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Opportunities for crop modelling in barley

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Abstract

Climate variability can reduce the profitability and sustainability of all cropping systems.

The Agricultural Production Systems Simulator (APSIM) and long-term historical climate data can be used to simulate consequences and risks associated with a range of crop and system management scenarios. APSIM has most crops available for analysis but currently does not have an operational barley module. APSIM integrates the crop modules with soil physical, soil water, soil nitrogen and meteorological modules. Whilst it was developed in northern Australia, APSIM modelling has also been successfully conducted in southern and western Australian environments. The seasonal climate forecasting system based on SOI phases has also been shown to be valid in southern Australia. An upgraded barley model could be constructed principally using data and code already in existence. Some field trials may be required to provide some parameters. An opportunity exists to define the key barley industry issues that are affected by climate variability. The modelling capabilities could then be developed.

A suitable decision support platform to facilitate risk management by agronomists and growers would be the Whopper Cropper program. This program consists of a database of pre-run APSIM simulations. Management inputs can be compared and the outputs displayed with an easy-to-use graphical interface.

Introduction

Crop models and long-term historical climate data can be used to simulate consequences and risks associated with a range of agricultural systems. Cropping system models, such as WHEATMAN (Woodruff *et al*. 1992) , maNage rice, (Angus *et al*. 1996), GrassGro (Alcock *et al*. 1998), PRISM (Faour *et al*. 1998), ShowDevel (Stapper *et al*. 1998) and various ASPIM applications, have been used. Currently, however, there is no operational barley module within APSIM. When combined with whole-farm economics, crop modelling can assist broader or longer-term decision making (Cox and Chudleigh 2000).

In 1991 the Agricultural Production Systems Research Unit (APSRU) began development of the cropping systems model, APSIM (Agricultural Production Systems Simulator). In the last 10 years APSIM has become the premier cropping systems model in the world and has seen a wide variety of applications to real-world problems in agriculture. APSIM integrates modules of crop production with soil, management and meteorological modules (Table 1). A notable omission to the comprehensive list of crop modules covered by APSIM is one for barley production. Whilst APSIM was developed in northern Australia, APSIM modelling has also been successfully conducted in southern and western Australian environments.

The APSIM modelling framework has many advantages over other crop models. One of the main benefits, is the ability to integrate components of fragmented research efforts. This enables research from one discipline to benefit some other discipline. It also facilitates comparison of models or sub-models on a common platform.

This functionality has been achieved via the "plug-in-pull-out" approach to APSIM design (Figure 1). APSIM allows the user to configure a model by choosing a set of soil and utility modules (McCown *et al* 1996). Any logical combination of modules can be specified by the user .

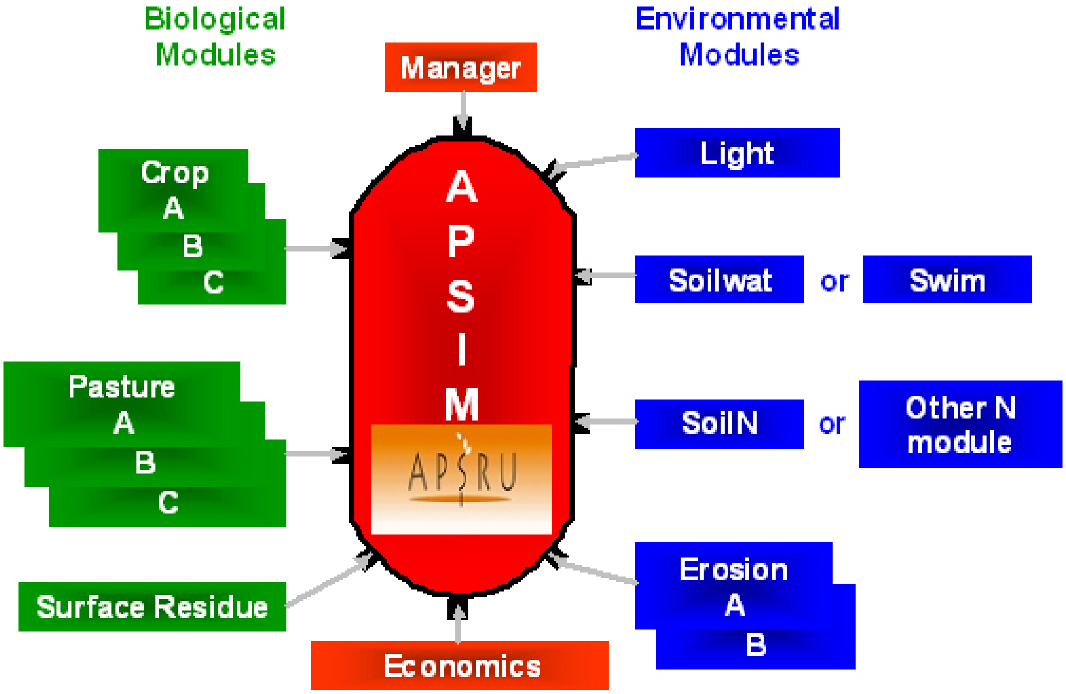

Figure 1**. Diagrammatic representation of the plug-in, pull-out functionality of the APSIM model**

Table 1. APSIM modules available

System modules	**Crop modules**
Soil water	Wheat
Soil nitrogen	Sorghum
Surface residue	Chickpea
Soil erosion	Mungbean
	Lucerne
Solute movement	Cotton
Soil phosphorus	Maize
Soil acidification	Sunflower
	Peanut
Pasture Modules	Cowpea
Temperate pasture (GRAZPLAN)	Pigeonpea
Tropical pasture (GRASP)	Sugar
	Soybean
Management modules	Cowpea
Irrigation	Canola
Fertilization	Forest
Manager	Millet
Operations	Navybean
Met	Weeds

Crop modules in APSIM simulate the effects of soil water, soil N and P supply, climate and management (fertiliser, irrigation, sowing date, crop density, cultivar) on crop growth, development, yield and quality (such as grain size and grain protein). They incorporate our latest understanding of how crops grow in response to their environment and the way they are managed, as well as key differences among the major cultivars. Grain protein and grain size are often difficult crop characteristics to simulate, but modules for wheat and sorghum currently available in APSIM perform a satisfactory job of simulating grain quality.

Communicating the results of APSIM using Whopper Cropper

Results from model output must be effectively communicated to interested end-users. Tactical decision making and risk management for single-crops can be supported using `Whopper Cropper'. Whopper Cropper is a database of over 400,000 pre-run APSIM simulations that can be queried to explore pre-planting decisions and help producers choose the best management options for the coming season. It provides crop management advisers with access to the outputs from APSIM and seasonal climate forecasting by predicting the production risk that growers face in the coming cropping season.

Whopper Cropper currently includes eight crop types and 21 regions from Clermont in central Queensland to Dubbo in New South Wales. Management inputs can be varied and the outcomes compared. The effect of the SOI and gross margin analyses are readily included. Outputs are presented with an easy-to-use graphical interface that produces a range of graph types. Users select a range of starting conditions such as soil PAWC, starting soil water, N fertiliser rates, crop type, crop maturity, plant population, row spacing. The program generates outputs such as yield, protein, flowering dates, number of wet days during grain fill, end of season soil water etc. Any of the outputs available in APSIM could be included in Whopper Cropper. As there is no barley module in APSIM, the crop is not currently included in Whopper Cropper.

Studies of production issues using APSIM

The APSIM model has be used in a large number of case studies involving long-term strategic sense and short-term tactical decision making. Some examples include;

- the production potential in `new' cropping areas (Carberry *et al.*1991),
- summer cropping rotations and fallow length (Carberry *et al.*2000)
- risks of opportunity cropping (Hayman *et al.* 1996)
- for grazing enterprises in north Queensland (Ash *et al.* 2000)
- the effect of climate and harvest conditions on peanut production (Meinke and Hammer 1995)
- illustrating the effects of SOI in 1997/98 season in Australia and farmer case studies on the benefits of varying management (Meinke and Hochman 2000)
- the cost of delay in harvesting wheat (Whan and Hammer 1985)

We now describe three examples of the application of APSIM to crop decision-making. The aim is to demonstrate by analogy how APSIM could be used for similar issues in the barley industry.

Case Study 1. Aflatoxin infection in Peanuts

The profitability of barley crop production is heavily influenced by crop quality (grain protein, grain size, grain colour), which is strongly influenced by weather and crop management. Better crop management could result from the ability to model the influences of weather and management on crop quality.

In peanut production, infection of kernels by the fungus *Aspergillus flavus* under conditions of high soil temperature and low soil water causes production of aflatoxin, a carcinogen. Aflatoxin contamination is a major food quality problem and costs the Australian peanut industry between $5-10M p.a. The processing sector allocates considerable resources to ensure aflatoxin levels in products are well below the maximum permissible level of 15 parts per billion. Payment penalties for growers range from $150 to $450/t. For an average penalty value of $300/ tonne and average dryland pod yield of 2.5 t/ha, the resultant loss could equal $375/ha.

Aflatoxin is a more severe problem in end-of-season drought years, but has averaged around 50% of the dryland crop over the past 10 years. ?he ability to model the effects of climate, soil type, cultivar and crop management on aflatoxin levels can provide guidance for crop management strategies to minimise infection levels. For example, some of the issues relevant to the risks of aflatoxin infection are: What are the risks of incurring a low, medium or high level of aflatoxin infection?, Does the SOI help in forewarning the likelihood of a problem season ahead?, Can quicker-maturing cultivar lessen the incidence of aflatoxin infection?

In order to address some of these issues, a pilot aflatoxin calculator for the peanut crop module in APSIM has been developed. This calculator is showing considerable promise in successfully predicting aflatoxin risk using inputs of soil water characteristics, rainfall, ambient and soil temperatures near harvest. Other pre-season decisions (e.g. variety choice, skip row, SOI phase) and within season decisions (e.g. cutting time) can be analysed. As an example of the application of modelling to management of the risk of aflatoxin in dryland conditions at Kingaroy, we simulated the long term risks of aflatoxin infection levels for cultivar Streeton sown on the 1st November each year on a medium depth red soil at Kingaroy (Figure 2).

Model output indicates that 40% of years would be of a very low risk category and the remaining 60% of years fall into six other classes from low to very high risk. This suggests that in the long term, aflatoxin (for this scenario) will not be a problem in about 40% of seasons, but will have to be managed in the other 60% of seasons. The simulations also indicated a weak relationship between aflatoxin risk and yield across seasons (data not shown). This means that high yielding and low yielding seasons are just as likely to coincide with seasons of high or low risk of aflatoxin infection.

It is notable that the incidence of the problem has been higher in the last 10 years compared to the years from 1960 onwards, due to the combination of climatic factors conducive to infection levels.

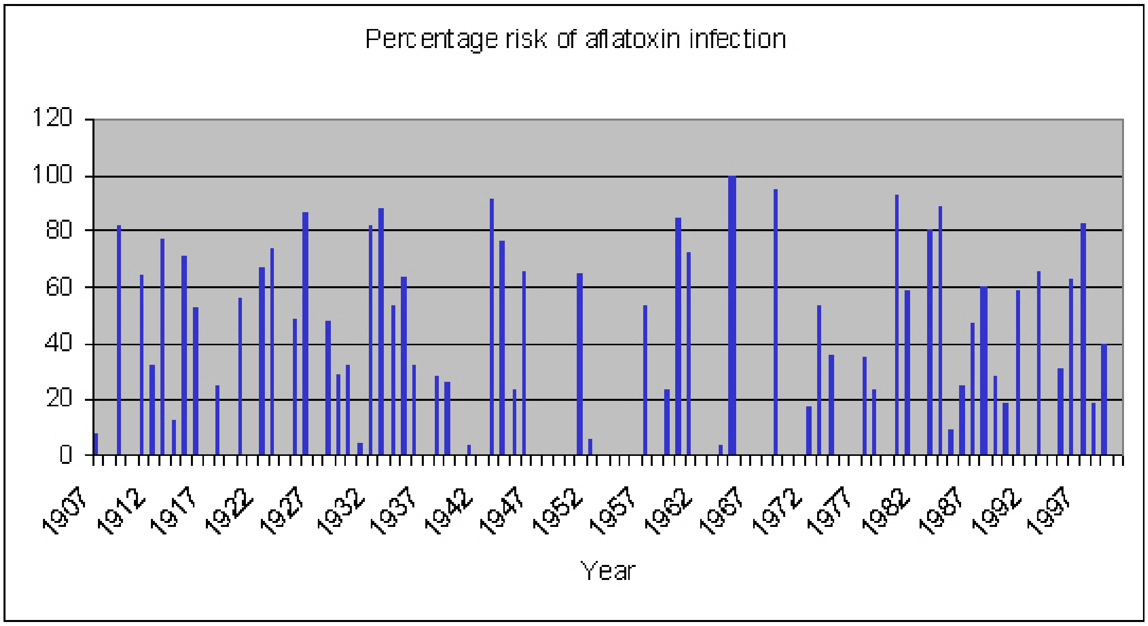

Figure 2. **Long-term simulation of aflatoxin infection at Kingaroy**

A pre-season indication of the likely aflatoxin risks could help within-season management decisions. However, we found that the SOI before the summer cropping season was not a good indicator of the likelihood of a high risk of infection. This is probably because the development of infection is due to dry conditions at the end of the season whereas the SOI is a coarse predictor of the probability of future climatic conditions.

Growing a quicker-maturing variety (eg similar to Chico) lessens infection levels because in some seasons the crop escapes end-of-season drought (Figure 3). The simulations indicate that use of a shorter maturing variety for the 1st November sowing date increases the chance of a nil or very low infection rate from 40 to 60% with a commensurate reduction in the chance of severe infection.

Using Whopper Cropper to display the output

The APSIM output has been collated into Whopper Cropper and a range of management inputs can be compared. Figure 3 shows the simulated historical incidence of aflatoxin for four cultivars. The cultivars Chico and Streeton have contrasting risks of aflatoxin infection. Such information can guide cultivar choice in high-risk situations.

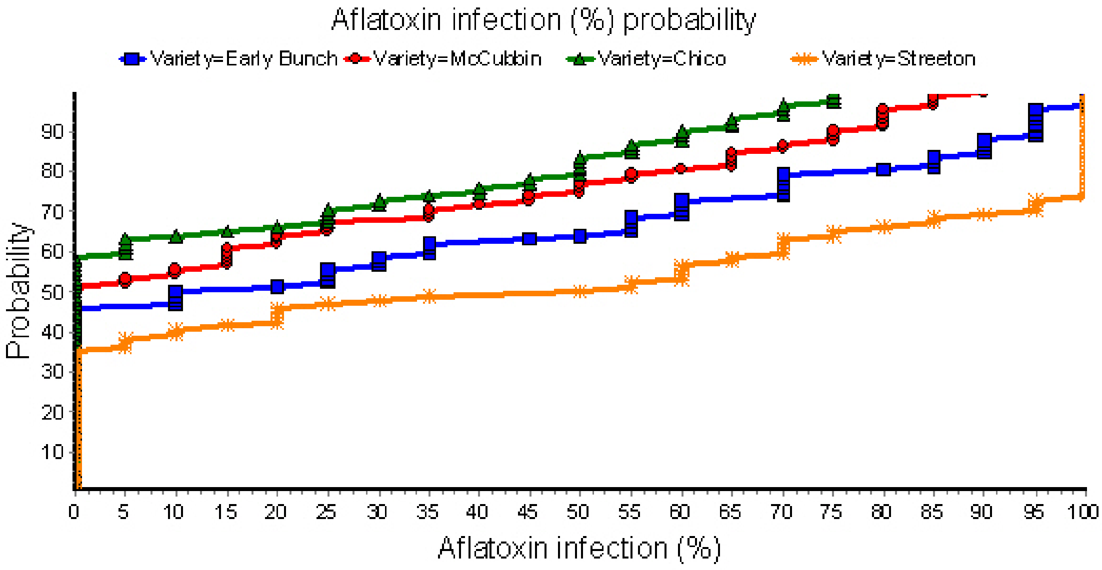

Figure 3. **Effect of cultivar on potential aflatoxin infection**

Improved aflatoxin management could also improve overall harvest management. This should increase returns by increasing quality (better grades, less splits and extraneous material) and reducing harvest losses. This analysis will use concepts previously in a similar study on wheat (Whan and Hammer 1985). A harvest loss routine has been developed for the APSIM peanut model (Meinke and Hammer 1995).

Case Study 2 Spring-sown mungbeans (and risk of weathering)

New "niches" or opportunities for barley need to be developed within the farming system. Simulation models can provide possible scenarios. As an example of this, we used APSIM to explore new niches for mungbean in the northern cropping region. In this region they are often grown as an `opportunity' crop immediately following a winter cereal. Because soil water reserves can be low following a winter cereal, the crop had developed a reputation for being unreliable. We were able to show that the option of early sowing mungbean with higher soil water storage following a fallow from a previous summer crop was feasible (Robertson *et al*. 2000). An associated issue was the perceived higher risk of weathering damage from the early sowing, which was analysed (Fig 4). Weathering risk was evaluated as the number of rainfall events during pod fill (Figure 5 a). This analysis could be considered overly simple but could be expanded to take into account of the increased rate of pod maturation form early sowing, the length of time the crop stays wet, and whether a second crop of flowers is present.

The study stimulated a program of on-farm monitoring of commercially-grown early-sown crops, to the point know that such a practice is now an acceptable part of the industry.

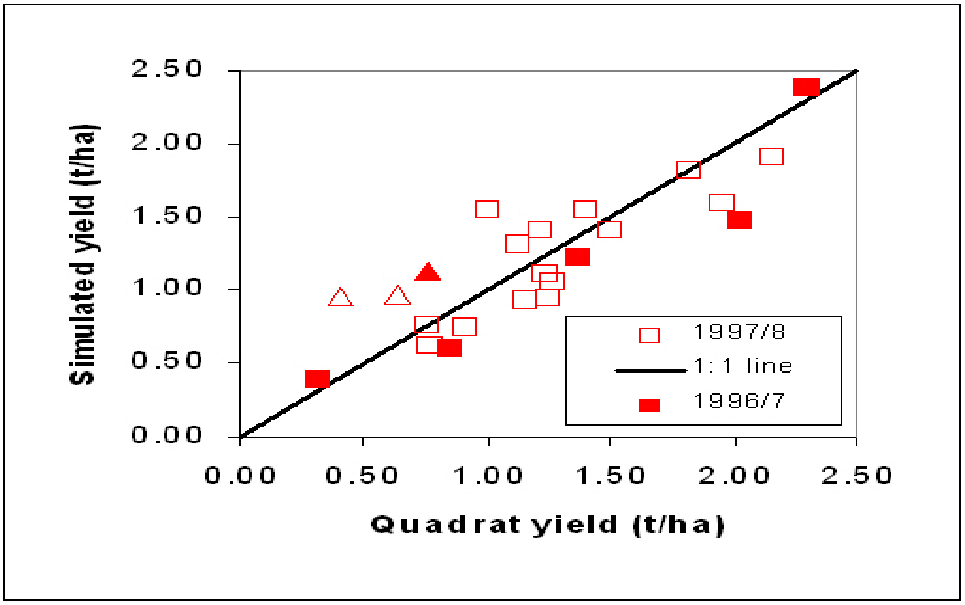

Figure 4. Relationship between observed quadrat yield and simulated yield (Robertson *et al.*)

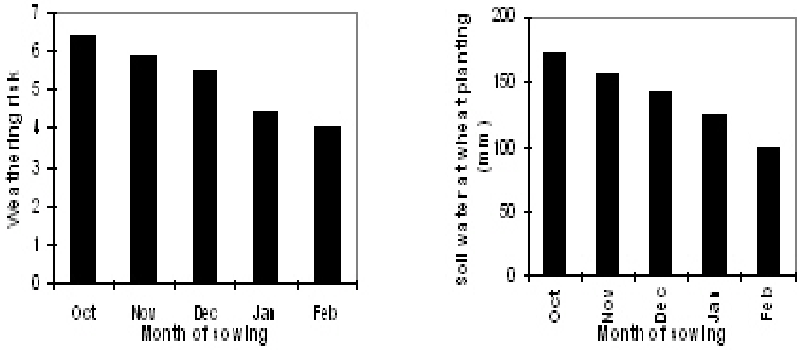

Figure 5. Simulated weathering risk (number of rainfall events during pod fill)

Longer-term scenario analysis using APSIM

Cox and Chudleigh (2000) used APSIM and whole farm economics to describe the production and economic effects of soil PAWC, soil fertility, climate, cropping system, nitrogen fertiliser input, the economics of ley pasture rotations and opportunity cropping in Central Queensland. This provided insights to cropping systems in which barley could be valuable part.

Possible applications of crop modelling for barley

The following issues have been developed for other crops and cropping situations. It is proposed that the barley industry could benefit from the combination of seasonal climate forecasting and crop modelling activities in a similar way.

Application of SOI phases

Hayman (2001) concluded that the correlation between the SOI phase and May to October rainfall in southern regions was equal to or higher than that of northern areas. The important observation was that the last 10 years was of a lower correlation (0.2) than the long-term average in the south temporarily lessening the credibility of the SOI forecasts. Meinke *et al*. (2000) and Stephens *et al*. (2000) showed that SOI phase one and phase three years (negative and falling respectively) generally showed a reduced wheat production potential in all states. Phase four and phase two years indicated higher production potential. The soil and climate parameters would be common to the wheat and barley industries and immediately available.

Grain yield, frost risk and grain prices

Examination of the potential effects of SOI phase on crop yield could lead to increased production, improved management of inputs or reduced costs in poor seasons. Meinke *et al*. (2000) presented a case study on the interaction of seasonal climate forecasting and wheat production in 1997and 1998. A case study recording the benefits gained by a grower's use of climate forecasting and crop management for summer crops was also given. An important issue was elucidated; that viable grain yields were possible in an El Ninõ year if soil water at sowing was high.

Other issues that can be influenced by SOI phases are frost risk (Stone *et al*. 1996) and grain pricing (Chapman *et al*. 2000). Some management activities can be varied in anticipation of seasonal effects.

Nitrogen management

Cox and Chudleigh (2000) and Hammer *et al*. (1996) showed that tactical application of nitrogen fertiliser could increase economic returns. The crops were wheat and sorghum in central Queensland and wheat in south Queensland respectively. Cox (1995) reported strategies for nitrogen application for barley that optimised grain yield whilst still retaining moderate grain protein levels. Dalal *et al*. (1997) detailed a `rule of thumb' for matching soil nitrate and soil water at sowing to target a desired grain protein concentration. In-crop rainfall will always be a major determinant of grain protein because of varying grain yield. The range and risk of outcomes can modelled and demonstrated as distributions and probabilities.

Grain colour

Kernel discolouration results from periods of rain or high relative humidity (RH) from grain filling to harvest (Young 1999). The cultivar Stirling was reported as being particularly susceptible to discolouration. There are several agronomic issues that can be managed to reduce kernel discolouration. These are the trade-off between later sowing resulting in lower RH but a potential grain yield reduction. The probability of receiving a certain amount of rain in a time period or with RH in excess of a certain value could be modelled. The output could be presented in `Whopper Cropper' allowing rapid scenario analysis. The analyses would be particularly valuable as part of discussion in the context of a grower group.

Grain size

Barley grain size is affected by genetics, phenology, plant density, water supply and rate of grain filling (Fettell *et al*. 1999). Data such as described in this paper could be used to model grain size. Nitrogen application has been reported to reduce grain weight and plumpness (Cox 1995, Young 1999). For most current APSIM modules, grain size is modelled and available as an output. The effect of agronomic variables could be examined and demonstrated using Whopper Cropper.

Disease management

Disease epidemics can cause large barley yield losses. The 1998 season in northern Australia highlighted this (Poulsen *et al*. (1999). Whilst cereal disease management is normally a breeding issue, there could be potential to improve preparedness for outbreaks.

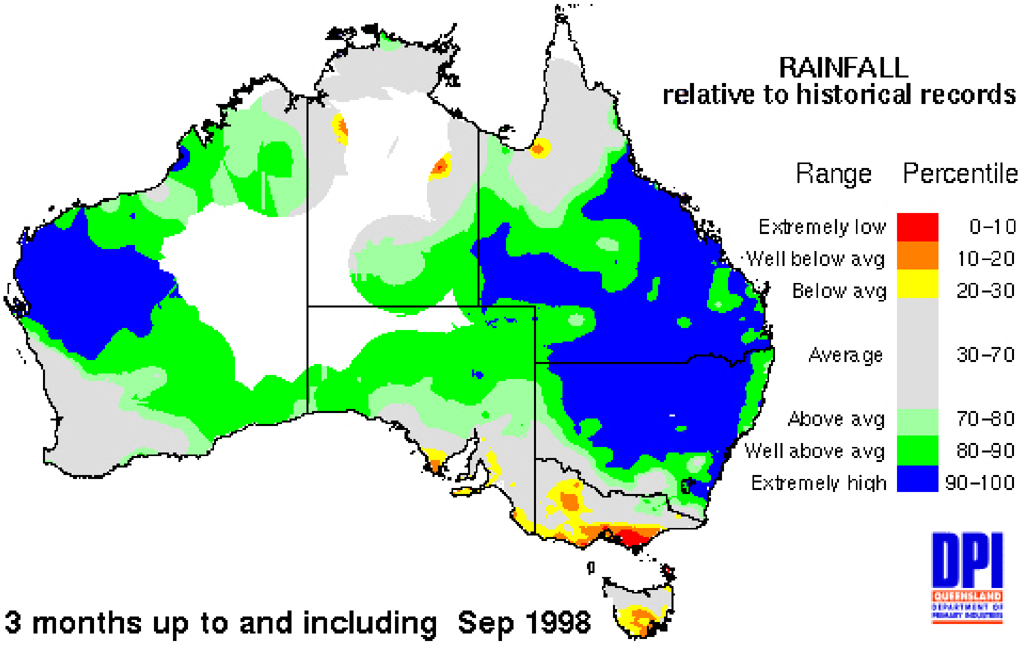

Figure 6. Percentile distribution of rainfall July to September 1998

The SOI in April-May 1998 prior to the wet winter/spring, was `rapidly rising' which can signal greater than median rainfall. The rainfall occurrence is shown in Figure 6. The cultivars Gilbert and Grimmett suffered more from infection by the net form of net blotch (Poulsen *et al*.1999). Schooner was less affected and hence a change to this cultivar may be advantageous if very wet conditions are possible. Of the 22 `La Niñã' events up to 1997/98, 11 have resulted in greater than average rainfall in most of the barley-producing regions, with another five receiving higher than average rainfall in at least some of the barley-producing areas (www.dnr.qld.gov.au/longpdk).

Regional Commodity Forecasting

Potgieter et al. (2000) developed a regional commodity forecasting system for wheat. The system is a operation in Queensland via the Regional Crop Outlook - wheat publication. The publication describes the wheat yield outlook for the each month on a shire basis (Figure 7 and www.dpi.qld.gov.au/fieldcrops/4525html). Shires at risk of very low yields are also identified. In Western Australia, a `fax back' service is provided through the Climate Risk and Yield Information Service (PYCAL and TACT models). Modified versions of the PYCAL and TACT models are used for a fax-back service in South Australia (Truscott and Egan (2000).

Regional wheat yield forecasting confers advantages to wheat marketing organisations, grain buyers, transport companies and government bodies. These benefits could be available to the barley industry if a barley production model was available.

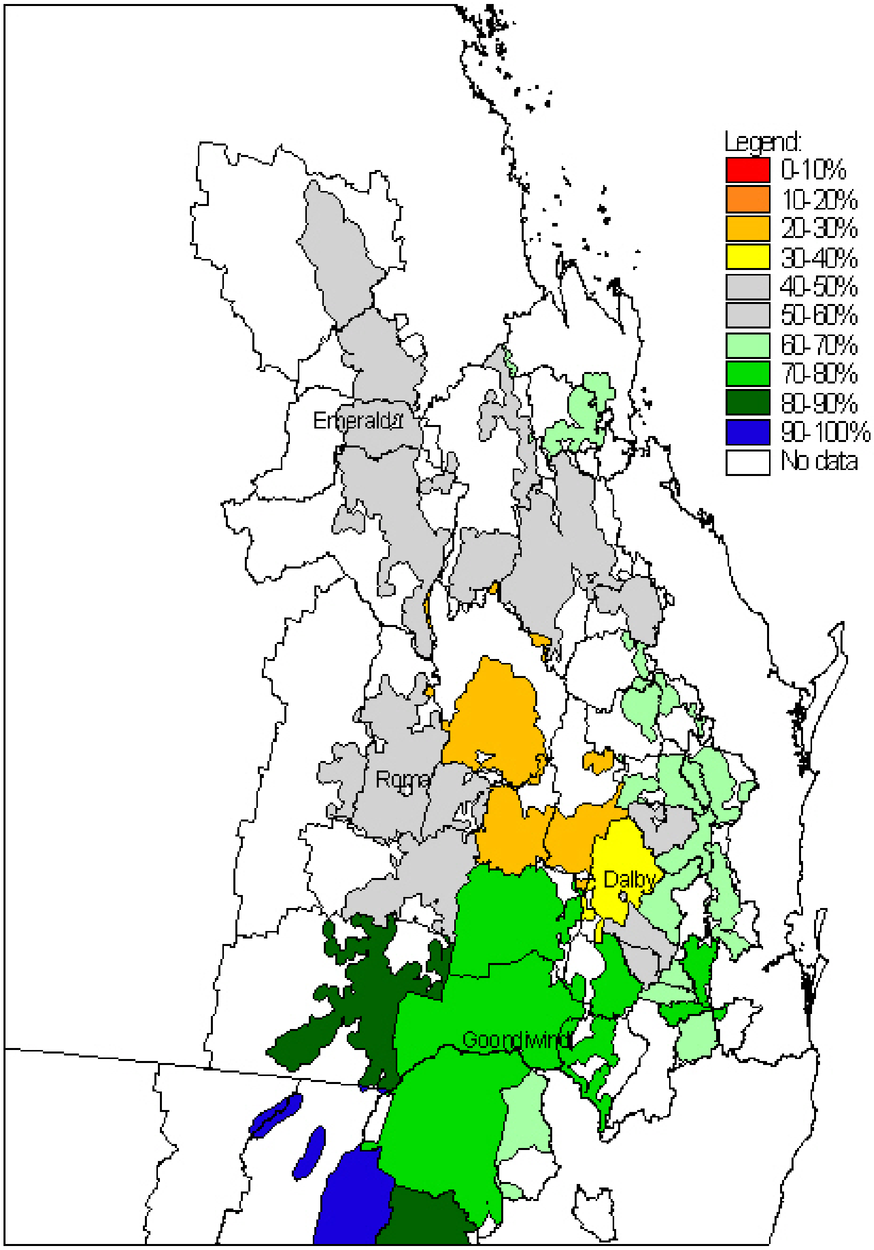

Figure 7. Forecast percentile wheat yield by shire in Queensland. (DPI Publication)

Conclusion

Crop modelling and seasonal climate forecasting is maturing in its application to grain industries. Scenario analyses have proven to be helpful in a number of examples of tactical management situations. APSIM is being increasingly used for resource sustainability issues, policy and economic studies. Grower groups are proliferating and familiarity with and acceptance of computers and associated technologies is increasing There exists considerable potential to utilise the power of the APSIM model and its derivatives to benefit a range of stakeholders. There could be considerable benefits to the barley industry from having a working APSIM barley module.

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