Hammer, G. L., McCown, R. L. and Freebairn, D. M. (1993) APSIM: the agricultural production system simulator - its role and structure. In: *Farming - from Paddock to Plate: Proceedings of the 7th Australian Agronomy Conference, Adelaide, 1993*. pp.232-35. (Australian Society of Agronomy: Parkville, Vic)

APSIM: the agricultural production system simulator - its role and structure

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Summary Production system modeling integrates our knowledge of the system in a way that enables information useful to system managers to be generated, and gaps in understanding to be highlighted. In this way it is a means of making agricultural research more relevant and adding value to existing knowledge. An example is presented of the insight gained by applying a model to the issue of variability of wheat yield in relation to water supply. The modular structure and computing environment of the Agricultural Production system simulator (APSIM) are presented. The approach incorporates novel features suited to the collaborative and long-term nature of system modeling effort. The pay-offs from investment in this modeling exercise derive from the ability to generate information relevant to decision-makers on the likely outcomes of alternative decision options and from bridging the gap between science and practice.

What is modelling and why do we need it?

A production system model is a set of mathematical equations that describe the dynamic interactions of the processes operating in the system. A cropping system consists of the soil with its physical and chemical properties. the crop with its biological properties, other organisms. the daily weather experienced, and management inputs. By simulating the cropping system, the state of the system at any point in time, the yield of crops, and losses to the system such as runoff, soil loss, and nutrient leaching. can be predicted. This provides a sound basis for economic and environmental impact analyses associated with management of the system.

By integrating our understanding of how a system works, a model enables insights that might otherwise go unnoticed. A good example relates to the work on wheat yield in relation to water supply in southern Australia (4,5). Grain yield was related to water use and it was argued that any points falling below the line delimiting the data were below "potential" due to effects of other factors, such as nutrient status, weed infestation, and/or pests and diseases. A similar plot of yield against water use (Fig.1) resulted from a simulation study of wheat in central Queensland (6,7). In the simulation, all factors other than rainfall were made non-limiting. Each data point is the outcome for one year of the 86 year simulation for a given planting date and soil water at sowing. The figure is very similar to that reported in the field studies (4). There is a significant, but weak, relationship between yield and water use and there is a scatter of data below a delimiting "potential yield" line. In the case using the crop model, we know that the scatter could be caused only by variability in rainfall distribution. In some years, excessive rainfall was lost as runoff and in other years, rain fell in a time pattern that was unsuitable (e.g. substantial early rain). The simulation analysis shows that much of the variability attributed to other factors, may have been caused simply by the distribution of rainfall in the season. The "potential" yield defined by the model gives a sounder basis to account for deviations below potential. caused by other factors, than the static approach.

The wheat crop management decision aid. WHEATMAN (18), uses the simulated yields derived from this type of analysis to provide information in a form suitable to decision-makers. Potential yield probabilities for a particular location and soil are derived first, and then allowances for weed infestation, nutrient limitation, and some pests and diseases arc introduced. In this way, targeted information on likely outcomes of alternative options, such as cultivar choice, planting date, and fertiliser rates is provided to decision-makers. This would not have been possible without the use of a crop model. This example can be extended to a range of decisions and decision-makers (1,2,7,9,12,15,16).

Good decision-making needs good information. The experimentation needed to provide adequate information in sufficient places and for sufficient durations is prohibitively costly. Using models that have been developed and tested with information from field experiments, simulation "experiments" can be conducted at a wide range of locations and for periods as long as existing weather records. Such a simulation approach adds value by adding flexibility in extrapolating knowledge. Not only does production system modelling integrate our knowledge on the functioning of the system in a way that enables more information to be made more useful to more system managers, it also highlights important gaps in understanding as priorities for experimentation. Appropriate models can bridge the gap between science and practice and make agricultural research more effective.

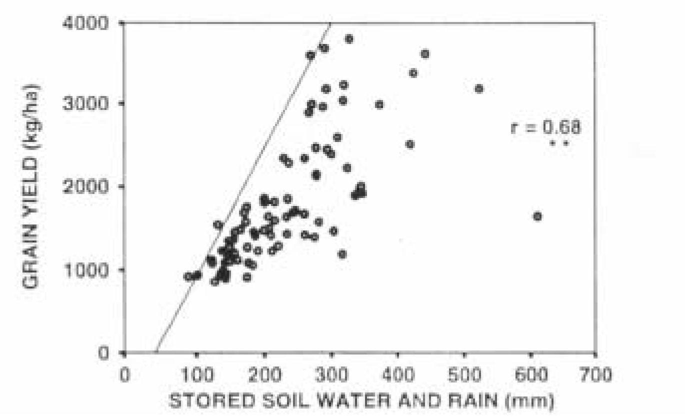

Fig. 1. Grain yield versus water use (stored soil water plus rain) for wheat in central Queensland

A new approach to cropping system modelling

Our modelling approach in the Agricultural Production system simulator (APSIM) has evolved from the concepts and experiences from our previous work in this field (11,14), and from the influence of others (10,17). APSIM is being developed as part of a systems and operational research approach to problems in the cropping systems of north-eastern Australia (13). Our approach is driven by a desire to -

- model soil and crop processes at levels that are balanced and appropriate to proposed applications,
- combine crop growth models to simulate various cropping systems,

- have an environment that facilitates ease of model improvement, application, and maintenance, and
- integrate research effort and manage research resources effectively.

No existing cropping system modelling effort has adopted this comprehensive approach. To date, the development of modelling software has been expedient and most packages consist of "patches on patches". As a consequence, previous models have either remained limited to a few applications or have gradually become cumbersome, difficult to use, and even more difficult to maintain and enhance.

This new approach involves a substantial investment and is being achieved by a co-ordinated team effort among scientists and programmers in APSRU and many collaborators elsewhere. APSIM maintains a daily tally of soil water and nitrogen status, soil surface and stubble condition, and crop leaf area. biomass and yield. It simulates the processes of the water and nitrogen balances, soil loss, and crop growth and development. given soil type, daily weather and the surface and crop management decisions. or the rules to initiate those decisions, for the system. The best functions of existing models have been utilised. The intention is to gather the best and progressively relieve inadequacies using well-targeted research. Added complexity is only sought if simple approaches show inadequate predictive capability.

APSIM is constructed in a modular fashion (Fig. 2) and resides entirely within a programming environment (Fig.3) (8). Each major soil or crop process represents a separate module (Fig. 2). The programming environment or shell (Fig. 3) allows rapid development and testing of new or improved modules. This structure facilitates the collaborative effort required in the development of a system simulation model where different processes are understood, and contributed. by different people. and where alternative representations of a single process are sometimes needed.

At present, modules for wheat, sorghum, sunflower. maize, cotton, and peanut are being installed. Modules for barley. chickpea, soybean, mungbean. and cowpea are being developed. The soil nitrogen module, which was derived from CERES-Maize (10), is currently undergoing testing and modification (3). The soil water and soil movement modules incorporate some routines from PERFECT (11). Development of modules depends on the availability of quality data sets from field experiments to quantify environmental responses of plant and soil processes. Often, existing data are available. but if this is not the case, targeted research is conducted.

All code undergoes a rigorous testing procedure (8). In this way, a system of version control is maintained that ensures integrity of the computer code. Any changes or additions must pass through the testing procedures before being incorporated in a new version.

APSIM can simulate crop production and soil resource outcomes for a range of management scenarios associated with tillage, crop rotation, fertilisation, and crop management. This information enables analysis of economic and resource risks in the variable climatic and marketing environments faced by most agricultural production systems in Australia.

What are the pay-offs?

Most of the investment in developing APSIM and its operating environment has already been made. The major pay-off comes from the ability this gives us to link research-derived understanding with decision- makers' needs to address difficult system management issues. There have already been some examples to indicate the potential pay-offs from this approach. They relate to decision support on crop management or crop choice (9,18), analysis of cropping potential on marginal lands (1,7), and analysis of yield decline due to soil erosion (12). All these examples use models to extrapolate our knowledge and experience over time and/or space. The ability to extrapolate in time and space is a key ability in deriving relevant information from a modelling approach to help evaluate alternative strategies for any specified environment and management.

Some applications of APSIM to cropping system issues will be presented elsewhere in this conference. The impact of seasonal climate forecasting on crop management (16), the analysis of cropping system strategies in relation to optimal utilisation of planting opportunities and rainfall (2), and the potential for expansion of peanut production in Australia (15), arc considered. Another key issue suited to this approach is the long-term management of the nitrogen dynamics of the system by appropriate use of legumes and pasture leys.

We consider that substantial pay-offs front production system modelling have only just begun and that lack of a systems research and development perspective has limited the economic returns to investment in agricultural research. There is much more that can be contributed as this modelling approach is harnessed. Marriage of simulation with experimentation and the development of software suited to agronomists with average computing expertise, should facilitate such a contribution.

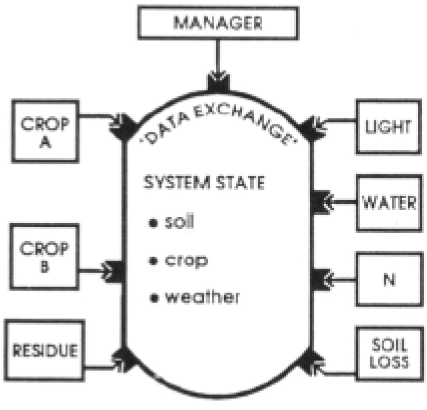

Figure 2. Modular structure of APSIM.

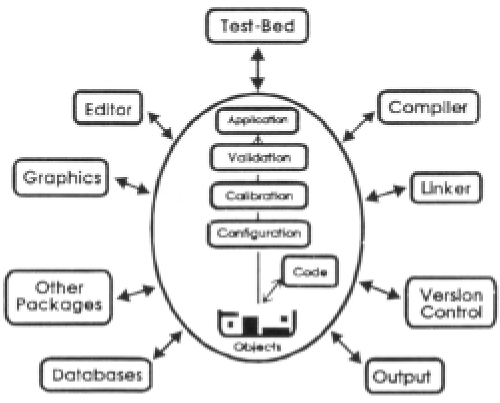

Figure 3. Programming environment for APSIM.

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