H APSIM

Key points

- The Agricultural Production System sIMulator (APSIM) is the leading example of CSIRO's extensive agricultural production systems modelling. This modelling involves computer simulation of the complex bio-physical interactions characteristic of agricultural and forestry land use systems
- APSIM, and agricultural and forestry production system modelling and decision support systems (DSS), have a long history within CSIRO and constitute an excellent example of the 'systems' approach to complex research problems employed by CSIRO
- APSIM, and other DSSs, has struggled to achieve widespread adoption by farmers and their advisors
- To overcome this, CSIRO has engaged in extensive research on farmer decision making, which according to CSIRO has generated considerable benefits. A significant investment made by CSIRO in exploring the application of simulation modelling to farm decision making was in the FARMSCAPE program. Benefits reported by CSIRO stemming from FARMSCAPE include:
  - Increasing farmer adoption nationally of soil moisture and nutrient monitoring to depth
  - Increasing industry acceptance of crop modelling as an diagnostic and decision aid
  - Promotion of the use of seasonal climate forecasts as important inputs into crop production decisions combined with stored soil moisture measurements
  - Diagnosis of important production constraints and elucidation of practices to increase yield and lower risks
- Yield Prophet®, an on-line risk management service based on APSIM, has been commercialized in conjunction with the Birchip Cropping Group (BCG). Subscriptions to this service have been increasing since its introduction in 2002
- However, at present it appears that the majority of the value of APSIM is generated when used by researchers to identify opportunities, constraints and risks, and ways of managing them and extending this knowledge to growers. Moreover, modelling has been extensively used by researchers to better prioritise research investments by allowing the testing of hypotheses through modelling rather than solely in field research
- Specific examples of where this value has been realized and more importantly how ASPIM creates value are:

- Demonstrating that mungbean production is profitable in northern Australian cropping areas when sown in spring with good soil moisture
- Demonstrating that canola can be a valuable and profitable crop in northern cropping rotations

APSIM and the suite of other agricultural based decision support tools developed by CSIRO are good examples of the systems approach to complex problems so often employed by CSIRO.

H.1 Introduction

This case study has been prepared to demonstrate the multidisciplinary 'systems' approach deployed by CSIRO in response to complex research priorities. This analysis of the likely impacts of the use of APSIM, and its associated research, draws on journal articles, provided by, and predominately authored, by those involved in the development and use of APSIM.

CSIRO has stated:

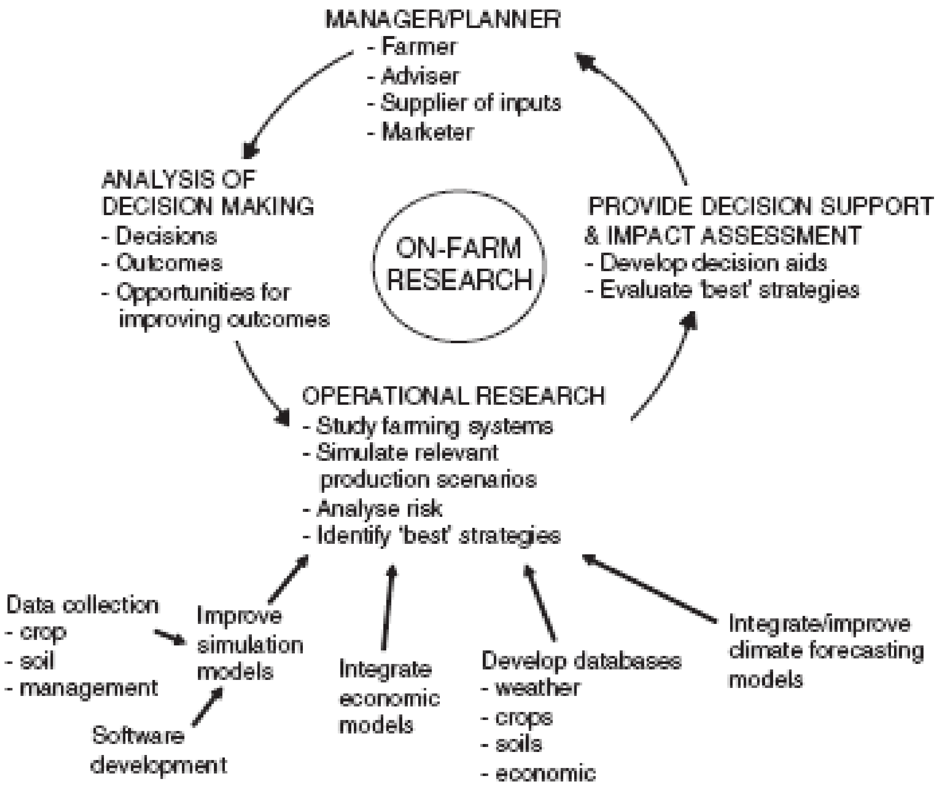
> APSIM is a modelling framework with the ability to integrate models derived in fragmented research efforts. This enables research from one discipline or domain to be transported to the benefit of some other discipline or domain. It also facilitates comparison of models or submodels on a common platform. This functionality uses a "plug-in-pull-out" approach to APSIM design. The user can configure a model by choosing a set of submodels from a suite of crop, soil, and utility modules. Any logical combination of modules can be simply specified by the user "plugging in" required modules and "pulling out" any modules no longer required. Its crop simulation models share the same modules for the simulation of the soil, water, and nitrogen balances. APSIM can simulate more than 20 crops and forests (e.g., alfalfa, eucalyptus, cowpea, pigeonpea, peanuts, cotton, lupin, maize, wheat, barley, sunflower, sugarcane, chickpea, and tomato). APSIM outputs can be used for spatial studies by linking with geographic information systems (GIS)

APSIM is one of a range of simulation models and agricultural decision support tools produced by CSIRO. Other decision support tools include:

- GrassGro – management of temperate grazing systems
- GrazFeed – estimates animal production
- WaterSense – a web tool for irrigation management
- IrriSatSMS - irrigation water management by satellite and SMS

Figure H1 illustrates the systems approach, with the multidisciplinary contributions outlined across the bottom of the diagram. The on-farm research cycle, occupying the top half of the diagram, shows how the simulation modelling research draws on CSIRO's on-farm field research and farmer's own experiences to continuously improve the models and their outputs.

Figure H1 **A frame work using models in farming systems research**



Source: (McCown, Carberry, Hochman, Dalgeliesh, & Foale, 2009)

APSIM has a long history of CSIRO investment. The current APSIM software and supporting services are the result of over 25 years of collaborative research on simulation and adoption research undertaken by CSIRO, the Queensland Government and the University of Queensland under the banner of the Agricultural Production Systems Research Unit (APSRU).

H.2 A brief history of APSIM

The development of APSIM began with the formation of APSRU (Keating, et al., 2003). The initial stimulus to develop APSIM came from a perceived need for modelling tools that could provide accurate predictions of crop production in relation to climate, genotype, soil and management factors, whilst addressing long-term resource management issues in farming systems (Keating, et al., 2003). At this point in time, perhaps the most important failing of simulation models was a lack of a 'systems' approach to crop and pasture production (Keating, et al., 2003).

Prior to the development of APSIM, production models dealt with single crops or seasons and could not cope with longer term effects. They were also based on variable software engineering standards.

Farm decision support tools and modelling had also been largely conducted in Australian in isolation, making the research fragmented. The formation of APSRU brought together a range of organisations to work collaboratively to improve modelling capability and address the lack of 'systems' simulation in current models.

However, the adoption of early versions of APSIM and other DSS tools outside the research community was poor. Farmer and advisor resistance was at the time seen as a major problem due to many attributed reasons, including perceptions of accuracy and a generally low uptake of computing technology by farmers. This low adoption by farmers appears to persist today:

> The idea that simulation models of agricultural production can serve as tools for farmers remains a compelling idea even after 3 decades of mostly disappointing development efforts (McCown, Carberry, Hochman, Dalgliesh, & Foale, 2009)

In response to this lack of early adoption, CSIRO invested in understanding the role simulations models may play in farm decision making and how the information produced by these models could be used by farmers. This formed the basis of the investment in the FARMSCAPE program.

> It [FARMSCAPE] initially involved research to explore whether farmers and their advisers could gain benefit from tools such as soil characterisation and sampling, climate forecasts and, in particular, simulation modelling. Its current focus is facilitating the implementation of commercial delivery systems for these same tools in order to meet industry demand for their access (Carberry, et al., 2002).

FARM SCAPE is an acronym for Farmers, Advisers, Researchers, Monitoring, Simulation, Communication And Performance Evaluation. It is a program of participatory research with farming communities in Australia (Carberry, et al., 2002). The aims of the FARMSCAPE project were:

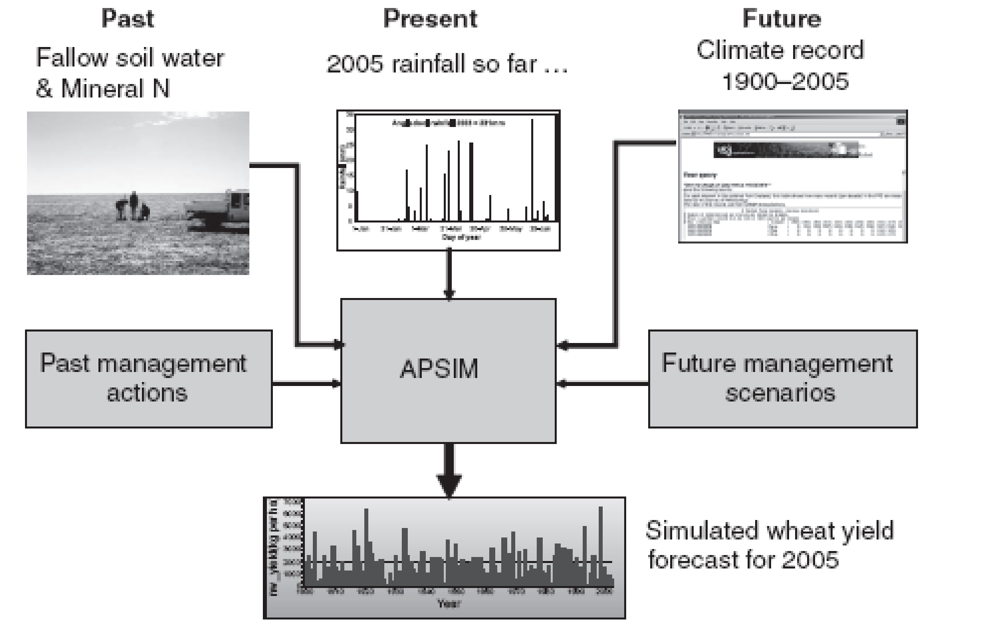
3. To develop networks of farmer groups, facilitated by consultants, advisers or extension officers to engage in on-farm monitoring of soil water and nitrogen; and to train the facilitators in the use of the simulator (APSIM) to add value to data and aid discussion.
4. To find cost-effective ways for farmers, advisers and researchers not in active groups to benefit from the output of aim 1.
5. To evaluate the impact on participants of the co-learning and communication activity (Carberry, et al., 2002).

FARMSCAPE established a direct working relationship between the researchers and over 230 farmers, organised within 28 groups working with 15 farm advisers. The project ran over 30 on-farm trials centred on 13 climate stations in northeast Australia. All crops monitored within the project were used to test APSIM simulations (Carberry, et al., 2002). Simulation with APSIM was a key tool in the program, being used for research analysis and diagnosis, co-learning with decision makers who were actively involved in the project and decision support for the wider farming community. Section H.6.1 contains a discussion of the benefits of FARMSCAPE.

One of the lessons from FARMSCAPE was that such intensive effort by scientists to engage with their clients was time consuming and expensive (Hochman, et al., 2009).

To reduce the cost of engagement with farmers and to assist farmers gain access to APSIM, a simpler and flexible web-based tool, Yield Prophet®, was developed in 2002 – see www.yieldprophet.com.au. Yield Prophet uses APSIM to combine historical production factors such as the length of fallow and soil water and N profile with rainfall to date, and future climate forecasts based on historical records. This process is illustrated in the following figure.

Figure H2 **Schematic representation of the process of in-season crop yield forecasting**



Data source: (Hochman, et al., 2009)

In its first year, the Yield Prophet® reports were based on three representative sites and disseminated by fax. As interest from farmers increased, individual reports were offered for a fee but based on estimated field conditions for each farmer (Hochman, et al., 2009). However, this led to a reduction in accuracy and required the use of actual data collected from the paddocks nominated by the farmer to improve accuracy. This accuracy improvement was facilitated when Yield Prophet® was developed as a web-based tool, which allowed farmers to enter their information directly and produce an automated APSIM report.

However, while much of Yield Prophet® is automated, it also requires considerable support in areas of field monitoring, scientific support to ensure APSIM is updated and reports validated, and assistance with interpretation of the results.

H.3 Current status

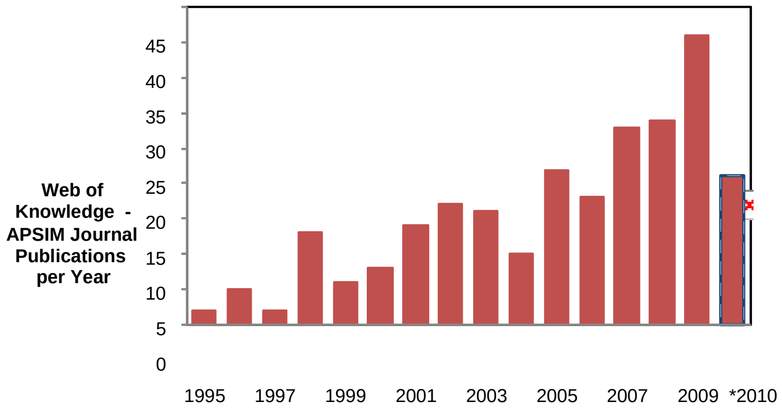
The way APSIM is used in its current form is a product of CSIRO's investments in better understanding farm decision-making processes and CSIRO's modelling and simulation capability. CSIRO has researched how farm decisions can be helped with simulation modelling that highlights prospective points of intervention.

Today:

- There are over 400 APSIM licenses issued worldwide
- Over 40 modules are included in the APSIM framework covering a range of crops, pastures, trees, soil processes, livestock production, management options (e.g. irrigation, fertilisation)
- The software design is constantly being updated, tested and verified. Supporting documentation is also being constantly revised
- The capability is currently underpinned by three full time equivalents (FTE) of software engineering effort and many FTEs of scientific input both from within and outside CSIRO
- While adoption by farmers and advisors of APSIM has been low, adoption by researchers is expanding. Assessing of the benefits of APSIM, based on direct adoption by farmers alone, can give a misleading impression of the impact of a tool such as APSIM.
- Adoption of the information produced by APSIM and distributed through a variety of channels, including researchers provides a better assessment of the value of the model and supporting research.

There is evidence of the rapidly widening adoption of the APSIM farming systems simulator as a research tool. The scientific uptake of APSIM (as roughly indicated by ISI Web of Knowledge) has increased steadily over time. CSIRO has advised that in 2009-10 there was a sharp jump in the number and diversity of scientific papers employing APSIM. Since January 2009, 63 APSIM-related papers have been published, with 30 non-CSIRO lead authors from 19 countries. APSIM-related papers received well over 500 citations in 2009 alone (see graph below).

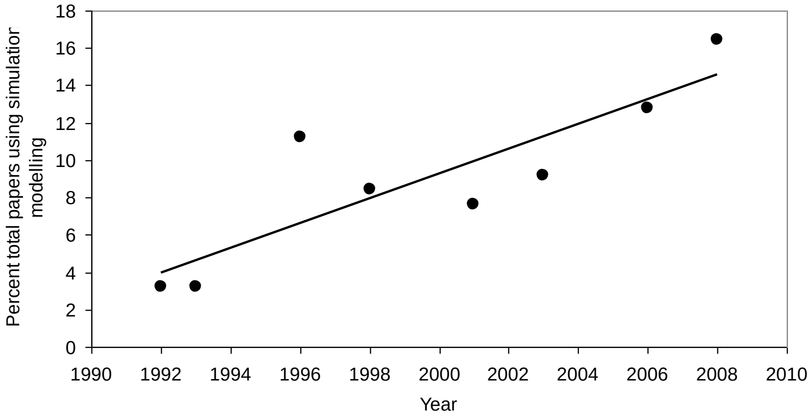
Chart H1 **APSIM citations**



Data source: (Carberry per comm. 2010)

APSIM has been increasingly accepted as a research tool by the research community in Australia (Chart H2) and around the world.

Chart H2 **Time trend of modelling papers as a percent of total papers presented at the Australian Agronomy Conference between 1992 and 2008**



Data source: (Robertson & Carberry, 2010)

H.4 Commercialisation

APSIM is able to be downloaded from the web. Fee-for-service training is offered to users on a regular basis.

Licenses are issued free of charge to organisations and individuals who intend to use the model to produce 'public goods' (R&D, extension and education). Intended commercial users of the software are required to pay a licence fee.

In early 2010, a new unincorporated joint venture for the ongoing development and management of APSIM was formed. The partners to this joint venture are CSIRO, Queensland Government, and the University of Queensland. However, other parties are being encouraged to join this joint venture.

As noted above, one of most significant commercialization opportunities that have emerged from the APSIM and FARMSCAPE research has been the web-based tool Yield Prophet®, providing an internet-based service that allows farmers and their advisors to explore tactical management options with their grain crops in "real-time" ash the potential to be a valuable farm resource. CSIRO has entered into a joint venture agreement with the Birchip Cropping Group (BCG). Yield Prophet® is now in its 5th season with considerable reach across Australia.

H.5 Demonstration of CSIRO capabilities

The CSIRO core competencies contributing to APSIM (and simulation modelling more broadly) appear to be:

- A systems approach to agricultural production systems and resource management
- Coordinating extensive on-farm experimentation, extension activities and simulation modelling capabilities
- Computer based simulation modelling skills
- An understanding of farmer decision making, approach to risk and the role of decision support

Agricultural simulation modelling, as with most economic or process models, assembles and replicates the interaction of a wide range of variables simultaneously. This modelling approach can have high powers in capturing the way variables interact, but perhaps the most powerful aspect of models such as APSIM, is their ability to assess the effects of permutations to a system.

However, application of a simulation model requires considerable data and a keen understanding of the system it is simulating. CSIRO maintains this capacity through its extensive investments in livestock, plant and soils research, and software engineering. These investment, when combined with its wide spread engagement with farmers (particularly through FARMSCAPE) has enabled CSIRO to develop simulation modelling and constantly improve its accuracy and applicability.

APSIM underpins much of the research being managed under the new CSIRO Sustainable Agriculture Flagship.

H.6 Key benefits emerging from the work

Overall the impacts of CSIRO's investment in APSIM, and associated extension and adoption investments to support it, appear to have produced considerable benefits for agriculture. They can be summarised as:

- Developing a greater understanding of the key production risk factors in crop and livestock production in Australia; and how these risks can be managed
- Providing farmers with tools to prioritise data collection (such as measured plant available water and key nutrients such as N in the soil profile)
- Providing a set of tools to interpret the field data collected and simulate a range of 'what if scenarios' using historical regional climate records

Some of the more specific impacts of the extensive investments made by CSIRO in this area are listed in the sections below.

H.6.1 FARMSCAPE impact

Section H.2 contains a history of FARMSCAPE and its relationship with APSIM. This section outlines some of the benefits produced by FARMSCAPE.

The investment in FARMSCAPE, to support the adoption of systems simulation, led to a series of impacts that can be summarised as:

- Improved awareness and adoption of deep soil monitoring (nutrient and stored plant available water) as a key management practice. This has influenced farmers and advisors by :
  - Demonstrating value in better knowledge of soil resources to depth.
  - Designing and developing inexpensive soil coring equipment for use by hand or using hydraulics, and arranging for two local manufacturing companies to build and sell this equipment
  - Writing and publishing the 'Soil Matters' manual (Dalgliesh and Foale, 1998) which contains information on sound procedures to sample soils and interpret results for distributiion to farmers and agribusiness.
  - Actively promoting these technologies through industry-sponsored publications and events to encourage wider uptake and use
- Increased industry acceptance of modelling. Indications of this include:
  - The establishment of a commercial FARMSCAPE Training and Accreditation program, in which four agribusiness companies paid to participate and be trained in using APSIM within their commercial advisory services. This program was designed and initiated through active industry support and sponsorship (see section on FARMSCAPE phase II)

- Industry-led conferences, update meetings and training courses now actively incorporate simulation modelling as a key component to their programmes – examples include dryland cotton pre-season planning meetings, grains industry annual update meetings, accredited agronomist courses for chickpea and mungbeans, and so on
- Direct sponsorship of the FARMSCAPE team and its activities by two agribusiness companies
- Expressions of interest from farmer groups throughout Australia for replication of FARMSCAPE interactions for their own regions, particularly in accessing APSIM simulations

- Development and promotion of the model for the use of seasonal climate forecasting
- Innovative changes to farm practices as a result of modelling feedback (see canola and mungbean examples below)
- Highlighting to farmers the potential improvements to water use efficiency that they could gain and the resultant improvements in yield that would result

H.6.2 Some of the impact of Yield Prophet®

While is difficult to demonstrate the impact of Yield Prophet® on farm decision making, its adoption by growers provides some indication that it is seen as a useful tool for cropping managers. The following table shows the growth in Yield Prophet® subscriptions between 2002 and 2007:

Table H14 **The growth of Yield Prophet®'s subscriptions and usage from 2002 to 2007**

	2002	2003	2004	2005	2006	2007
Subscribed fields	5	29	50	356	550	558
Consultants	1	1	3	37	37	50
State government /researchers	0	0	2	5	8	21
Reports produced	7	260	1200	6800	8300	9200

Data source: (Hochman, et al., 2009)

H.6.3 APSIM impacts

In summary CSIRO's investment in APSIM and associated management decision support research benefits farmers and researchers. These benefits include:

- Improved farmer and researcher understanding the management of farm resources in particular soils

- For those farmers using APSIM or a web based interface using ASPIM such as Yield Prophet®, better on-farm prioritisation of management interventions
- For the increasing number of researchers, and research managers using APSIM, a potential reduction in the level of field experimentation required and/or improved prioritisation of research investments – possibly rendering previously unjustifiable R&D cost effective and delivering earlier access to outcomes
- For the grains and livestock industries generally, a potential bringing forward of innovations because some early-stage research station and field trials can be avoided or abridged by using simulation modelling to pre-test hypotheses
  - A potential for substantial improvements in farm risk management as farmers can simulate a range of potential negative shocks on their businesses and determine the most appropriate risk management strategies including responding to climate change and changes to climate variability

The major factor limiting private benefits generated from most simulation models is adoption – an issue that has been identified widely in the literature. However, productivity gains for individual businesses which use these tools could be large. APSIM also now has a broad application base, over different formulations and types of application, affording scope for overhead sharing of the core system even where take-up of individual applications is modest.

The public benefits that could be generated from this type of simulation modelling include improved management of water and soil resources – with natural links into sustainable agriculture. This could also be extended to greenhouse gas management – APSIM may well have significant potential in addressing the impediments to accounting for soil carbon (as discussed under the biochar vignette).

Modelling capability is often a critical enabler of market based and other policy instruments dealing with the allocation and management of scarce resources and externalities – such as in relation to water or GHGs. Agricultural and land use systems modelling has been identified by ACIL Tasman as a critical initial step in several recent policy development processes such as:

- The management of water interceptions in the landscape and their impact on extractive water users and environmental flows
- Incorporation of agriculture into carbon mitigation policy, including via voluntary offsets markets

H.6.4 Some specific examples of the use of APSIM and its impact

The following case studies are examples of the types of impact APSIM has had. They should not be construed as a demonstration of the total or even a significant portion of the value of APSIM as this has been discussed in preceding sections.

These case studies have been included to provide a tangible demonstration of one of the ways in which APSIM is applied and the results that stem from the application. In these case studies the application of APSIM can be summarised as:

6. Identification of possible options through simulation of scenarios
7. Testing the new practices with innovative farmers and advisors
8. Monitoring the management and performance of commercial crops and comparing yields with benchmarks estimated with the model

Two examples of the use of APSIM to investigate farm management changes and new crop options in the southern Queensland and northern NSW regions are mungbean and canola. Each is discussed in more detail below.

H.6.5 Canola

Canola production has increased dramatically in the southern grain growing areas. Current annual production is approximately 1.0 to 1.2m tonnes per annum in favourable years.

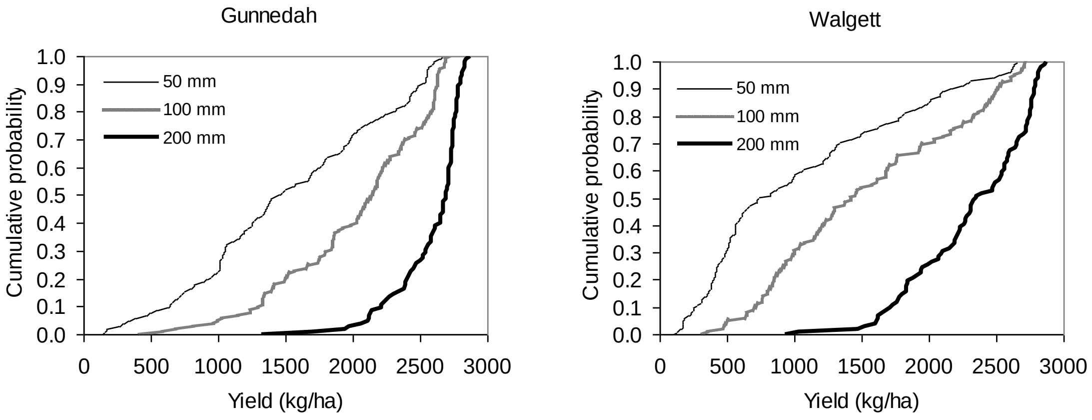
Canola, from the Brassica family, has also been a good disease break crop in cereal rotations and allows a range of alternative chemical weed control options to cereals. The advent of Roundup Ready GM canola has also introduced another important weed control option in crop rotations.

However, despite these rotational advantages, canola has not been included in northern crop rotations as extensively as in the south. The limited adoption of canola in the north is largely due to higher variability of rainfall in this region compared to the south and canola's lack of dry period tolerance compared to cereals.

CSIRO used APSIM simulations of canola production in the northern wheat belt to identify and develop strategies to reduce the risk of growing canola in the region (and to test the suitability of a close relative of canola Indian mustard which is far more drought tolerant).

The results of the simulation modelling showed the sensitivity of the crop to soil moisture at sowing based on 103 simulated seasons (see Chart H3).

Chart H3 **Cumulative distribution functions of grain yield for different levels of available soil water at sowing for a reliable (Gunnedah) and marginal (Walgett) canola production area in northern NSW. Each composed of 103 simulated seasons (1990-2002)**



Data source: (Holland J. , Robertson, Wratten, Bambach, & Cocks, 2003)

The APSIM simulations in Chart H3 show the probability of achieving certain yields, with 50, 100 and 200mm of stored moisture at sowing it Gunnedah and Walgett. The slower the rise the slope the less likely yield increases will be.

The rainfall years were then grouped according to April-May SOI trends. The results of the SOI affect are shown in Table H15. These results suggest a higher probability of a higher grain yield and gross margin in years when the SOI in April to May is neutral to positive.

Table H15 **Long term average (1990-2002) simulated grain yield, oil content and gross margin by April-May SOI phase for Moree. Simulations assumed 100mm available soil water at sowing**

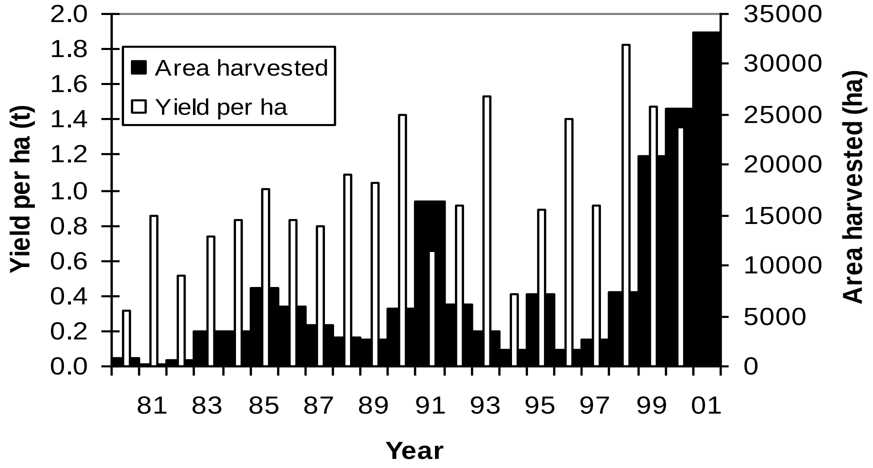
SOI Phase	Number of years	Grain yield	Oil content	Gross margin
		(kg/ha)	(%)	($/ha)
Negative	16	1449	39.0	77
Positive	22	1797	40.7	86
Falling	14	1289	38.1	82
Rising	26	1898	40.6	100
Zero	25	1741	40.2	101
All years	103	16886	39.9	91

Note: Assuming a grain price of $350/t and variable costs of $200/ha

Data source: (Holland J. , Robertson, Wratten, Bambach, & Cocks, 2003)

The results of the modelling provided growers with sufficient confidence to trial canola under certain conditions and in certain areas. It also allowed growers a quantitative assessment of the risks and rewards of canola production that was not available in the past without expensive commercial trialling of the crop.

Chart H4 **Area and yield of canola in northern cropping areas of NSW and southern Queensland**



Data source: (Holland J. F., Robertson, Cawley, Thomas, Dale, & Cocks, 2001)

Chart H4 shows the steady growth of canola yield and area between the early 1980s and early 1990s. Between 1990and 1997 canola areas and yield stopped increasing. The data in the chart then shows a marked increase in area and yield between 1995 and 2001.

H.6.6 Mungbean

In mid 1990s CSIRO began a series of simulations and trials looking at the optimum time for sowing mungbean. At that time farmers perceived mungbean as being a low yielding, high risk crop. Due to this perception, farmers were planting mungbean following winter cereals, essentially as an opportunity crop to utilise residual soil moisture and take advantage of summer rainfall should it occur. This practice meant that the mungbean was being planted on suboptimal soil moisture and were susceptible to heat stress over summer. This practice created negative, and self-fulfilling, experiences with the crop.

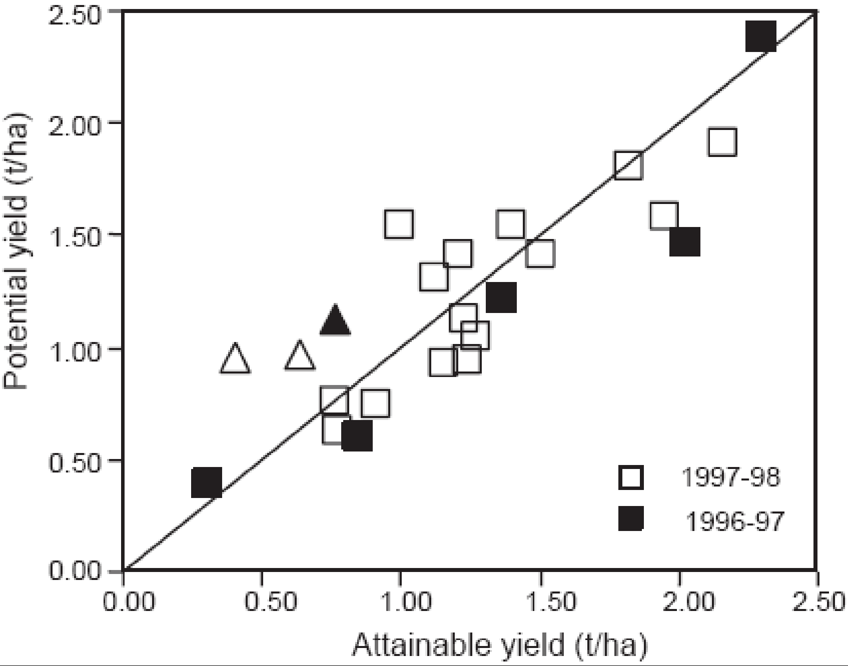
CSIRO APSIM simulations showed a strong relationship between available soil moisture at planting and mungbean yield. This modelling also showed that yields and gross margins could be increased if the crop were sown earlier.

Prior to 1996, all crop research trials investigating planting time effects on yield excluded planting before October. APSIM modelling using historical annual monthly rainfall showed that yields could be increased if mungbean was sown on good soil moisture in September. As the beans would be harvested in December, a long summer fallow would allow the accumulation of soil moisture prior to the planting of the winter cereal the following year.

This APSIM modelling was refined with the help of, growers, agronomists and grain traders. This exposure to, and working with, the model gave these participants the confidence to trial spring sowing mungbeans.

By closely working with farmers and their advisors the accuracy and the applicability of the model was able to be demonstrated to them. Plotting actual yields achieved in the plots (attainable yield) against model simulations yielded a good statistical fit (see Chart H5).

Chart H5 **Potential (simulated) yield v attainable yield (quadrat) for the spring-sown crops grown in 1996-97 (n=6) and 1997-98 (n=19)**

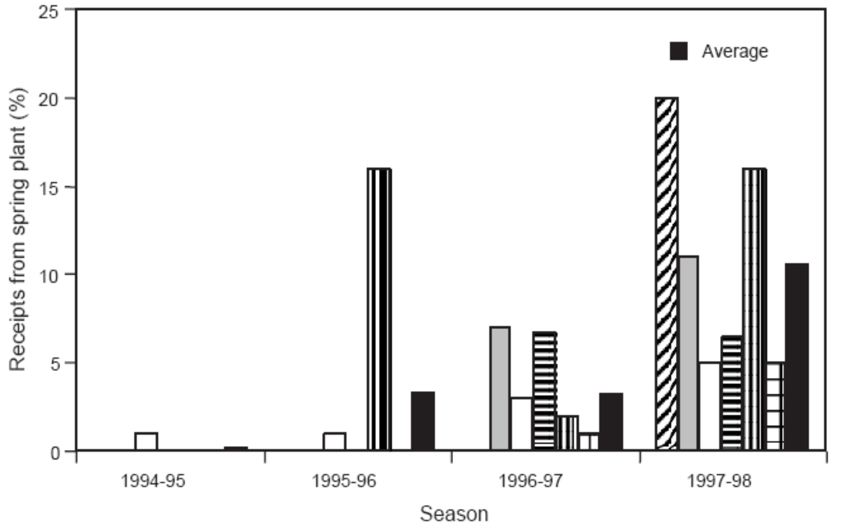


Data source: (Robertson, Carberry, & Lucy, 2000)

Note: Points with the triangle symbol had a significant discrepancy between the potential and attainable yields (see text for discussion). Also shown is the 1:1 line.

The yield improvements and extension of the results by CSIRO, QDPI and commercial agronomists contributed to an increase in spring sown mungbean production from virtually zero in 1994-95 to 25 per cent of total mungbean receipts by traders in 1997-98 (see Chart H6).

Chart H6 **Percentage of total seasonal receipts that came from spring-sown mungbean crops, over the 4 growing seasons 1994-95 to 1997-98**



Data source: (Robertson, Carberry, & Lucy, 2000)

Since 1996, mungbean production has grown from an area of 20,000 ha to over 52,000 ha. Current mungbean production is approximately 39,000 tonnes with a net value of $7m per annum.

H.7 Emerging risks/issues

Critical to the continued development of simulation modelling is an improvement in adoption of, or the use of modelling outcomes, by farm business managers and/or their advisors.

Farmers have been resistant to using APSIM themselves but the experience of Yield Prophet® suggests that increasingly farms may be willing to use web based DSS tools driven by APSIM applications

Agriculture and other land uses are entering a period where real time, sophisticated data collection is occurring at an increasing number of points in the farm system. Yield and quality monitoring of crops, pastures and forests is increasingly being integrated to sowing, harvest, spraying and other farm activities. This is likely to reduce the barriers to entry of commercial simulation modelling products and provide a far more comprehensive data source for APSIM

H.8 Why CSIRO is investing in systems modelling research and development?

The material provided by CSIRO which forms the basis of the case studies contains information which demonstration of considerable value produced by

APSIM and associated decisions support research. However, a critical questions for the counterfactual is what value would have been created had CSIRO not invested in these models or alternatively curtailed its investment in this area. That is, how additional is the value created by CSIRO?

While it is not possible to comprehensively answer this question given the scale of this case study, there are indications that CSIRO's investment would not have otherwise been made by industry or others. This is due to:

- The high cost of collecting large amounts of field data to validate models which is beyond the capability of farmers, advisors and other even other industry or state based research organisations
- The until recently, low up take of computers in farm businesses
- The high transaction costs associated with assembling and coordinating the large multidisciplinary teams that are required to develop and verify farm production system models
- The associated need to spread the high development costs of such a diverse application base.