., Bethune, M. (2003) *CSIRO Land and Water Technical Report* 14/03, April 2003.

Keating, BA. et al (2003) “An Overview of APSIM, a model designed for farming systems simulation”, *European Journal of Agronomy*, Jan 2003 Vol 18, pp 267-288

Khan, S., Robinson, D., Beddek, R., Wang, B., Dassanake, D., Rana, T. (2004) , *CSIRO Land & Water Technical Report* No. 5/04, January 2004.

Lehane, L (1983) “Rice ponding and rising water tables”, *Rural Research* 117, 9-11.

Simpson, H.J., Herczeg, A.L. and Meyer, W.S. (1992) *Geophysical Research Letters* 19, 1992, pp 377-380.

Zhang, X., Jae-Hong Lee, Abawi, Y., Young-ho Kim, Hee-Dong Kim (2006) “Testing the simulation capability of APSIM-ORYZA under different levels of nitrogen fertiliser and transplanting time regimes in Korea”, *Australian Journal of Experimental Agriculture*, submitted, in review.