Tools to manage climate risk in cropping (Australia)

Howard Cox, Peter de Voil, Daniel Rodriguez

Department of Primary Industries and Fisheries, Toowoomba Queensland, Australia - howard.cox@dpi.qld.gov.au

Abstract: *Because of the variable and changing environment, advisors and farmers are seeking systems that provide risk management support at a number of time scales. The Agricultural Production Systems Research Unit, Toowoomba, Australia has developed a suite of tools to assist advisors and farmers to better manage risk in cropping. These tools range from simple rainfall analysis tools (Rainman, HowWet, HowOften) through crop simulation tools (WhopperCropper and YieldProphet) to the most complex, APSFarm, a whole-farm analysis tool. Most are derivatives of the APSIM crop model. These tools encompass a range of complexity and potential benefit to both the farming community and for government policy. This paper describes, the development and usage of two specific products; WhopperCropper and APSFarm. WhopperCropper facilitates simulation-aided discussion of growers' exposure to risk when comparing alternative crop input options. The user can readily generate 'what-if'scenarios that separate the major influences whilst holding other factors constant. Interactions of the major inputs can also be tested. A manager can examine the effects of input levels (and Southern Oscillation Index phase) to broadly determine input levels that match their attitude to risk. APSFarm has been used to demonstrate that management changes can have different effects in short and long time periods. It can be used to test local advisors and farmers' knowledge and experience of their desired rotation system. This study has shown that crop type has a larger influence than more conservative minimum soil water triggers in the long term. However, in short term dry periods, minimum soil water triggers and maximum area of the various crops can give significant financial gains.*

Keywords: *APSIM, risk management, WhopperCropper, APSFarm*

Introduction

The Agricultural Production Systems Research Unit (APSRU) is committed to providing 'decision' and 'discussion' support tools that actually result in improved farmer decision making and outcomes (Nelson *et al.* 2002). Experience has shown that 'decision support' packages have generally had a low uptake and impact when marketed directly to farmers (Hayman and Easdown 2002, McCown *et al.* 2002) hence tools for 'discussion support'. For this reason, the 'discussion support' products are marketed to farm advisors and private consultants to better utilise the combined knowledge of the farmers *with* their advisors as well as giving the advisors a competitive advantage in their market (Nelson *et al.* 2002). It is *not* expected that the products will make decisions for farmers rather they will complement the farmers and advisors experience and promote learning.

Farmers in all regions of Australia endure widely varying rainfall conditions whilst needing to make critical management decisions prior to every cropping season. Each input option comes with a possible range of outcomes and potential interactions with other inputs. There are significant opportunities for improved risk management involving these options. Over the past 15 years, APSRU has developed a suite of tools to assist advisors and farmers to better manage risk in cropping , two of which are discussed in detail here. WhopperCropper is an easy-to-use tool that has surprising value as an educational tool. APSFarm is a research tool that encompasses whole farm systems. These tools both use APSIM simulations as their basis.

The APSIM crop modelling system

The backbone of APSRU's modelling capability is the APSIM model (Keating *et al.* 2003). APSIM is a framework that provides plant, soil and management modules (Figure 1). These modules simulate biological and physical processes, allow specification of management rules for the scenario being simulated. Other modules facilitate data input and output. A simulation 'engine' drives the simulation process and facilitates communication between the independent modules.

At paddock level, analyses of crop monocultures or rotations are readily constructed. APSIM has been used in a broad range of applications including: support for on-farm decision making (Carberry *et al.* 2000), farming systems design for production or resource management (Meinke and Hammer 1995), assessment of the value of seasonal climate forecasting Rodriguez *et al.* 2007), analysis of supply chain issues in agribusiness, development of waste management guidelines (Snow *et al.* 1999), risk assessment for policy making (Nelson *et al.* 2007) and as a guide for research and educational activities (Nelson et al 2002). Gross margin analysis has been conducted post-simulation.

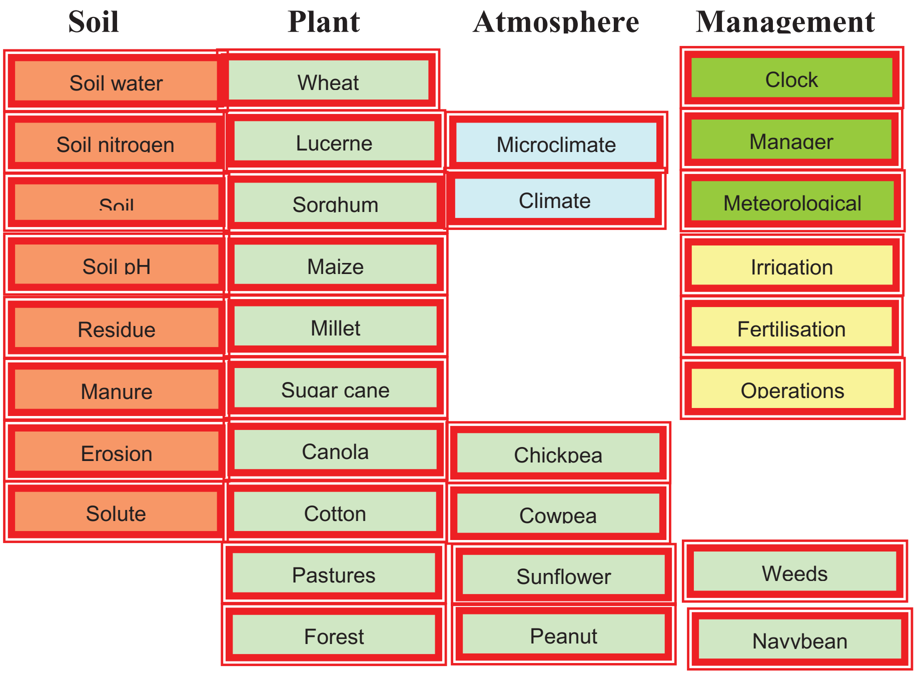

Figure 1. Components of the APSIM crop modelling system

WhopperCropper

WhopperCropper is a database of a factorial combination of runs using the APSIM model (Agricultural Production Simulator). It was developed to assist advisors analyse the production variability and risk from alternative input levels, and the SOI phase system. It operates at the paddock level and has yield, physiological and gross margin outputs. The package was developed with direct input from advisors. Software development occurred as advisors used and tested the product. WhopperCropper facilitates simulation-aided discussion of growers' exposure to risk when comparing different management options (Cox *et al.* 2003, Nelson *et al.* 2002). Different levels of inputs can be compared using the factorial of simulations run over a 100-year climate record. The scenario options are tick-selected from menus and no other data entry is required. Data from meteorological stations represent farming areas of a 50 to 100 km radius. The user can 'build-up' 'what-if' scenarios that separate then integrate the major influences whilst holding other factors constant. A manager can examine the interaction of input levels and Southern Oscillation Index (SOI) phases and match this to their attitude to risk[1]. Yields for every factorial combination of the inputs listed below (Figure 2) are generated for

[1] The southern oscillation is a major air pressure shift between the Asian and east Pacific regions whose best-known extremes are El Niño events. The southern oscillation (strength and direction) is measured by a simple index, the SOI (Nicholls and Wong 1990).

each year of the available weather data (more than 100 years). The full range of input parameters are:

• Crop type	common summer and winter crops
• Soil water-holding capacity	up to five levels
• Soil water at planting	1/3, 2/3 and full
• Planting date	up to five dates
• Maturity length	three categories
• Plant population	typically three levels
• Row configuration	wide rows in sorghum and cotton
• Effect of soil nitrogen content	typically three levels
• Nitrogen fertiliser rate (planting and in-crop)	typically six nitrogen rates
• SOI phase system	

Grains yields (and many other outputs) are generated for each of approximately 100 years of weather data for a site.

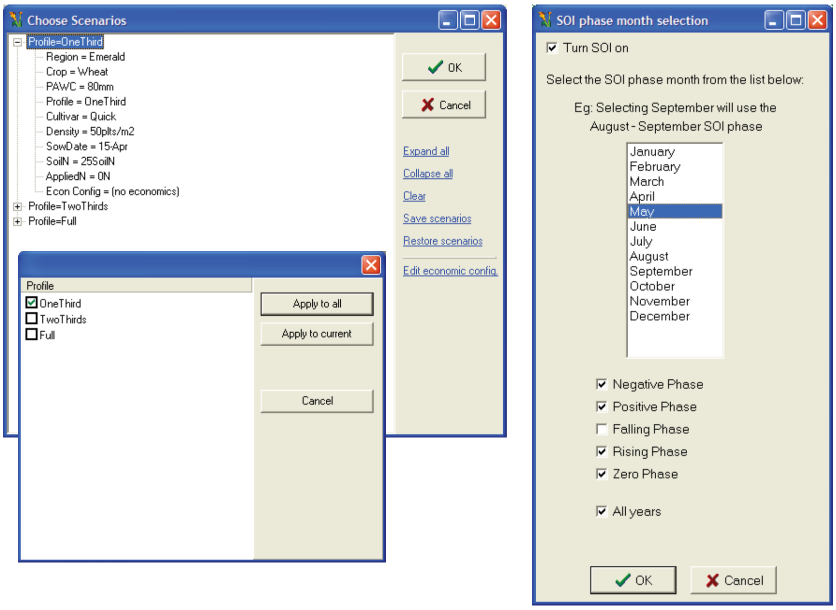

Figure 2. Selection screens from the WhopperCropper program.

There are more than 50 outputs options from which to chose including: grain yield, grain protein, gross margins, water use efficiency, biomass yield, leaf area index, rainfall quantity to flowering and harvest, temperatures ranges during critical growth stages, time to critical growth stages, soil water and nitrate at harvest and harvest date.

Examples of use of WhopperCropper

Figure 3 demonstrates the yield variability and median for the stated single scenario over approximately 100 years. These annual yields are also used to create the probability distributions of the other graph types. Different inputs levels can be compared with this, and any graph type but other graph types give clearer distinction (e.g. Figure 4).

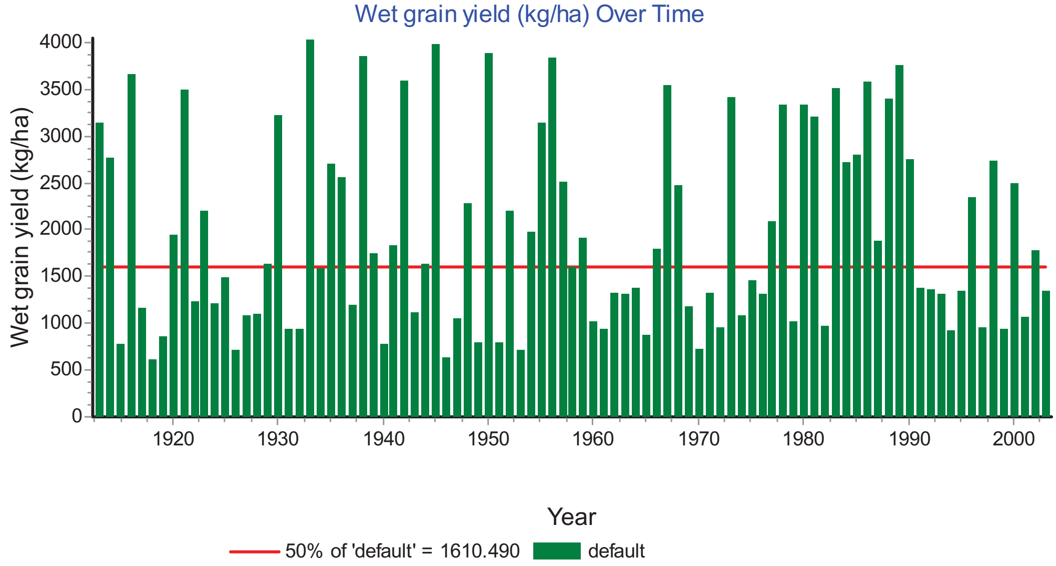

Figure 3. Wheat grain yields for the period 1915 to 2004 at Emerald, each with monoculture cropping with two-thirds of a full profile stored soil water. Other setup factors were: wheat crop, medium maturity length, 100 pl/m2 density, 25kgN/ha soil nitrate, 150 mm soil water-holding capacity, 2/3 full at planting every year, Emerald, Queensland, Australia

Figure 4 demonstrates how variance and central tendency values differ for different treatments. The spread demonstrates risk whilst the median and mean indicate the overall value of the strategy. When expressed as a gross margin, the financial outcomes and risks are evident (Figure 4 c and d). If the advisor or farmer knows the starting conditions of the crop in question, they are able to see the variability and downside risk of the input strategy as influenced by the range of potential rainfall outcomes. In Figure 4a), extra soil water at planting increases the median yield and increases the frequency of higher yields. Thus it adds some 'insurance' of better yields although in any one year there is no guarantee that a yield will be better when there was greater soil water at planting.

Figure 4c) is expressed in terms of gross margin and shows a larger proportion of low gross margins if 75kgN/ha fertiliser is applied under low soil water at planting conditions. Whilst the median value is slightly greater, the user must decide if the potential for greater returns outweighs the possibility of lower returns in some years (i.e greater risk). Segregating the data on the basis of the SOI phase system (Figure 4d) shows that fertiliser application with low soil water contents at planting, together with a negative SOI phase, further increases the risk of low returns and an overall reduction in the median gross margin.

A project evaluation in 2007 reported instances when advisors were able to recommend NOT planting a crop under conditions of limited soil water. Whilst there is no guarantee that this was going to be the correct advice, the weight of probaility was that it would be correct. With subsequent low in-crop rainfall, NOT planting proved to be the correct strategy.

APSFarm

Whilst paddock-level simulations can provide help with tactical management decisions they do not provide insights on the optimal allocation of limiting resources across the farm business enterprise (Rodriguez *et al.* 2007). In contrast to single paddock simulations, whole farm simulation analyses allow for the study of complex trade offs in the management of the farm. Farmers operate under declining terms of trade, environmental pressures, limited rural labour, and in a constantly changing production environment i.e. markets, climate, policies. Questions that can be investigated include: what proportion of the farm should be dedicated to alternative crops or what proportion of the available irrigation water should be applied to which crop.

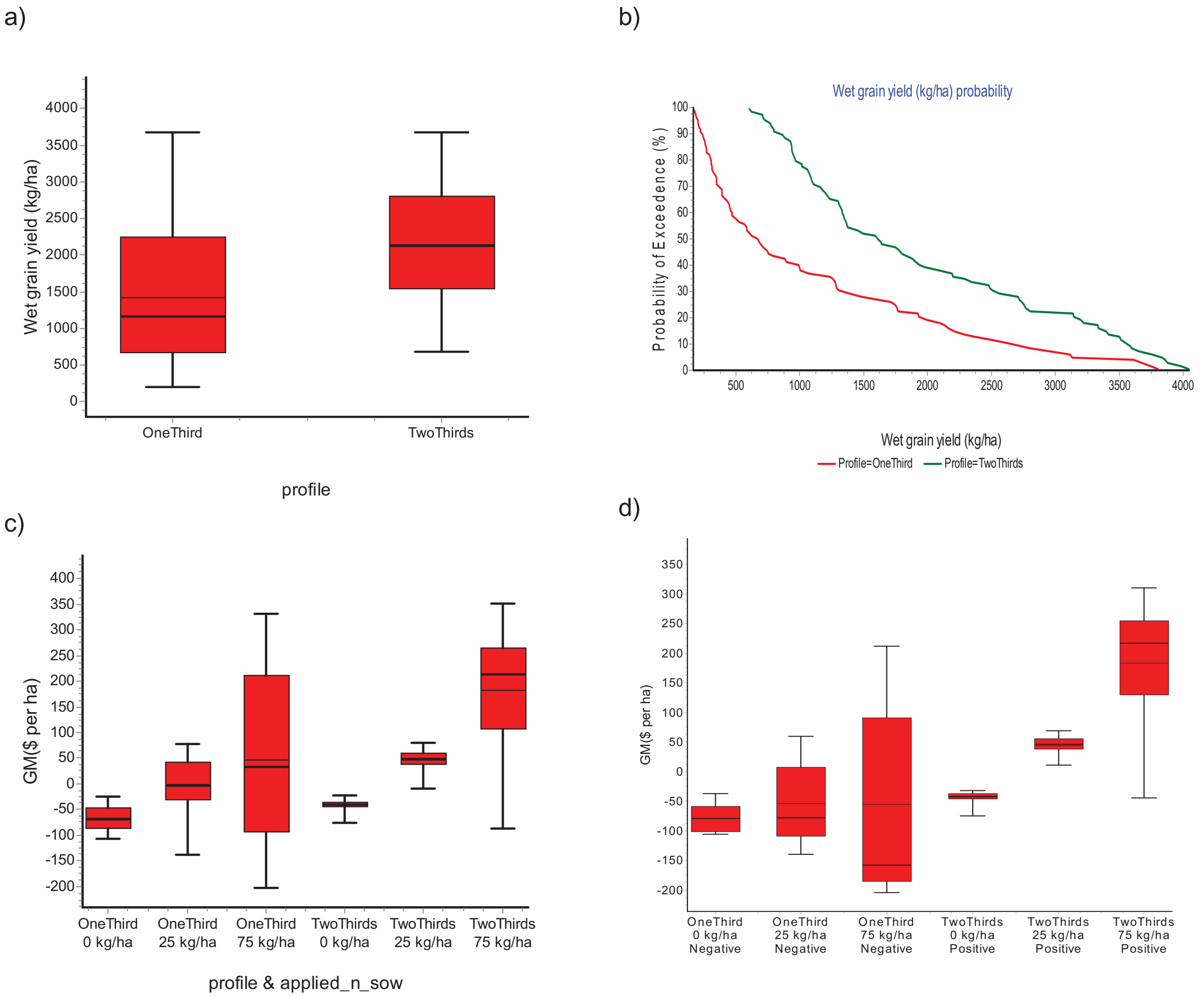

Figure 4. Building the complexity of risk analysis from: a) effect of soil water at planting on yield outcome, b) an alternative graph type of scenario a), c) effect of soil water at planting and fertiliser rate on gross margin and d) effect of soil water at planting and fertiliser rate under contrasting SOI phases Other setup factors were: wheat crop, medium maturity length, 100 pl/m2 density, 25kgN/ha soil nitrate, 150 mm soil water-holding capacity, 2/3 full at planting, weather data 1915 to 2005, Emerald, Queensland, Australia. The whiskers and edges of the 'box' represent 0, 25,75 and 100 percentiles. Within the box are the median (solid) and mean (dashed) lines.

Adaptation to any of these may include agronomic input changes or complex changes such as integrating pastures and livestock into cropping systems.

APSFarm is an extension of the 'graphical user interface' version of APSIM (v5.3). Collections of paddocks are included and 'rules' for management can be at 'paddock' level as well as 'farm' business level. This whole-farm analysis approach examines allocation of limited resources in change scenarios: for example, the availability of land, labour or water in the farm enterprise, or the impact of changing climate. Thus, APSFarm can quantify trade-offs of profit / environment / risk / social outcomes. It includes both the tactical management and strategic planning of the farm, which in our case studies to date include grain cropping, mixed grain/grazing and irrigated grain/cotton systems. Trade-offs are explored during the interview process with farmers - the management "alternatives" identified. Multi-objective evaluation coupled with evolutionary computation techniques has proved useful in case studies to date, for example confirming that the different strategies employed by farmers during wet and dry decades are close to 'optimal'.

Building APSFarm scenarios

APSFarm setup is described by a tree of paddocks and other top level components (e.g. p1) in the left section of the screen (Figure 5). The main difference between the paddocks will be the water-holding capacity of the soils and whole-farm rules. A separate economics menu allows the user to set up the prices and costs relevant to the crops and the whole farm.

The whole-farm modelling process involves interviews with consultants and farmers to elucidate farm decision 'rules'. The rotation structure is shown graphically in the top right hand corner (Figure 5). These rules are translated into crop or pasture 'states' and 'transitions' by the whole farm systems simulator. Clicking on the arrows displays the rules that apply to the particular *transition* written in the 'rules' area below it (bottom right hand screen of Figure 5). These rules tell the model whether a transition can be made between two states, and the actions that need to be undertaken to make that transition. For example, a transition from "wheat crop" to "fallow" can be made if the wheat crop is mature; and the action that is taken is to harvest the wheat crop.

Scenario analyses are generated for historical or developing environmental states (e.g. reduced rainfall) in order to develop improved solutions that can be optimised for particular environments or time periods. The results are discussed with participating farmers and/or consultants to facilitate learning.

The quantification of the whole-farm outcomes can assist researchers, consultants, policy makers and farmers to better manage complex crop and grazing systems in a changing environment. The longer term aim is to improve the viability and adaptation ability of such farms thereby making farms, and their communities, more resilient and less vulnerable to change.

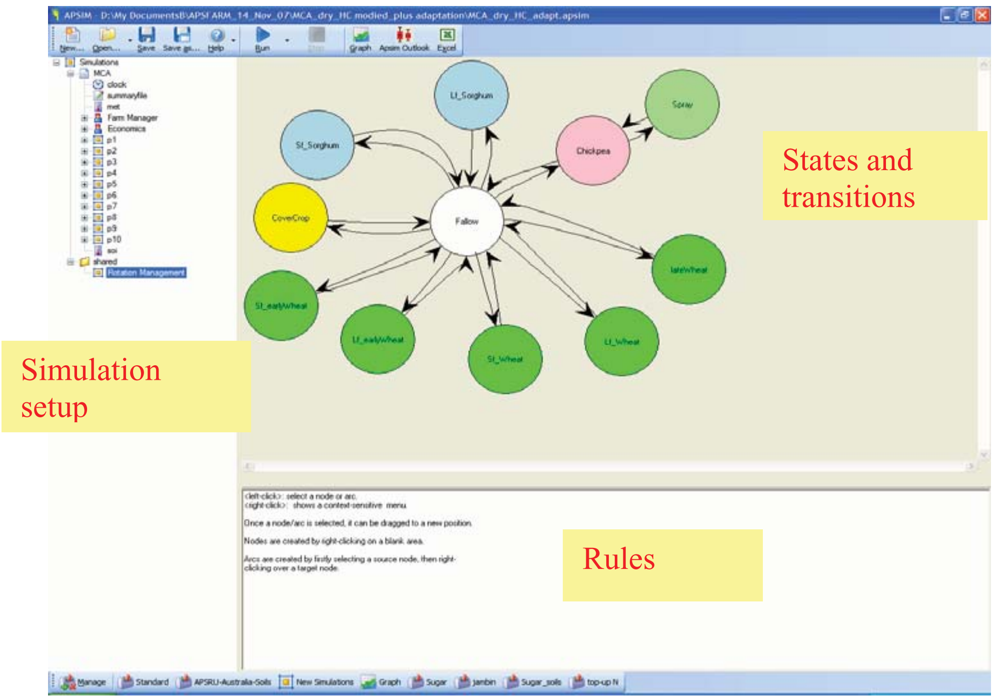

Figure 5. Graphical format of APSFARM input. The simulation setup refers to the physical and economic factors that affect the whole farm. States and transitions display the rules that apply to the rotation system.

Example of the use of APSFarm

In consultation with a field consultant, the following rotation was established as being representative to his district.

Systems question 1: how does cash return and cash flow vary between wet and dry (12 year) periods?

The rotation below is described as being the main option for the majority of years:

| - W | - - | S - | - W | - CP |

where W = wheat, S = sorghum and CP = chickpea and - = 5 to 6 month fallow. M = millet
Alternative rotations on weather conditions can be:

| - W | - - | S - | S - | - W |	slightly wetter conditions
| - W | - - | S - | S CP | - W |	very favourable conditions
| - W | - - | S - | M W | - W |	when very dry conditions for sorghum (S) millet creates extra cover

The 'generalised' APSFarm rotation diagram for this rotation is as shown in Figure 5.

Rules were applied to the minimum soil water at planting, occurrence of a rainfall event for planting, maximum area planted, planting date windows, days since previous harvest and availability of tractor/implement. Costs and prices are applied to inputs and operations in order to calculate gross margins. The economics refer to a 3000 ha farm with 10 paddocks typical of that farming district.

Figure 6 describes the annual gross margins for two 12–year periods; a wet period (1983 to 1994) and dry (1938 to 1949).

Outputs
Considerable variation occurred in both periods although the 'wet' period had several years of favourable returns. The cropping frequency in the 'wet' period was 81% with no crops having a modelled yield less than 1 t/ha compared to dry period in which the cropping frequency was 63% with four crops having less than 1 t/ha. Note that in the final two years of each 12-year period, the types of seasons had both reversed in nature significantly changing the gross margins.

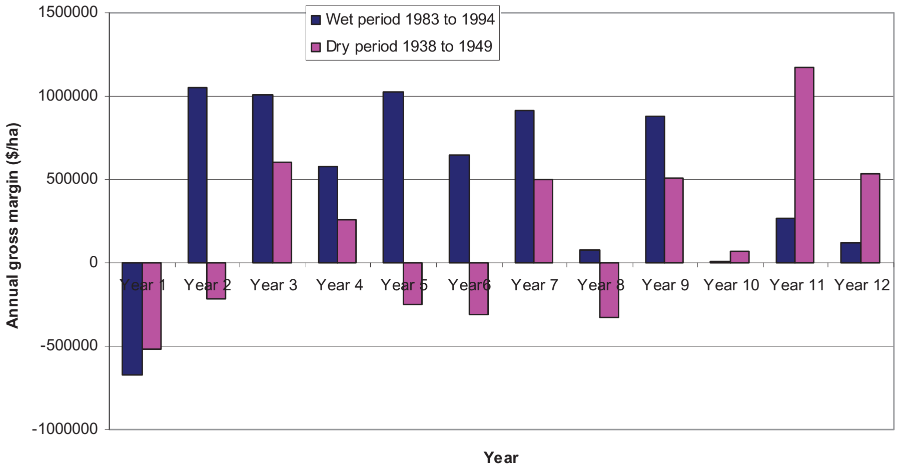

Figure 6. Annual gross margins for the time periods 1983 to 1994 (wet) and 1938 to 1949 (dry).

Figure 7 indicates the widely varying cumulative cash flow that could have occurred in contrasting 'wet' and 'dry' periods. The years 1938 to 1947 indicate drought periods that Australian farmers must sometimes endure. The intermediate period (1960 to 1971) had both dry and wet seasons in the sequence.

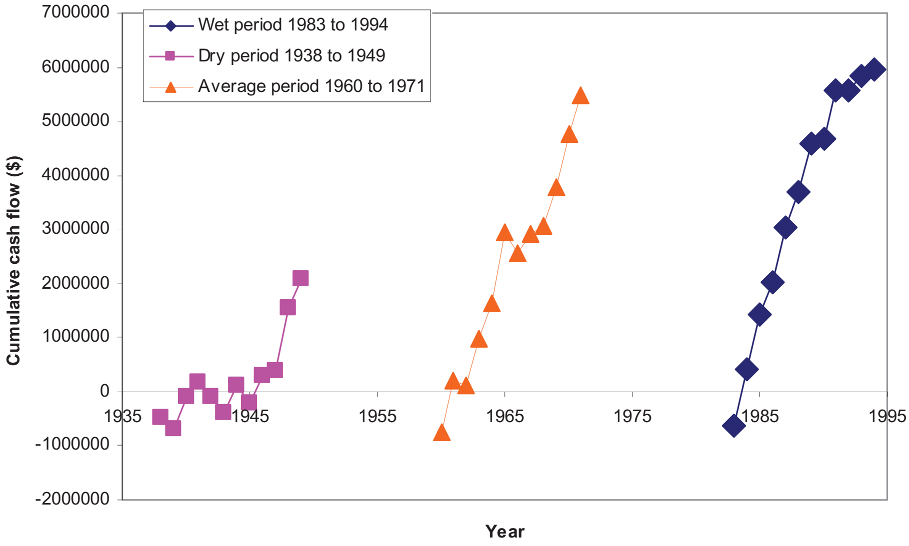

Figure 7. Cumulative cash flow for three contrasting time periods

Systems question 2: How can inputs be modified to improve the cash return in a dry period?

Small changes were made to the input rules reflecting a slightly more conservative approach regarding the amount of soil water (SSW) prior to planting a crop. These included:

- Increasing the minimum soil water for short fallow sorghum from 100 to 130 mm
- Increasing the minimum soil water for long fallow sorghum from 100 to 120 mm
- Increasing the minimum soil water for chickpea from 80 to 100 mm

An additional change was also tested:

- Reducing the maximum area of the short fallow wheat and sorghum crops from 80% of the farm to 20%
- Reducing the maximum area of the sorghum crop only from 80% of the farm to 20%

By implementing a small change in input 'rules', the annual surplus or deficit (Figure 8) was increased (or losses reduced) in most of the seasons during the 'dry' period.

When the SSW and area strategies were combined, the surplus/deficits were much more variable than the SSW strategy alone. In some years, especially the poorer years, there was considerable improvement in the surplus/deficits, whilst in other years there was a reduction.

The cumulative cash flow was increased from the fourth year of the period with a final cumulative cash position of $200 000 more with the modified SSW (to $2.4m) than the modified approach (Figure 9). This represents a 9.9% increase in cumulative cash flow. The same number of crops resulted but there was a change in the mix of crop types. There was one more long-fallow wheat crop, one more (high value) chickpea crop and two less short fallow sorghum crops. None of the remaining sorghum crops yielded less than 1 t/ha compared to one low yielding sorghum crop in the 'standard' setup.

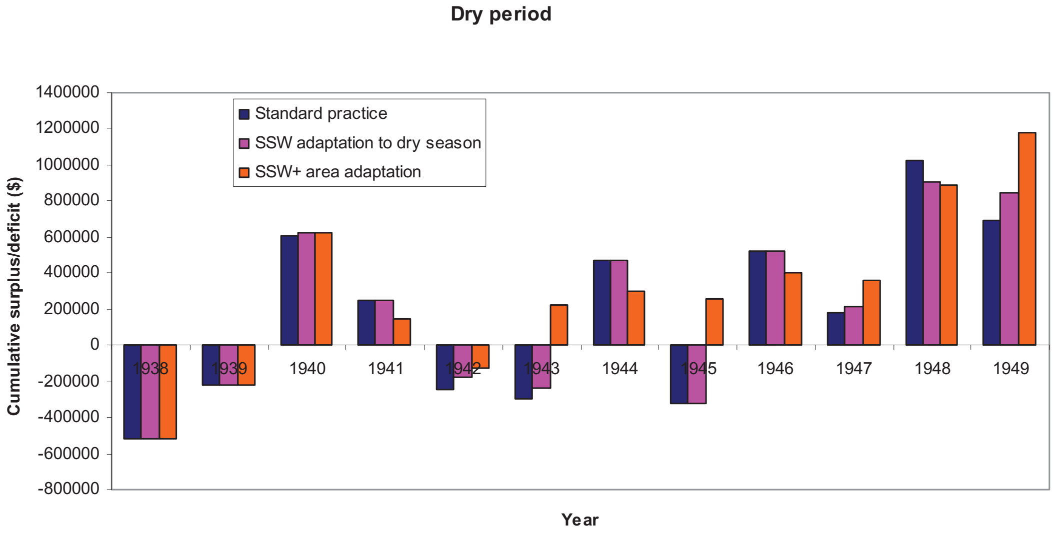

Figure 8. Annual surplus/deficit for the time periods 1938 to 1949 (dry period) with small changes in the rules reflecting the minimum soil water on which crops would be planted.

The cumulative cash position was considerably improved by combining the SSW change with the crop area change compared to the ‘standard’ rotation (Figure 9). This was a 62% increase to $3.4m. However, it can be seen that the area strategy has the major effect as indicated by the area-only change. The cumulative cash result was increased by 63% (to $3.6m) compared to the ‘standard’ practice.

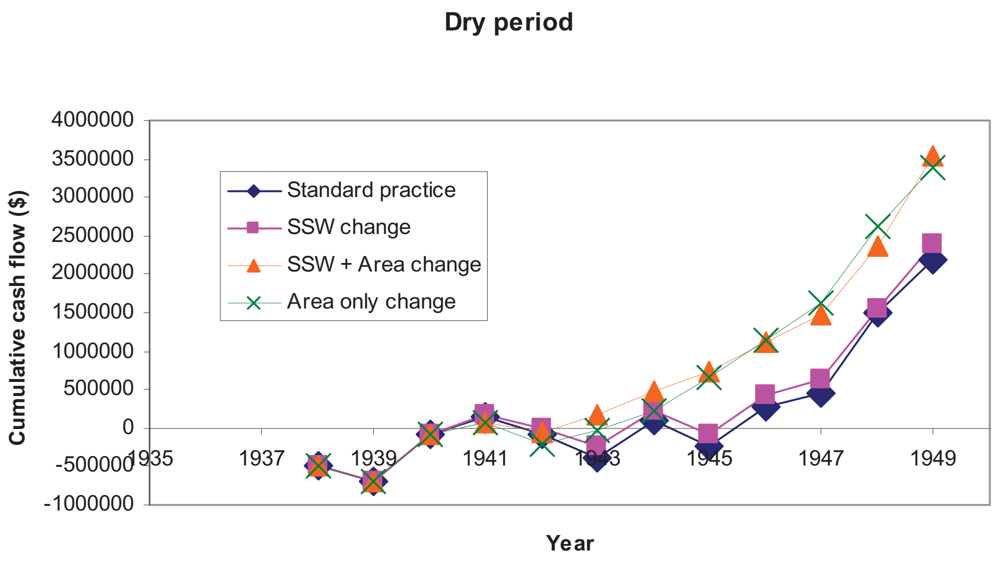

Figure 9. Cumulative cash flow for the dry period for the standard (un-adapted) strategy, an adaptation in the rules reflecting the minimum soil water (SSW) as well as a combination of SSW and the maximum area of crop that could be planted.

Systems question 3: If it is not possible to know if or when a dry decade will occur, the strategies need to be tested over a longer time period. Hence, what would be the effect of the more conservative strategies of SSW, maximum area and their combination, approach in the longer term (1957 to 2007) ?

Long-term simulations reveal very little difference in the cumulative cash flow between all of the rotations tested: minimum SSW, maximum area, and minimum SSW+maximum area strategies. The values were $26.2m $26.3m $26.2m respectively (data not shown). This was also similar to the standard strategy tested ($26.3m). This represents only a 0.2% difference between the strategies. This difference is much less than the 9.9% difference ($200 000) evident in the short-term 'dry' season between the 'standard' and 'conservative' setups. This suggests that annual variability will 'even-out' returns in the long-term.

However, it was shown that restricting the short fallow sorghum area but not the short fallow wheat area increased the cumulative gross cash flow to $31.6m; a 20% increase over the 'standard' strategy. This reflects the importance of a strategy that favours wheat cropping compared to sorghum cropping in this district. Crop choice is thus another factor that can be tested with APSFarm in consultation with local advisors.

Conclusion

Annual variability in rainfall and returns is the dominant factor operating in Australia. Hence, farmers in Australia must be able to survive large annual variations in income whilst taking a longer term view of the income-earning potential of their current enterprise mix. The products described here can meet those analysis needs. WhopperCropper can be used to demonstrate annual variability and to separate and integrate the effect of important crop input decisions. A manager can examine the effects of input levels and SOI phase and broadly match this to their attitude to risk. The product is currently commercially available. APSFarm can be used to test the effect of paddock and whole-farm variations in farming 'rules'. There is potential for financial gain from small management changes in contrasting wet and dry climate periods. However, management changes need to be tested in both short and long periods to get a balanced view. In this study, it has been shown that the 'standard' management strategy and minor practical variations to it, would be equally profitable in the long-term but quite different in contrasting seasons of shorter length. APSFarm can be used to examine whole-farm rotation effects that flow on from year to year over any time period. It is also anticipated that the value of APSFarm will be used to evaluate significant changes in management structure such as; major crop choice variations, converting areas of land from cropping to pasture or vice versa or long time-frame changes in climate. Such work is currently underway. It could also be used in policy decisions involving changes to land use. At this stage the product is in the research realm and not commercially available.

References

Ash, A., McIntosh, P., Cullen, B., Carberry, P., Stafford Smith M 2007.Constraints and opportunities in applying seasonal climate forecasts in agriculture, *Australian Journal of Agricultural Research*, 58 10, 952-965.

Carberry, P. S., Hammer, G. L., Meinke, H., and Bange, M., 2000. The potential value of seasonal climate forecasting in managing cropping sytems. Applications of seasonal climate forecasting in agricultural and natural ecosystems - the Australian experience. G.L. Hammer, N. Nicholls, and C. Mitchell (Eds). Kluwer Academic, The Netherlands (in press). Keywords: climate variability/cropping systems/APSIM application - climate impacts. *No. 777*

Cox, H.W., Chapman, V., J, and McLean, G B 2003 .WhopperCropper – supporting risk management discussion. In*: Proceedings First Australian Farming Systems Conference*, Toowoomba, Queensland September 2003

Hayman P,T., Easdown W,J. 2002. An ecology of a DSS: reflections on managing wheat crops in the northeastern Australian grains region with WHEATMAN. Agricultural systems, 74, 57–77.

Keating, B. A., Carberry, P. S., Hammer, G. L., Probert, M. E., Robertson, M. J., Holzworth, D., Huth, N I., Hargreaves., J. N. G., Meinke, H., Hochman, Z., McLean, G.M., Verburg, K., Snow, V., Dimes, J. P., Silburn, M., Wang, E., Brown, S., Bristow, K. L., Asseng, S., Chapman, S., McCown, R. L., Freebairn, D. M., Smith, C. J. 2003. An overview of APSIM, a model designed for farming systems, *European Journal of Agronomy*, 18**,** 267-288.

McCown, R.L. 2002. Changing systems for supporting farmer' decisions : problems, paradigms and prospects, *Agricultural Systems,* 74**,** 179-220.

Meinke, H. and Hammer, G. L.1995. A peanut simulation model. II. Assessing regional production potential. Agronomy Journal , 87: 1093-1099. land use studies. *No. 219*

Nelson, R.A., Holzworth, D.P., Hammer, G. L., Hayman, P.T. 2002. Infusing the use of seasonal climate forecasting into crop management practice in North East Australia using discussion support software, *Agricultural Systems,* 74**,** 393-414.

Nelson, R., Kokic, P.,Meinke, H. 2007. From rainfall to farm incomes - transforming policy advice for managing climate risk in Australia. Part II: Forecasting farm incomes, *Australian Journal Agricultural Research*, 58, 1004-1012.

Nicholls N., Wong K.1990. Dependence of rainfall variation on mean rainfall, latitude and the southern oscillation. *Journal of Climate,* 3, 163–170.

Rodriguez, D., de Voil, P., Cox, H.W. 2007. Helping practical wisdom: a niche for whole farm systems. In: Modelling farming systems design 2007,In proceedings : International symposium on methodologies on integrated analysis on Farm production systems, September 10-12, 2007 – Catania, Italy.

Snow, V. O., Smith, C. J., Polglase, P. J., Probert, M. E., 1999. Nitrogen dynamics in a eucalypt plantation irrigated with sewage effluent or bore water. *Aust. J. Soil Res.*, 37: 527-544.