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Final Report to Cotton Research and Development Corporation

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Project CSP67C

Improved Cotton Management through the Application of Cropping Systems Models

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Aims

To utilise the Cotton Research Unit (CRU) and the Agricultural Production Systems Research Unit (APSRU) modelling capabilities to identify where and how cotton management can be improved and to deliver these outcomes to the cotton industry. Specific objectives will be to:

- to utilise the total modelling capacity of CRU (CERCOT) and APSRU (APSIM) to undertake a risk analysis study, for each cotton region, to provide information for better agronomic management, especially addressing the issues of soil fertility, nitrogen application, sowing date effects, use of limited irrigation water, varietal selection and row configuration

- to demonstrate the value of linking crop and soil monitoring with the predictive capability of a cropping systems model (APSIM) to make better decisions regarding planting options (crops), timing and fertiliser input requirements

- to assist with development and validation of stable parameters to quantify differences between cotton varieties and incorporate these into CERCOT, to allow the model to accurately reflect varietal differences in performance and enhance the value of predictions

- to involve industry in developing and implementing mechanisms for delivery of simulation outcomes and to provide access to information from this project for evaluation.

Background

The problems:
The consequences for profitability of many of the strategic decisions that growers and consultants make are being amplified by chronic water shortage within the main irrigated

cotton valleys over recent years. Margins have been reduced and every bale possible must be squeezed out of the resources that are available in any one season. For the increasing proportion of the industry facing severe shortages of water, important decisions include: how to best utilise limited irrigated water supplies, how much to plant, when to sow, what variety to sow (short or long season) and so on. As cotton has captured the attention of many farmers in the traditional dryland grain cropping regions of northern Australia, the above decisions, as well as the decision about which crop to plant, are relevant. Most of these decisions involve risk and many of the factors involved are unknown, eg when will it rain? In many of these situations, history can serve as our best guide to the potential risks or benefits of a particular strategy. This knowledge can be tempered with local information to provide a basis for making informed decisions with a reasonable understanding of the risks and benefits. The use of crop models is an ideal and often the only way to address these sorts of issues.

The Cotton Research Unit has considerable expertise in modelling and in the agronomy of cotton and over the years it has developed, first, the OZCOT cotton simulation model and more recently the CERCOT crop model. Both OZCOT and CERCOT provides a useful and very powerful tool for obtaining a long term historical perspective for specific problems in cotton production. Given weather information, basic soil physical and chemical characteristics, and a set of agronomic inputs the model can be used to determine potential yield for each year of weather data. The Agricultural Production Systems Research Unit (APSRU) was established to assist in improving the production efficiency, risk management, and sustainability of the dryland farming systems of northern Australia. APSRU's core expertise and research technology is in crop and soil management and in the computer simulation of crop production systems. The APSRU model is called APSIM (Agricultural Production Systems Simulator) and it has the capability to simulate many aspects of the cropping system, including a range of crops grown in rotation or with fallows. The cotton module in APSIM is the OZCOT model developed by CSIRO Cotton Research Unit at Narrabri.

Industry Significance

This collaborative project between the CRU and APSRU used models to provide access to information regarding the benefits and risks of crop and agronomic decisions, of critical value to the cotton industry, that would not otherwise be available. Furthermore, it considered the value of different approaches to ensure effective extension of this information to industry. This information has led to examples of better, more informed decision-making on-farm aimed at reducing risk and increasing profitability and sustainability. Specific points of significance are expanded on below:

a) risk analyses were conducted using the OZCOT crop simulation model and APSIM farming systems model to explore options and provide information to the cotton industry for existing and new regions on five key issues; cotton production with limited water, the effect of sowing date on yield potential, the optimal use of nitrogen fertiliser, the impact of row spacing and varietal selection. Application of crop models was an efficient means for this information to be made available to the cotton industry. Outcomes were presented in a form where growers, consultants and industry development officers were able to easily assess the associated risks of different management strategies in terms of yield and other state variables (soil water storage, mineral N etc).

b) the value of linking crop and soil monitoring with the predictive capability of a farming systems model (APSIM) was conclusively shown to assist growers in making better agronomic decisions, such as planting options or fertiliser requirements. This approach was tested by working closely with groups of dryland cotton growers and their consultants and providing them with better information on their soil, the performance of crops and the impact of their management decisions within the context of the whole climate record rather than a single season. To CRDC this provided an assessment of the value of combining on-farm research and simulation models in providing practical benefits to growers. For the industry it helped developed a framework by which use of models to assist in decision making could be extended to all growers, both dryland and irrigated. This project followed on from a previous pilot CRDC project (DAQ69) in which key issues in dryland cotton management were addressed using on-farm trials, crop and soil monitoring and simulation modelling.

c) the issues identified above come up repeatedly in requests to researchers and agronomists for information. This proposal provided the opportunity to make the relevant information widely available to growers and consultants and to consider different ways of using models to provide information. Furthermore, it provided the opportunity to use and capitalise on the power of our models, and to realise the value of the years of agronomic and physiological research and of the validation and calibration that have gone into their development.

Research Methodology and Justification

This project had three major components, the first was to undertake a detailed risk analysis for each region for key agronomic decisions such as nitrogen application, sowing date effects, use of limited irrigation water, varietal selection and row configuration. This was largely undertaken at CRU using OZCOT and CERCOT. The second component was to demonstrate the value of linking crop and soil monitoring with the predictive capability of a farming systems model (APSIM) to make better agronomic decisions and to evaluate the effectiveness of this means of communicating information from models. The third component was to assist with the collection of data to derive varietal specific parameters for the cotton crop simulation models. Details are given below:

a) Risk analysis - Growers and consultants are faced with the perennial problem of identifying the best strategy from a number of options. Dr Brian Hearn investigated these issues using OZCOT and long term weather data. He produced tables and charts of the risks in terms of yield probability distributions. These analyses need to be undertaken for a greater number of growing regions and management options (including nitrogen rates, irrigation management and sowing time).

b) Value of systems models - in 1994/95, CRDC funded a one year pilot project (DAQ69) in order to trial an approach to delivering benefits to a targeted group of dryland cotton growers by making use of APSRU's expertise in systems research. In this pilot project of on-farm research on dryland cotton systems, key issues in cotton management were addressed using on-farm trials, crop and soil monitoring and simulation modelling. Model credibility was established through simulation sessions with small grower groups and, once achieved, subsequent results were fed on to other growers and consultants through established grower networks. The response of participating growers and their consultants was very enthusiastic, both to the approach used by and the benefits resulting from this pilot study. This support was acknowledged by CRDC in its review of the pilot study (Dec. 1994).

c) Developmental parameters for varieties - A final objective of this project was to make OZCOT and CERCOT more variety sensitive. OZCOT and CERCOT use a suite of six 'genetic coefficients' to describe the genetic attributes of a variety. A detailed study prior to this project had been undertaken to establish differences between varieties for four of these parameters. The study showed that (i) there were differences between varieties in the parameters measured; (ii) the crop model responds as expected to these differences and (iii) but most significantly, the parameters as measured were not stable between different sowing dates or between years. Analysis indicated that the underlying assumption that the rate of development of the plant and fruit is linearly related to temperature was incorrect, it is more likely to be linear up to a maximum temperature, then to be constant or even decline slightly as temperature increases further. Preliminary analyses have indicated that using the latter assumption greatly improves the stability of some of these parameters. This approach will be investigated further in this project and will probably require some small field experiments.

Summary of Outcomes

A brief outline of the major results and outcomes from this project is given below. Research outcomes will be discussed under the relative objective headings. Where research has been written, published the appropriate reference in the list of publications is given.

To utilise the total modelling capacity of CRU (CERCOT) and APSRU (APSIM) to undertake a risk analysis study, for each cotton region, to provide information for better agronomic management.

In investigating the application of cropping systems models for strategic farm management we identified that it was necessary to conduct a multitude of simulations for different management scenarios for many regions. The output of the model simulations was used to undertake risk analyses across cotton producing regions. An example of the type of information produced is shown in the extract of the Dryland Cotton Production Guide attached to this report.

It was soon found that the amount of data created by the model would be difficult to handle without a detailed database system. The advantages of utilising a database would be that data for specific management scenarios could be accessed much more quickly, with greater precision and with much more control. A database was soon created for a range of specific management options for the major cotton growing regions. Information on crop risk was provided as Excel spreadsheets. Graphs taken from this database were used for the following initiatives and by participants in the cotton industry:

- Information provided directly to growers and consultants - This information mainly related to investigating the risks associated with production with limited water and the effects of sowing time

- Insurance and Financial firms – Over the duration of the project information on the relative risks and potential yield for different management options were provided to numerous insurance firms and financial firms. This information was used by insurance firms to help develop strategies for insuring different regions, while the financial firms used the information with growers to asses the potential yields and risks of cotton production in their financial planning.

- Extension officers and commercial seed companies - Strategic risk analyses were used by these people as part of their extension activities which included numerous presentations at field days.

- Best management practice group in Emerald – Strategic risk analyses were used by the Best Management Practice group in Emerald to confirm existing agronomic management strategies and to identify opportunities and possible limitations in their farming systems.

- Dryland Cotton Production Manual – Information taken from the database was used to derive strategic risks analyses for agronomic management to asses potential and risks associated with dryland cotton production for all cotton producing regions. (Shown in list of publications attached – Document 1).

- Specific databases were created to investigate potential cotton production and associated risks with different management options in new regions. They included irrigated production at Inverell, Richmond (Qld), and Windorah (Qld). Dryland cotton production was also investigated for Coonamble, Burren Junction, Trangie, Walgett, and Warren.

Other uses of the cotton simulation model for strategic risk analyses not specific to this project were:

- Strategic information derived from the database on the effects of sowing time on potential yield and crop development is being used in studies by Dr P. Wright to assist in investigation on the effects of poor early season growth 'cotton doldrums'.

- Strategic information on the effects of water allocation on the associated risks of production is being provided to the Department of Natural Resources in Queensland who are investigating the impacts of seasonal climate variability of streamflows on cotton production and profitability.

- While simulations were conducted for cotton production at Kununurra, the results have not been successful as predicted yields failed to match observed yields from dry season cotton production trials. Investigations with the help of Dr Brian Hearn are continuing to improve the models for dry season production in Northern Australia. There is an ongoing need to optimise the model for these environments.

Development is continuing on a decision support package using the 'Whopper Cropper' concept derived by Dr Graeme Hammer and Dean Holzworth at APSRU. In collaboration with APSRU a number of tools will be developed to conduct multiple simulations more effectively and to store and access model output more easily and graphically. Prototypes of these tools have already been developed.

Demand for information derived from the models has increased rapidly. The cotton industry development officers and other extension personnel in both the public and private sectors are significant users of model simulations in the 1998/99 season. New growers in both existing and new regions are using model outputs to investigate the potential of dryland cotton production, while both irrigated and dryland growers are using model information to evaluate potential effects of delayed sowing caused by the wet weather.

The dramatically increased demand for this type of information is a significant highlight of this project which indicates that the potential of models is now more widely accepted and understood by many elements of the cotton industry. Much of this acceptance can be attributed to the enhanced credibility of models in being able to simulate commercial yields. This was demonstrated through the FARMSCAPE approach employed by APSRU and CRU as part of this project. This is discussed further below.

To demonstrate the value of linking crop and soil monitoring with the predictive capability of a cropping systems model (APSIM) to make better decisions regarding planting options (crops), timing and fertiliser input requirements

This part of the project employed the FARMSCAPE approach. The methodology and examples of where this approach has been used is outlined in the invited paper to the 1998 Australian cotton Conference (Document No. 7 attached). Research was conducted to determine whether farmers could gain benefit from tools such as soil characterisation and sampling, climate forecasts and, in particular, simulation modelling and, if so, how such tools could be delivered cost-effectively. While APSRU managed this part of the project Dr M.P. Bange of the CSIRO Cotton Research Unit participated in all components of this research. Key outcomes of this research included:

- Established farmer networks. As part of FARMSCAPE activities, this project contributed to direct working relationships with a range of farmer and adviser collaborators - indicated in the following table. These collaborators from both the public and private sectors, have influenced project direction and provided strong support for continued development towards commercial application of FARMSCAPE tools and techniques.

Collaborator	*District*	*No. advisers*	*No. groups*	*No. Farmers*	*No. strips*	*Full Weather Stations*
IAMA Seed&Grain	Pittsworth	3	12	100	17	4
	Dalby	3	4	38	8	2
Michael Castor & Assoc. (MCA)	Goondiwindi	3	5	50	6	2
Mike Lucy, QDPI	Brookstead	1	2	10	25-35	2
Nevil Olm,	Brigalow	1	2	14		1

Landcare						
Mike Bange, Cotton Research Unit, Narrabri	Narrabri, Moree	3	2	8	5	1
Farmer initiated	Kupun	1	1	12	-	1
TOTAL		15	28	232	70	13

- Established a baseline of current management practices. Over the duration of the project FARMSCAPE, Peter van Beek (SyTREC Pty Ltd) has been contracted as an independent consultant to interview a range of project stakeholders to elicit information on both current and possible changes to management practice. To date, five consultancy reports have been completed (~100 interviews). Sufficient baseline data now exists against which the project's impact can be assessed.

- Train collaborators in soil & climate monitoring. A number of soil characterisation, soil monitoring and weather station training days have been conducted. A comprehensive soil monitoring handbook is being produced and is in final draft form. Training activities have been run by APSRU and have used outside experts such as Cliff Thompson (soil characterisation). Some collaborators have become active in providing water and N monitoring services to farmers. IAMA S&G has invested in several weather stations, two drying ovens and are building up their own soil characterisation database. Likewise, MCA is now providing soil monitoring services to its clients. Several farmers have equipped themselves with coring equipment and are doing their own coring and in some cases drying (using a micro-wave oven). Intensive soil monitoring has become a commercial management tool for many northern farmers.

- Train advisers in running APSIM. Fifteen agronomists have completed one day training courses on APSIM/OZCOT and received a workbook containing six exercises covering a wide range of APSIM applications. Evaluation of the course showed a very high level of appreciation for the course, the workbook and the APSFRONT user interface. Eight APSIM licences have been issued to farmer and adviser collaborators. While appreciation of APSIM/OZCOT is high, their use by collaborators has been limited through their high competency requirements and steep learning curve.

- APSIM/OZCOT tested against field measurements. All crops that have been monitored within the project (>30 over the past 12 months) have been used to test APSIM and OZCOT simulations. These tests have confirmed that these models are able to simulate commercial crop production in most cases. For many collaborators, APSIM/OZCOT have proved credible enough to be now employed in benchmarking the performance of their own crops. (Examples given in Documents No's. 2 & 7).

- APSIM/OZCOT has been used to extrapolate field experiments in time, using historical weather data. Over the past 12 months, 10 interactive sessions based on APSIM/OZCOT simulations have been conducted with collaborating farmers. In addition, the outputs of long runs have been presented in numerous media articles, to about 100 farmers in 12 IAMA groups, to about 50 farmer clients of MCA, a group of bank managers invited by QGGA, the Big Grain day at Roma, QGGA meetings, IAMA northern agronomy conference, Moree Conservation Farmers Association Farming Systems day, CSD/CSIRO review at Narrabri, a QGGA Precision Farming day and four CSD dryland farmer information days. Many topics of discussion related to dryland cotton production in farming systems. APSIM and OZCOT simulations have become a legitimate source of information to assist management of northern cropping systems.

- Evaluation of impact of collaboration on relevant behaviour of farmers and advisers. Under the guidance of Dr Jeff Coutts, UQ Rural Education Centre, a number of evaluation activities have been undertaken, including (i) "entry/exit" questionnaires at all interactive sessions, (ii) annual external evaluations conducted by Peter van Beek, (iii) targeted interviews with select stakeholders, and (iv) a mail survey of 150 farmers from the eastern Downs. The following is an extract from a recent paper by Coutts et al. "The evaluation process provided strong evidence that the project was having a positive impact on: learning within each participant group; attitudes, decision-making and practice. The evaluation highlighted the complexities in the management of dryland crops and the limitations of simulation aided decision making. However, the evaluation has shown that simulation, adequately contextualised, was valued by participating farmers and advisers in (a) gaining insights into production system function and (b) augmenting their farming experience in making judgements required in tactical responses and the evolution of improved production strategies." Tools and methods used in this project and techniques have had significant impact. (Document No. 10).

- Transfer capabilities to private consultants. The soil monitoring tools and APSIM/OZCOT have been made available to collaborating consultants through a series of training workshops. APSRU/CRU have also provided at-call help services to all collaborators and have contributed to a number of collaborator-initiated activities - eg. tailored simulations were undertaken for MCA and delivered to a client base of around 50 farmers. However, in most cases, the models have not being run directly by the consultants, for reasons attributed mainly to a lack of in-house expertise and time. In a innovative response to this constraint, an APSRU researcher, Zvi Hochman, joined IAMA Seed&Grain for a three month period as a "Scientist in Residence" in order to research the feasibility of an agribusiness firm, if it did have the capability, delivering APSIM services to its customers. IAMA's reaction to this experiment has been to increase their interest and investment in FARMSCAPE tools and techniques. There exists strong support for commercial delivery of FARMSCAPE tools via agribusiness.

- Provide FARMSCAPE data and information to farmer clients. APSRU/CRU has serviced requests for soil data and simulations for a significant number of farmers mainly through collaboration with agribusiness but also on an individual request basis - over 100 simulation scenarios have been conducted and delivered in the past 12 months – see details in previous section. One APSRU member, Natalie Brodie, has essentially been providing a full-time service for simulations to clients. The demand for simulations has increased rapidly to the point where neither APSRU nor CRU can meet demand, nor justify, providing a "commercial" delivery service.

- Carry out evaluation interviews, provide feedback and respond to views of stakeholders. On-the-spot evaluation of all interactive sessions has been introduced. External evaluation by Peter van Beek was found to be highly useful, and the re-deployment of resources to enable a change of emphasis in other areas (eg setting up of the web page, and instigation of the "scientist in residence" activity) have resulted from the evaluation activities. The van Beek evaluation reports make several references to changed practices, for example: "effects have been quoted by farmers and observed by others in a wide range of practices - using coring and soil testing; applying fertiliser; stubble mulching; crop and varietal selection; crop rotations; using limited irrigation water; investment decisions about water harvesting; soil surface management; land levelling; tram lining; and trying out new crops. Even when current crop rotations are the optimum choices (best practice) and firmly set, and where cropping practices are very advanced, the products are seen as useful scientific confirmation of these choices and practices. The existence of APSIM is valued as a stand-by for when prices and conditions change dramatically, as they will.". The evaluation activities have provided evidence of impact as well as giving direction as to future effort. A copy of an evaluation report is attached to this report (Document No. 14).

To assist with development and validation of stable parameters to quantify differences between cotton varieties and incorporate these into CERCOT, to allow the model to accurately reflect varietal differences in performance and enhance the value of predictions

In attempting to quantify the physiological and developmental differences between long and short season cultivars, two seasons of field experimentation and analysis of data were conducted in collaboration with Dr S. Milroy. Results showed that assimilate production did not differ between the cultivars, and light interception and assimilate partitioning were similar. Analysis of fruiting dynamics is presently being conducted. Further field experimentation is continuing to provide data sets for validation of the cotton model for different cultivars (ie. long and short) (Documents Nos. 3,4 & 6).

In addition to the field experimentation, we conducted a phytotron (controlled environment) experiment using short and long season cultivars. This experiment demonstrated that high average temperatures can actually slow crop development. Work is continuing to refine a degree-day function, which accounts for these effects of high average temperatures (Document No. 12).

Future Research

A new project (CSP98C) is already underway titled 'Delivering to industry the benefits of cropping systems models'. This focuses primarily on identifying and researching the most appropriate means of delivering systems simulation to industry clients. There is now significant market demand for access to cotton simulations. The key to having growers value systems simulation was the positioning of these simulations in the context of on-farm research, grower groups, soil characterisation, monitoring of the crops, soil and climate and "what if" analysis sessions. Although successful, this approach is not sustainable because of the high cost of scientists being so closely associated with growers and advisers and the limited number of beneficiaries from such an association.

The new project will have three major components in delivering results of systems simulation to industry:

1. **Enhanced role of systems models** - In CRDC project CSP67C key issues in dryland cotton management were addressed using on-farm trials, crop and soil monitoring, and simulation modelling. Model credibility was established through simulation sessions with small grower groups and, once achieved, subsequent results were fed on to other growers and consultants through established networks. The response of participating

growers and their consultants has been very enthusiastic. The same enthusiasm was expressed by irrigated growers who were part of these existing grower groups or were involved in other activities utilising simulation modelling capabilities (eg. best management practice workshops). This project aims to further explore the role of paddock monitoring and systems simulation in the commercial management of cotton by maintaining involvement with existing dryland grower groups and expanding efforts in irrigated cotton production.

2. **Assisting in the analysis of results from the CRC Farming Systems trials and in the extension of their outcomes to all cotton production regions -** In recognition of the increasing importance of crop rotations to maintain productivity in both irrigated and dryland cropping systems the CRC has established long-term farming systems experiments at a number of key locations. Certain aspects of these trials are being recorded in order to provide information on system sustainability. However, experimental measurements alone will be largely specific to the particular site and the run of the seasons that are encountered. Clearly, for the wider industry benefit, this farming systems initiative requires a means of extending lessons learnt beyond these trials to other cropping regions and future seasons. Part of this proposal is targeted at fulfilling this role, of employing systems simulation to assist in the interpretation and extrapolation of results for the benefit of the broader cotton industry.

3. **Undertake research into the appropriate means of delivery of systems simulation to industry clients** - This part of the project will involve researching some alternative means of delivering systems simulation to cotton industry clients. Two approaches have been proposed and their feasibility will be investigated:

(i) the development and delivery of the CERCOT crop simulation model in a form for use directly by industry clients - This will assist growers with agronomic decision making with issues purely related to cotton production (especially irrigated cotton). Development of a User -friendly version will also finally allow other researchers and extension personnel access to cotton simulation model. Developing and evaluating this approach will use the groups established as part of the first objective outlined in this project, as well as the involving the CRC development officers and other extension staff.

(ii) the development and support of a simulation capability within agribusiness and private consultantancy services to enable provision of simulation services to their clients – This approach will involve market research on the prospects for commercial delivery of simulation results (from APSIM and OZCOT via agribusiness consultants.

In addition to this new project other activities that are linked to this work, the cropping systems models (APSIM and OZCOT), and components of the FARMSCAPE approach are:

- Using the models for benchmarking cotton crop performance as part of the Cott-Check program being trialed at Moree.

- Water use efficiency studies conducted by Dr Sunil Tennakoon (Project CSP93C 'Assessing the water use efficiency on Eastern Australian cotton farms').

- Simulation results from OZCOT being used in the Whopper Cropper project initially in QLD. The project will use a database of cotton model simulation output for a range of crop management options for the major crops in the NE Australian cropping system and to use a friendly front end to interrogate this data base to examine production and economic risks associated with management options. The target client for Whopper is the public and private extension/adviser. The range of management options to be covered includes planting date, starting moisture, nitrogen management, planting density/arrangement, and crop maturity. The Queensland Centre for Climate Application has just employed a number of extension specialists who will be using this material in their planned new round of workshops on managing climate variability.

Publications arising from this Project

Bange, M.P. (1996). Dryland cotton potential yield and risk. In: Australian Dryland Cotton Production Guide. CRC for Sustainable Cotton Production. (no. 1)

Bange, M.P. and Carberry, P.S. 1998. Application of soil monitoring, benchmarking and crop simulation in commercial dryland cotton management. In Proc. 2nd World Cotton Conf. 6-12 Sep. Athens Greece. (no. 2)

Bange, M.P. and Milroy, S.P.(1998). Growth analysis of early and late season cotton cultivars. In preparation for submission. (no. 3)

Bange, M.P. and Milroy, S.P. (1998) Growth analysis of short and long season cotton cultivars. Proceedings of the 9th Australian Agronomy Conference, Wagga Wagga, N.S.W. 1989, pp. 415-416. (no 4)

Bange, M.P. and Milroy, P.S. 1998. Effects of specific leaf nitrogen on the radiation use efficiency of cotton. In Proc. 2nd World Cotton Conf. 6-12 Sep. Athens Greece. (no. 5)

Bange, M.P. and Milroy, S.P. 1996. Characterising the fruiting dynamics of commercial cotton varieties. In Proc. 8th Aust. Cotton Conf. 14-16 August, Gold Coast Aust. The Aust. Cotton Growers Research Organisation, pp. 215-219. (no. 6)

Carberry, P.S. and Bange, M.P. 1998. Using systems models in farm management. In Proc. 9th Aust. Cotton Conf. 10-14 August, Gold Coast Aust. The Aust. Cotton Growers Research Organisation, pp. 153-160. (no. 7)

Carberry, P. and Bange, M.P. (1996). Farming Systems Research - dryland cotton. In Proceedings of the soils and agronomy coordination meeting. Narrabri NSW. Cotton Research and Development Corporation and CRC for Sustainable Cotton Production. (no. 8)

Carberry, P.S., Hammer, G.L. and Meinke, H., 1998. The potential value of seasonal climate forecasting in managing cropping systems. Hammer, G.L. (Ed.), Application of Seasonal Climate Forecasting in Agricultural and Natural Ecosystems - The Australian Experience. Cambridge Uni Press (no. 9).

Coutts, JA, Hochman, Z, Foale, MA, McCown, RL, and Carberry, PS, 1998. Evaluation Of Participative Approaches To RD&E: a case study of FARMSCAPE. Proc. 9th Aust.Agron. Conf. pp. 681-682. (no. 10)

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Sadras, V.O., Bange, M.P., and Milroy, S.P. (1997). Reproductive allocation of cotton in response to plant and environmental factors. Ann. Bot. 80: 75-81. (no. 11)

Milroy, S.P. and Bange, M.P. 1998. Do Degree Days accurately describe rates of cotton development? In Proc. 9th Aust. Cotton Conf. 10-14 August, Gold Coast Aust. The Aust. Cotton Growers Research Organisation, pp. 209-214. (no. 12)

Milroy, S.P., Bange, M.P. and Sadras, V.O. (1998) Leaf nitrogen gradients in cotton canopies vary with ontogeny and nitrogen supply. Proceedings of the 9th Australian Agronomy Conference, Wagga Wagga, N.S.W. 1989, pp. 417-418. (no. 13)

Other Documents

Example report of FARMSCAPE evaluation from Peter Van Beek. (no. 14)

PLAIN ENGLISH SUMMARY

Project Title: Improved Cotton Management through the Application of Cropping Systems Models

Aims: To utilise the Cotton Research Unit (CRU) and the Agricultural Production Systems Research Unit (APSRU) modelling capabilities to identify where and how cotton management can be improved and to deliver these outcomes to the cotton industry.

Summary:
This project involved three major components, the first is to use the cotton crop model to undertake a detailed risk analysis for each region for key agronomic decisions such as nitrogen application, sowing date effects, use of limited irrigation water, varietal selection and row configuration. The second component was to demonstrate the value of linking crop and soil monitoring with the predictive capability of a farming systems model (APSIM) to make better decisions regarding planting options (crops), timing and fertiliser input requirements and to evaluate the effectiveness of this means of communicating information from models. A third minor component will be the derivation of parameters to enable the CERCOT crop model to more accurately simulate differences between cotton varieties (ie. between short and long season varieties). Major outcomes of the project were:

- Current significant market demand for access to cotton simulations.
- An established database of cotton model simulation output used to assess the potential yields and risks associated with different agronomic management options for many regions now available to industry on request.
- Demonstrated value in linking crop and soil monitoring with the predictive capability of a farming systems model (APSIM) to make better agronomic decisions.
- Clear direction on the most appropriate means of delivering systems simulation to industry clients resulting in the new CRDC project titled 'Delivering to industry the benefits of cropping systems models CSP98C'.
- Greater physiological understanding of the differences between long and short season cultivars leading to stable parameters for the cotton simulation model for biomass accumulation, partitioning and light interception.

Dryland Cotton Potential & Risk

Dryland cotton growers need not take uncalculated risks. Mike Bange from CSIRO Cotton Research Unit at Narrabri has used long term climatic records (90 to 100 years)and the OZCOT crop simulation mocel, developed by Brian Hearn, to study the prospects for dryland cotton production in the major cotton growing regions.

Rainfall in these regions differs greatly and generally the risk of less rainfall between the months of October and April is greater in the southern cotton growing areas (**Table 1**).

Table 1. Average rainfall for cotton producing regions between the months of October and April and between December and March (Source: *Australian Rainman*).

Region	Rainfall October to April (mm)	 December to March (mm)
Gunnedah	405	255
Wee Waa	387	251
Bellata	394	253
Moree	390	253
Croppa Creek	396	258
Goondiwindi	421	275
Dalby	489	319
Biloela	534	373
Emerald	496	363

Some assumptions used in this study were:

- Cracking clay soil storing 200 mm of available soil moisture in 1.5 m profile.
- Siokra variety.
- Row spacing 1 m.
- Established population of 7 plants per metre of row.
- Solid plant configuration.

Sowing Opportunities

The risk of failing to obtain a sowing opportunity was assessed for three, 30 day periods starting on September 15. A sowing opportunity was defined in terms of adequate soil moisture and temperature:

25 mm (1") of water in top 100 mm (4") soil;
18°C mean temperature for 3 days.

The Darling Downs and Gunnedah had a slightly lower risk of failing to sow for the 90 day period starting September 15 for dryland cotton production than for most other areas especially for the period October 15 to December 15 (**Table 2**). Recent experience in the region has confirmed this finding.

Fallowing

Growers can reduce the risk of not breaking-even if they plant with greater soil moisture. Fallowing between crops is a strategy to increase subsoil moisture which will reduce the risk of crop failure and increase average yield. **Table 3** (overleaf) shows that in all regions at least half a profile of soil moisture will increase yield significantly when the crop is sown on October 15.

Table 2. Probability of failing to sow based on the sowing rule for different periods starting September 15.

Region	Probability of failing to sow (%) Sep 15 to Oct 15	 Oct 15 to Nov 15	 Nov 15 to Dec 15	 Overall Sep 15 to Dec 15
Gunnedah	43	15	14	24
Wee Waa	49	18	25	31
Bellata	55	21	13	30
Moree	42	16	18	25
Croppa Creek	36	18	17	30
Goondiwindi	39	17	24	27
Dalby	52	10	10	25
Brookstead	44	13	12	22
Biloela	52	18	10	27
Emerald	50	33	17	33

Table 3. Effects of three starting soil moistures on yield (bales/ha) and chance of crop failure (%). Yields associated with 80% and 20% probability of exceedence are also presented.

Region	One Quarter of a Full Profile			One Half of a Full Profile			Full Profile		
	Mean	80%	20%	Mean	80%	20%	Mean	80%	20%
Gunnedah	**2.5**	0.7	4.1	3.5	2.2	4.7	**3.4**	2.2	4.7
Wee Waa	**2.2**	0.2	4.2	3.5	2.1	5.3	**3.6**	2.4	5
Bellata	**2.3**	0.7	4.3	3.5	2.3	5.2	**3.6**	2.4	4.9
Moree	**2.0**	0.4	3.1	3.4	2.1	4.6	**3.4**	2.3	4.6
Croppa Creek	**2.3**	0.5	4.2	3.7	2.2	5.3	**3.6**	2.3	4.9
Goondiwindi	**1.9**	0.1	3.6	3.4	2.2	4.7	**3.5**	2.4	4.4
Brookstead	**2.8**	1.5	4	3.5	2.5	4.6	**3.4**	2.4	4.4
Dalby	**3.3**	2.1	4.4	3.6	2.5	4.7	**3.6**	2.4	4.5
Biloela	**3.7**	1.9	5.4	4.3	3.2	5.5	**4.1**	3.1	5.0
Emerald	**3.2**	1.2	4.9	4.1	3.0	5.5	**4.1**	3.0	5.0

It also shows that a full profile is not essential for achieving higher average yields. If the crop is established it requires minimal soil moisture prior to first flower, thereby increasing the chance of subsequent rainfall providing useful moisture for later crop growth. In some cases a full profile increased the chance of waterlogging and reduced average yields.

Average yields, along with yields associated with 'Probability of exceedence' values, for each region are also presented in Table 3. This is used to indicate the yield variability that exists with different seasonal climatic conditions experienced in each region. An. 80% probability of exceedence means that there is an 80% chance of at least achieving the yield presented for that region.

The advantages of fallowing however, must be balanced against the loss of production when a successful crop could have been grown on the fallowed country. The risk of crops failing (0 bales/ha) from lack of moisture was eliminated when the profile was at least half full. However, other environmental factors ensure the risk is never completely eliminated.

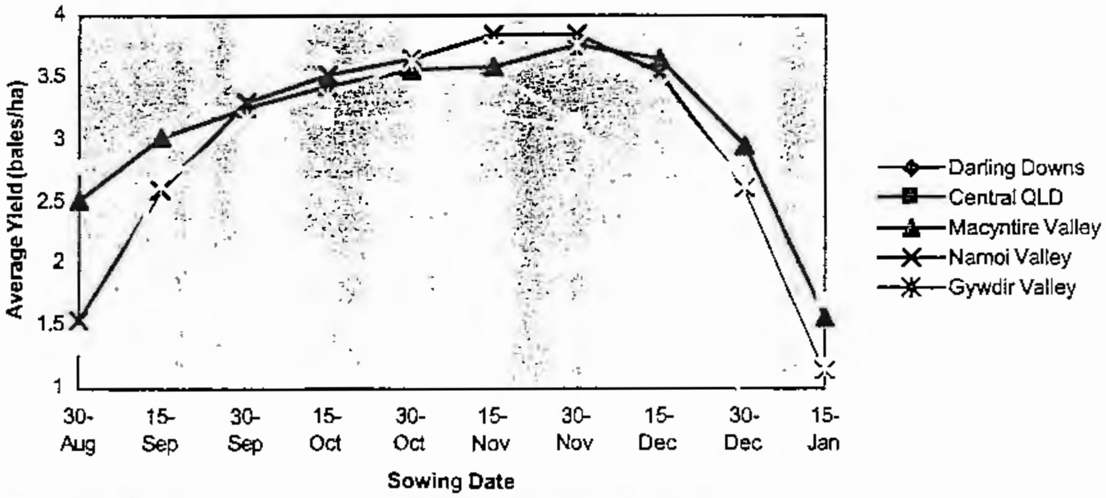
Time of sowing

In all regions average yields were less when crops are sown before September 30 (**Figure 2**). The latest sowing dates where there was no penalty to average yield is November 30 for all regions except the Darling Downs, where yield reduced after November 15. When considering the effect of sowing date on potential yield the timing of crop maturity must also be considered as rainfall at harvest can affect lint quality.

Skip Row Planting

Skip row planting reduces the risk of crop failure in years where rainfall is limiting. A comparison of solid plant yields with single skip

Figure 2. Sowing date effects on crop yield.



row yields showed that a skip row configuration performed better in environments that had less average rainfall and more variable rainfall (Table 4). The disadvantage of skip row however, was that in years where rainfall was high the solid plant configuration produced substantially higher yields.

Nitrogen Fertiliser

The addition of fertiliser N improved average yields in all regions. Increased averages were mainly due to those years where rainfall was high and crops were better able to utilise this nitrogen. Yields showed little response to nitrogen in low rainfall years in any region

Table 4. Proportion of years where a single skip row configuration performed better than solid plant configurations.

Region	Proportion of years better than solid plant (%)
Wee Waa	68
Moree	74
Bellata	74
Croppa Creek	57
Goondiwindi	56
Brookstead	54
Dalby	76
Biloela	51
Emerald	60

CONCLUSIONS

Growing dryland cotton is subject to relatively large risk, not only in achieving yields but also because costs are a high proportion of income. Therefore, the potential and risks associated with dryland production need to be calculated.

Risk can be reduced where dryland cotton production forms part of a mixed cropping enterprise or, is undertaken in conjunction with irrigated cotton production where water allocations are unreliable.

Document 2

Application of soil monitoring, benchmarking and crop simulation in commercial dryland cotton management

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ABSTRACT

Many agronomic decisions involve risk as many of the factors involved are unknown or uncertain (eg. rainfall). History can often serve as our best guide to the potential risks and benefits of a particular strategy. The use of crop simulation models is a powerful, and often the only, way to address such issues. Participatory research approaches were used to address key issues in dryland cotton management through on-farm trials, crop and soil monitoring, and simulation modelling (OZCOT and APSIM). Model credibility was established through simulation sessions with small groups of farmers. Subsequently the results provided farmers and consultants with information on their soil, benchmarked performance of commercial crops, and provided an assessment of the impact and risk of their management decisions within the context of the whole climate record rather than a single season. The results were also provided to other farmers and consultants through established networks. Future studies aim to investigate the more efficient means of delivering systems simulation to industry.

Introduction

Australian dryland cotton farmers face increasing pressures with rising production costs in a rainfall environment that rates among the most variable in the world. Adding to this, farmers also face uncertainty about the amount of water and nitrogen that is stored in their soil. Farmers can overcome much of this variability by achieving a greater understanding of their soil and linking this information with crop simulation models.

Simulation models can predict the performance of crops under different environmental and management conditions. They are a means of easily and efficiently achieving understanding and gaining "experience", without suffering the consequent pain and cost of real-life experience when mistakes are made.

The questions remain, however, as to how well simulation models perform in relation to commercial agriculture and how can industry make use of these tools? Scepticism on the applicability of models is neither due to their rarity nor lack of exposure. While many computerised decision support systems (DSS) have been developed and/or supported in Australia farmer acceptance has been disappointing low (Cooke, 1994).

The first objective of this paper is to relate the experiences of some cotton farmers and consultants which have benefited from monitoring their soil and crops, benchmarking their cropping system, and applying systems models in their farming operations. The second objective of this paper is to describe a recent effort employing a participatory action research approach within the Australian cotton industry towards commercial delivery of systems simulation. This approach has important distinguishing features from past efforts into decision support systems.

Participatory Research

FARMSCAPE (*Farmers, Advisers, Researchers, Monitoring, Simulation, Communication And Performance Evaluation*) (McCown et al., 1998) is an acronym employed to represent a participatory action research approach that explicitly addressed the question of relevance of systems models to commercial farming. Using an action research approach allows for an evolution of a research methodology rather than limiting understanding and outcomes through undertaking traditional scientific experimentation. In the context of 'farming systems research' hard systems tools (models) have been used in interactions with the FARMSCAPE participants in ways that utilise soft systems methodologies (McCown et al., 1998). The research explores whether any farmer or adviser could gain benefit from tools such as soil characterisation and sampling, seasonal climate forecasts and, in particular, simulation modelling and, if so, how such tools could be delivered cost-effectively to industry. FARMSCAPE has been based on the key elements identified in its name:

(i) close collaboration of farmers, their advisers and researchers in groups discovering together how best to explore management options;
(ii) implementation of research on farms, especially incorporating improved soil monitoring to gain better knowledge of soil water and nitrogen in individual paddocks;
(iii) application of the APSIM systems model (McCown et al 1996) linked with the OZCOT cotton model (Hearn, 1994) with a requirement that simulations be credible against real-world experience;
(iv) the broader communication of project outcomes not only through public extension activities but particularly through agribusiness client services, and
(v) continual assessment of project activities and impacts via formal evaluation processes.

Direct working relationships have been established with over 200 farmers and 15 advisers who have influenced research direction and provided strong support for continued evolution of the FARMSCAPE tools and techniques.

Crop and soil monitoring

Farmers benefit from understanding their soils and knowing the current status of their soil nitrogen and water availability. This information while initially collected to parameterise and initialise the simulation models has become in itself a valuable source of information for farmers. Participatory research activities involving co-learning between the researchers, farmers and advisers have allowed for the development of robust and inexpensive equipment that allow simple characterisation of the soil with respect to plant rooting depth and plant available soil water holding capacity; and to allow rapid measurement of soil water and nitrogen status at depth (Foale et al., 1997). Farmers are using this information to change management practices such as fertiliser rates or crop selection, or to confirm their existing strategies (Dalgliesh et al., 1998).

Monitoring crops is also important in order to establish model credibility and relevance to commercial farming practices. Commercial cotton crops have been monitored and used to test OZCOT simulations (Fig. 1). Most crops where predictions were significantly different, discrepancies were mostly due to impacts of factors not accounted for in the models (eg. severe pest damage). For many farmers and consultants, APSIM and OZCOT have proved credible enough to be relevant to commercial cropping practices and now use them in benchmarking the performance of their own crops and in exploring alternative management strategies.

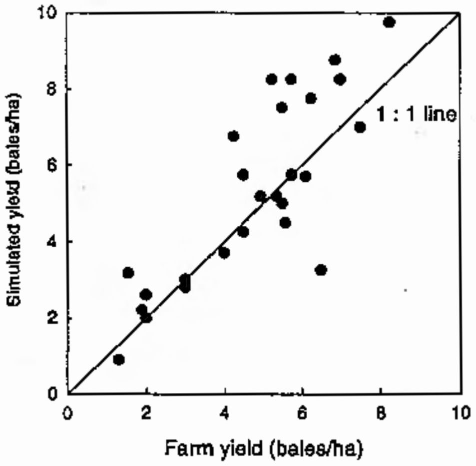


Figure 1: Predicted yields versus commercial crop yields.

Crop simulation in commercial crop management

The following sections provide several examples of how simulation has been used in commercial management.

Benchmarking performance of commercial crops

Whether a crop has performed to its potential is often of great interest to farmers. Given actual seasonal climate and management inputs, models are used to predict what a crop should have yielded in the absence of extraneous factors, thus providing a benchmark against which actual crop yield can be assessed. The models are then used as a learning tool to explore other management options which could have been use to better yields in a particular season. If an option is more successful it can then assessed using simulation within the context of the whole climate record rather than a single season.

Strategic decision making

A common and useful application of simulation models is to explore new options or environments as general scenarios that are broadly relevant to a region or group of farmers. An example of this is taken from a group of farmers investigating the potential of dryland cotton production. The OZCOT cotton model was run with inputs generated by the farmers and a local consultant in order to generate risk analyses and gross margins for dryland cotton assuming a full and half a profile of soil water at sowing time (Table 1).

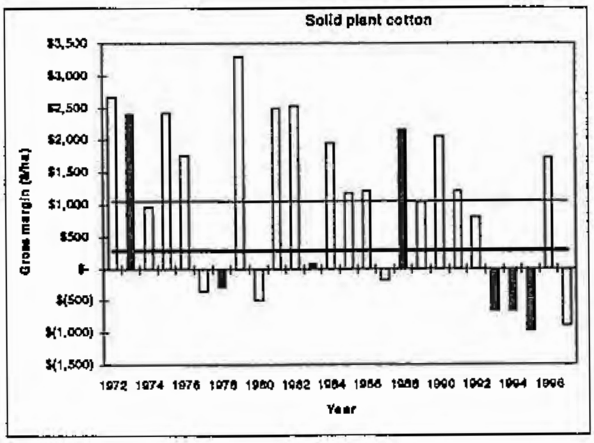
Table 1: Information provided to farmers to assess risk of dryland cotton production.

Outcome	Probability of Achieving Outcome (%)	
≥ Greater than or equal to	Full Profile Soil Moisture	Half Profile Soil Moisture
≥ 1.70 bales/ha (0.7 bale/ac breakeven)	84	78
≥ 2.47 bales/ha (1.0 bale/ac)	63	53
≥ 3.71 bales/ha (1.5 bales/ac)	43	34
≥ 4.94 bales/ha (2.0 bales/ac)	32	22

The resultant predictions were mostly consistent with the expectations of both a neighbouring cotton farmer and the local consultant. While there was risk, the farmers considered the risk in crop failure was not much greater than that for their other crops. The group discussed offsetting this risk by limiting the area of cotton in relation to their other summer crops. While some growers decided to grow cotton it is important to note that this simulation exercise did not make the decision for the farmers, but merely provided them with another source of information to assess the returns and risk of a new farming option.

Tactical decision making

The APSIM or OZCOT models can be used in planning for the current or upcoming crop. Decisions on crop choice, varietal selection, fertiliser rate, sowing date, plant population, row configuration and so on can be assessed based on knowledge of pre-plant soil water, soil chemical analysis and seasonal climate outlook. Based on this information, the models can provide an assessment of expected crop performance in the upcoming season by simulating what would have happened under these same conditions in past years for which climate records exist. Figure 2 presents an example for cotton planted as either solid or single skip row configuration under low starting soil water conditions. The farmer for whom these simulations were undertaken, changed to single skip cotton in the 1997/98 (*El Nino*) season rather than his normal solid plant configuration. Another significant advantage of APSIM is that it is a model of a cropping system, able to simulate the production and environmental consequences of different crop rotations.



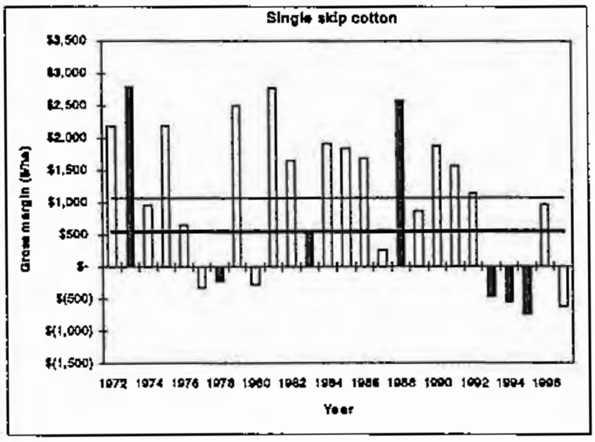


Figure 3: Predicted gross margins for solid and single skip cotton crops. Solid bars represent *El Nino* seasons, the average for which is represented by the horizontal thick line, whereas the thin line is the average over all seasons.

Learning and Evaluation in FARMSCAPE

FARMSCAPE is a research activity that recognised early on that, in exploring ways in which farmers could better manage their farms, then farmers needed not only to be consulted on the design of what should undertaken, but they also needed to participate in the implementation of the research and the interpretation of its outcomes. In other words, instead of using scientific models to build derivative tools which scientists believed could help farm managers (such as a computerised Decision Support System DSS), base models were taken to farmer and advisers to design and test applications for their own situations. What emerged has been confirmation of the benefits of farmers gaining better knowledge of their water and nitrogen resources through increased intensity of soil monitoring and the discovery of a role for systems models in assisting the management of cropping systems.

Assisting in this learning and steering the direction of the research has been the formal evaluation component of FARMSCAPE. The evaluation process sought to monitor and interpret the project through the eyes of all participants in a longitudinal study. Through iterative interviews of participants this provided an effective mechanism to capture perceptions, learning and management practice changes (Coutts et al., 1998).

FARMSCAPE has helped demonstrate that the key to farm managers valuing simulation is the positioning of simulations in the context of their own farming situation. In contrast, many DSS packages, provide generic or representative information for a district, they depend on plausible answers (as many of their assumptions cannot be tested using one's own data), and many DSS are generally targeted at single or few issues. Another important distinguishing feature is that many DSS packages have been designed to provide recommendations on what decisions should be taken. The FARMSCAPE approach however, leaves the interpretation to the farmers, while providing a means of learning about their farming systems.

The Future

Developing the FARMSCAPE approach and tools to the point of commercial delivery is the next step for this research and development activity. A market now exists for timely and high quality interactions based on soil monitoring and simulation amongst a significant sector of the dryland farming community. Formal evaluation of the current FARMSCAPE project has demonstrated impacts on participating farmers and advisers. The demand for simulations has increased rapidly to the point where researchers cannot meet the demand, nor justify providing a "commercial" delivery service. One preferred delivery mechanism is to establish and support an Accredited Adviser Network of agribusiness and private consultants for delivering simulation and related products. Finally, on the research front, the intention is to continue exploring the role for simulation, expanding to include irrigated cotton production systems and include other agribusiness service sectors (bank lenders, crop insurance, product inventory, marketing advice, etc.). Whether better information on seasonal climate forecasting and cropping prospects can improve institutional decision making is an emerging area worthy of further exploration.

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Document 3

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Growth analysis of early and late season cotton cultivars

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Abstract

There is a need for cotton simulation models to be able to differentiate between early and late maturing cultivars. Cotton is an indeterminate species; the timing of crop maturity is determined by the capacity of the plant to continue the production of new fruiting sites. According to the nutritional hypothesis, the cessation of fruit production ('cutout') occurs when the demand for resources by growing fruit leaves none for the initiation of new fruiting sites. Fully irrigated field experiments were conducted in which early and late maturing cultivars were sown on different occasions. Growth analysis was used to ascertain whether differences in resource supply occurred between the cultivars which could contribute to differences in crop maturity. The production of dry matter, as a function of radiation use efficiency (RUE) and light interception, and its partitioning to different plant parts were calculated as indirect measures of carbon supply.

Differences were found in the total dry matter production of the cultivars but not in the dry matter partitioning. The early cultivar produced more dry matter due to greater light interception and RUE. The difference in RUE persisted after adjustment for the energy content of different organs. Light interception was greater due to an earlier production of a larger canopy and not differences in light extinction coefficient. These differences do not explain the differences in maturity. Intra-season changes in RUE occurred with the fall in RUE of the early maturing cultivar occurring just prior to a rapid reduction in square (flower bud) numbers. It is hypothesised that this may have been involved in determining the timing of cutout in this cultivar.

Additional keywords: *Gossypium hirsutum*; growth; development; radiation use efficiency; light interception

1. Introduction

There is an increasing need for simulation models of cotton (*Gossypium hirsutum* L.) to account for differences in the timing of crop maturity or 'earliness' of cultivars in different environments because it is an important consideration in crop management. Late maturing cultivars are suited to regions with longer growing seasons, while early maturing cultivars are used in short season areas, for late plantings, or to avoid late season pest infestations.

Cotton is an indeterminate species. The timing of crop maturity is not directly governed by temperature and photoperiod, but is determined by the capacity of the plant to continue the production of new fruit. As the fruit load on a crop increases, the rate of production of new fruiting sites (hence flower buds, 'squares') decreases and eventually ceases (Ehlig and LeMert, 1973; Patterson et al., 1978). The cessation of fruit production, commonly termed 'cutout', is generally considered to result from the monopolisation of resources, nitrogen or carbohydrate, by fruit that are already growing, resulting in a limitation of resources for the production of new sites (Hearn, 1981; Hearn and Constable, 1984; Guinn, 1985) although the involvement of plant hormones cannot be excluded (Guinn, 1986). The simulation of fruiting dynamics in the cotton simulation model OZCOT (Hearn, 1994) is based on this approach. Using a surrogate for carbon supply/demand ratio, the model successfully simulates the dynamics of fruit production and timing of crop maturity. The rate of fruit production in OZCOT is described by the following equation:

$$\frac{dS}{dT} = q\sqrt{S}\left(1 - \frac{B}{C}\right)$$

Hearn and da Roza (1985). The squaring rate constant (*q*) is a cultivar specific parameter which determines the potential rate of site production in thermal time, T (base=12°C). *S* is the number of fruiting sites already present per plant. The boll load (*B*) is a sum of the number of bolls on the plant weighted for age. Carrying capacity (*C*) is the number of bolls that can be maintained by the plant's carbon assimilation. The relationship of *B*/*C* represents the balance of carbon supply (*C*) and demand by the fruit (*B*). As the ratio B/C increases, site production is reduced below its potential rate. When $B/C = 1$, site production ceases; cutout occurs.

Within this framework, a change in *C* through changes in the capacity of the plant to supply carbon, will effect site production thence cutout and ultimately crop maturity. On the other hand, the demand for resources will be affected by the rate of fruit production, the proportion of fruit that survives, boll period (the time it takes for a boll to mature), and the potential size of the individual bolls (Hearn and Constable, 1984).

OZCOT has been used as a tool for strategic (Hearn, 1992, 1995) and policy level (Dudley and Hearn, 1993) decision making. While OZCOT is a good generic simulator of cotton crops (Hearn, 1994) it lacks the capacity to simulate the difference in behaviour of early and late cultivars. Wells (1994) attempted to measure cultivar specific parameters for OZCOT in the field, but found that they were not stable between different sowing times, or between experiments. He suggested that an improved method of accounting for the environmental effects on fruiting development needed to be derived.

If the timing of crop maturity in cotton is determined by the carbon balance of the plant, to be able to reliably predict the maturity of different cultivars we need to identify whether differences in carbon supply exist, and whether production and development of fruit differ. This study specifically compares the physiological determinants of crop growth of an early and a late cotton cultivar which determine the supply of carbon to the crop which may affect carrying capacity and hence influence crop maturity. Subsequent investigations will investigate production and development of fruit.

2. Materials and methods

2.1. *Cultural details*

Two field experiments were conducted at the Australian Cotton Research Institute (ACRI) and one on a neighbouring farm at Narrabri (30° S 150° E), in a semi-arid environment of north-west New South Wales, Australia. Two okra leaf cultivars, Siokra S324 and Siokra L22 (hereafter S324 and L22), were used in all experiments. S324 is an early maturing cultivar used for late plantings or in shorter season areas while L22 is later maturing and suitable for longer, hotter growing areas. All experiments were sown with a commercial row crop planter.

The first experiment (Exp. 1) sown at ACRI consisted of three sowing times and two genotypes arranged factorially. Plots (4 m by 75 m), containing four rows spaced at 1 m, were sown on 10 October (S1), 20 November (S2) and 5 December 1995 (S3). A completely randomised design was used with four replications.

The second experiment (Exp. 2) also sown at ACRI consisted of two sowing times with two genotypes arranged factorially. Plots (8 m by 20 m), containing eight rows spaced at 1 m, were sown on 11 October (S1) and 13 November (S2) 1996. For this experiment a randomised complete block design was used with four replications.

The third field experiment (Exp. 3) sown in the same season as the second experiment but on a neighbouring farm had a single sowing time using the two genotypes. Plots (4 m by 150 m), containing four rows spaced at 1 m, were sown on 14 October (S1) arranged in a randomised complete block design with three replications.

All experiments were established and grown with full irrigation on a grey-clay soil utilising high input management and insect control as described in Hearn and Fitt (1992). Nitrogen was applied as anhydrous ammonia at a rate of 150 kg ha^{-1}, 62 days before the first sowing in Exp. 1, 113 kg ha^{-1} 44 days before the first sowing in Exp. 2, and 142 kg ha^{-1}, 61 days before sowing Exp. 3.

Meteorological data for the experimental period was measured 2 km from the sites at a fully serviced weather station. Daily maximum and minimum temperatures, and incident solar radiation were measured throughout the experimental period (Fig. 1).

2.2. *Measurements*

Plants samples were taken approximately fortnightly from each plot starting just prior to the appearance of the first square in each sowing. Sampling involved taking all plants from within one metre of row, selected randomly from the inner two or four (from eight row plots) rows of each plot. Total fresh biomass was measured and a sub-sample of four plants was taken for partitioning and dry matter determination. Sub-samples were partitioned into green leaf (laminae), stem (including petioles), tap root, squares, green bolls and open bolls. The number and type of fruit were recorded. A square was defined as being present when the leaf that subtended the square had unfolded. Leaf area was measured in each sub-sample using a leaf area planimeter (Licor 3100, Nebraska, USA).

All samples were dried in a forced draught oven at 70° C for at least 48 h, weighed and measurements were then converted back to m^{-2} basis using a drying ratio. Masses are presented on an oven-dry basis. Dried samples were ground to pass through a 2 mm sieve. Samples were analysed for nitrogen content using Near Infrared Refractometry (Perten Inframatic 8100, Germany).

Measurements of photosynthetically active radiation (PAR, 0.4-0.7 μm) were taken in each plot above (PAR_O) and below of the canopy (PAR_T) at approximately weekly intervals. Three measurements were made on each plot using a ceptometer (Decagon, Delta-T Devices Ltd., Cambridge, UK) between the 1100 and 1300 hours (Eastern Standard Time).

2.3. Data analysis

The proportion of radiation intercepted by the crop (Q_I)was calculated as:

$$Q_I = \left(PAR_O - PAR_T\right) / PAR_O.$$

Because light interception measurements were not always taken on the same day as the biomass harvests, Q_I was then regressed on days after sowing (DAS) to allow interpolation between measurements. An exponential function was fitted to data collected from each plot:

$$Q_I = a\left[1-\exp(-bDAS)\right]+c \qquad (1)$$

where a, b, and c are fitted coefficients.

Using values of Q_I for the day of the biomass harvests as derived from equation 1, a canopy light extinction coefficient (k) was derived for each plot from a non-linear regression between Q_I and leaf area index (LAI):

$$Q_I = d\left[1-\exp(-kLAI)\right]+e \qquad (2)$$

where k is the canopy extinction coefficient, d and e are fitted coefficients. Treatment effects on k were tested using forward stepwise regression analysis.

LAI was calculated using the product of specific leaf area of sub sample and the total mass of leaf material (m^2), both measured at each biomass harvest. Specific leaf nitrogen (SLN), which is the amount of nitrogen (g) per unit of green leaf area (m^2), was calculated as the quotient of leaf nitrogen concentration and specific leaf area.

Charles-Edwards and Lawn (1984) reported that the proportion of intercepted PAR for a day is under estimated if instantaneous measurements are used instead of integrating them over the day. Therefore before deriving radiation use efficiency (RUE, g MJ^{-1}) Q_I was adjusted using their relationship:

$$Q_D = 2Q_I / (1 + Q_I)$$

where Q_D is an estimate of the proportion of PAR intercepted over the day. Again because light interception measurements were not always taken on the same day as the biomass harvests, Q_D was then regressed on days after sowing (DAS) to allow interpolation between measurements using a function of the same form as equation 1.

Average RUE for the season was derived from the linear regression of shoot biomass against cumulative intercepted radiation (RUE_{dm}). In Exp. 1 measurements were used from 67 to 131 DAS in S1, 41 to 111 DAS in S2, and from 48 to 90 DAS in S3. In Exp. 2 measurements were used from 54 to 137 DAS in S1, 34 to 119 DAS in S2. Measurements were used in Exp. 3 from 59 to 162 DAS.

To account for the high cost of synthesis of cotton fruit relative to vegetative tissue, biomass was converted to glucose equivalents using production values (g glucose per g dry matter) from Wall et al. (1994) for cotton leaves, stems, roots, squares and fruits. A glucose adjusted total dry matter (TDM_g) could then be derived. RUE was thence also derived in glucose equivalents (RUE_g).

In all experiments, variation in RUE_g within the crop life cycle was examined by deriving RUE_g for periods including three consecutive dates of dry matter and PAR measurements. Regressions were centred on harvests from 77 to 117 DAS in S1, and from 57 to 97 DAS in S2 for Exp 1. In Exp. 2 the regressions were centred from 67 to 122 DAS in S1, and from 50 to 104 DAS in S2. Finally in Exp. 3 regressions were centred from 70 to 147 DAS. This method is similar to that employed by Sadras (1996).

Significant differences are expressed at the 95% ($P<0.05$) confidence level unless otherwise stated.

3. Results

3.1 Fruit Production

Cultivar S324 developed significantly higher peak number of squares than L22 in five of the six sowings (Figures 1 & 2); the exception being S2 in Exp 2. In all cases the rate of increase in square numbers was greater in S324 than L22. It should be noted that this rate will be effected both by the rate of square production and the degree of early shedding.

The higher peak square number of S324 was generally translated into a higher peak number of green bolls (Figures 1 & 2). The exceptions were S1 in Exp 2, where the two cultivars showed very similar patterns of green boll numbers over time, and the very late sowing (S3) in Exp 1 in which development of the crop was severely truncated. Reflecting the rate of increase in square numbers in S324, this cultivar set a larger number of green bolls sooner than L22. Interpolating between sampling dates indicates that S324 set 100 green bolls m^{-2} at least ten days earlier than L22 in four out of five cases. In S1 of Exp 2 it was only three days earlier.

S324 produced more open bolls in each of the normal sowing times (Figures 1 & 2): Exp 3 and S1 in Exp 1 and Exp 2. For the November sowings in Exp 1 and Exp 2 the cultivars produced similar numbers of open bolls at similar rates.

Fruit numbers varied between sowings. Excluding S3 in Exp 1, the peak number of squares varied between 160 and 235 m^{-2} for S324 and 120 and 190 for L22. Peak green boll numbers also varied but to a lesser extent: S324 ranged between 130 and 160 m^{-2} and L22 between 100 and 120 m^{-2}. In S3 of Exp 1 the peak square number was 155 for S324 and 90 for L22, these numbers were translated into only 65 and 50 green bolls respectively.

3.2. Dry matter production

Total above ground dry matter production converted to glucose equivalents (TDM_g) from each sampling date was plotted against DAS (Fig. 3). In Exp. 1 S1 cultivar S324 was greater at 89 and 105 DAS and then later at 161 DAS. In Exp. 2 S2 TDM_g for S324 was again greater between 57 and 83 DAS then later at 132 DAS. The third sowing of Exp. 1 had no apparent differences in TDM_g between cultivars. Greater TDM_g was achieved in S1, followed by S2 then S3, although S2 and S3 produced biomass earlier.

In Exp. 2 S1 there was no consistent difference in TDM_g. For S2, TDM was similar until 76 DAS then S324 was greater on 89, 104 and 131 DAS. Finally in Exp. 3 there were no apparent differences in TDM_g throughout the season.

Total fruit dry matter glucose adjusted in Exp. 1 was simular until 117 DAS in S1, 83 DAS in S2, and 90 DAS in S3 (Fig. 3). After these times in all sowings S324 had greater fruit biomass. In Exp. 2 S1 fruit biomass was simular until 94 DAS and on at 164 DAS, but S324 was greater between 109 and 137 DAS. At 152 DAS L22 had greater fruit biomass. In Exp. 2 S2 fruit biomass was simular until 89 DAS and on at 131 DAS, but S324 was greater on 104 and 119 DAS. At 145 DAS L22 had greater fruit biomass. Finally for Exp. 3 there were no apparent differences in total fruit biomass.

3.3. Radiation interception and leaf area index

Equation 1 was fitted to radiation interception data collected from each plot and allowed interpolation of Q_D between measurements. For each plot the responses were used in conjunction with daily PAR to derive accumulated intercepted PAR for the period of measurement. In Exp. 1 cultivar S324 intercepted significantly more radiation than L22 in each sowing during these periods (Table 1). There were no significant differences between cultivars in Exp. 2 or Exp. 3. In addition there were no differences between sowings in Exp. 2 (Table 1).

In each sowing of Exp. 1, S324 intercepted a higher proportion of light sooner than L22, but by the end of the season L22 had attained the same level of light interception as S324. There were no apparent differences between cultivars during growth of the crop in experiments 2 and 3.

LAI differed significantly between cultivars and across cultivars (Fig. 4) in Exp. 1. In each sowing S324 developed its canopy sooner than L22. Higher peak LAI was produced by both cultivars in S1 followed by S2 then S3. As for light interception, LAI increased later in S1 than in S2 and S3.

In Exp. 2 LAI did not differ between cultivars in S1, but in S2, S324 was significantly greater than L22 between on 89 and 104 DAS. LAI remained high for a longer period of crop growth in S2 compared to S1 and as in Exp. 1, the canopy took longer to begin to develop in the earlier sowing. In Exp. 3 L22 had greater LAI on 129 DAS, while S324 was greater on 147 DAS. The differences between cultivars in

LAI between cultivars in experiments 2 and 3 did not correspond to any differences in light interception.

Using data from all replicates, equation 2 was used to fit a regression of Q_I against LAI to estimate canopy light extinction coefficient (k). Forward stepwise regression analyses were used to test for differences between cultivars and among sowings for each experiment. No significant differences between cultivars were found in any experiment. Pooled across times of sowing and cultivars, k was 0.75 (±0.13, $P < 0.05$) in Exp. 1 and 0.74 (±0.14, $P < 0.01$) in Exp. 3. In Exp. 2 differences were identified between sowings. The k value for S2 (0.58±0.04, $P < 0.01$) was significantly less ($P < 0.05$) than for S1 (0.68±0.03, $P < 0.01$).

3.4. Radiation use efficiency

RUE_{dm} was derived as the slope of the linear regression of total above ground dry matter against accumulated intercepted PAR. Again, forward stepwise regression analyses were used to test for differences between cultivars and among sowings (Table 2). In Exp. 1, significant differences were found between cultivars; S324 being greater than L22 when pooled across sowings. In Exp. 2 the cultivars had similar RUE_{dm} in S1, but in S2 S324 had a significantly greater RUE_{dm} than L22. Similar results were obtained when RUE was based on glucose equivalents (RUE_g). There were no significant differences between cultivars in RUE_{dm} or RUE_g in Exp. 3. No significant differences across sowings were found in experiments 1 and 2.

RUE_g calculated for shorter time periods showed different patterns in RUEg over the development of the two cultivars. In Exp. 1, RUE_g for S324 was greater than that for L22 at 77 and 89 DAS in S1, and at 57 DAS in S2 in Exp 1 (Fig. 5). In Exp. 2 S1 there were no differences between cultivars, however, in S2 RUE_g of S324 was greater than cultivar L22 at 89 DAS. In Exp. 3 there were no differences between cultivars throughout the duration of crop development (Fig. 5).

3.5. Specific leaf nitrogen

Trends in specific leaf nitrogen (SLN) over time were similar for the two cultivars in both experiments 1 and 2 (Fig 6). No leaf nitrogen measurements were taken in Experiment 3 in b. In Exp. 1, S1 and S3, and in both sowings of Exp. 2 SLN generally declined over the period of measurement whereas in S2 of Exp. 1 there was an initial significant increase prior to the decline. Substantial differences between the cultivars rarely occurred across all sowings.

3.6. Dry matter partitioning

When considered on a harvest by harvest basis, fruit dry matter of S324 tended to be higher than for L22. This only sporadically reached significance. As S324 also tended to have a greater total dry matter, to test whether there was a significant trend for one cultivar to partition more dry matter to fruit over time, a distribution index (DI) for the partition of dry matter to fruit was calculated for the interval between each sampling. This was derived as the ratio of the increment in fruit dry matter to the increment in total dry matter over the interval expressed in glucose equivalents. DI for L22 was plotted against DI for S324 using data up to the time of peak green boll number from all experiments (Fig. 7). The regression line fitted through this data had a slope of 0.70 which was significantly different from unity ($P<0.001$). This indicated that S324 partitioned significantly more dry matter to the fruit during the initial period of boll growth than did the other cultivar. A single regression held over both years and all times of sowing.

4. Discussion

The aim of this experiment was to determine whether or not there were differences in the dry matter production or partitioning of a late and an early cotton cultivar which could have contributed to the differences in crop maturity. Differences were found between S324 and L22 in terms of accumulated light interception and radiation use efficiency as measured over the whole period of measurement but not in a way that explained their respective maturities.

Acknowledgements

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Tables

Table 1. Accumulated intercepted PAR (MJ) for cultivars S324 and L22 for each sowing and experiment.

Experiment	Sowing	Cultivar S324	Cultivar L22
1	1	657	611
	2	753	724
	3	394 (CM 601)	385 (CM 573) †
2	1	626	602
	2	602	611 (GM 609)‡
3	1	780	776 (GM 768)

† LSD (least significant difference, $P < 0.05$) = 28.02 MJ for cultivar means (CV)

‡ Grand Mean

Table 2. Radiation use efficiency calculated from dry matter (RUE_{dm}) and glucose equivalents (RUE_g) for each experiment (Exp.). Sowings of experiment 2 were 11 October (S1) and 13 November (S2) 1996 and cultivars are S324 and L22.

Experiment/ Sowing/ Cultivar	RUE_{dm} (g/MJ)	SE	RUE_g (g/MJ)	SE
Exp. 1, S324	0.99	0.04	1.54	0.06
Exp. 1, L22	0.85	0.04	1.32	0.06
Exp. 2, S1	1.04	0.03	1.61	0.04
Exp. 2, S2, S324	1.14	0.04	1.7	0.07
Exp. 2, S2, L22	0.97	0.03	1.47	0.05
Exp. 3	0.99	0.02	1.54	0.04

Figure Captions

Fig. 1. Fruit development for cultivars ● S324 and ○ L22 across three sowings of experiment 1 (1995/96 season). Error bars are one standard error of the mean.

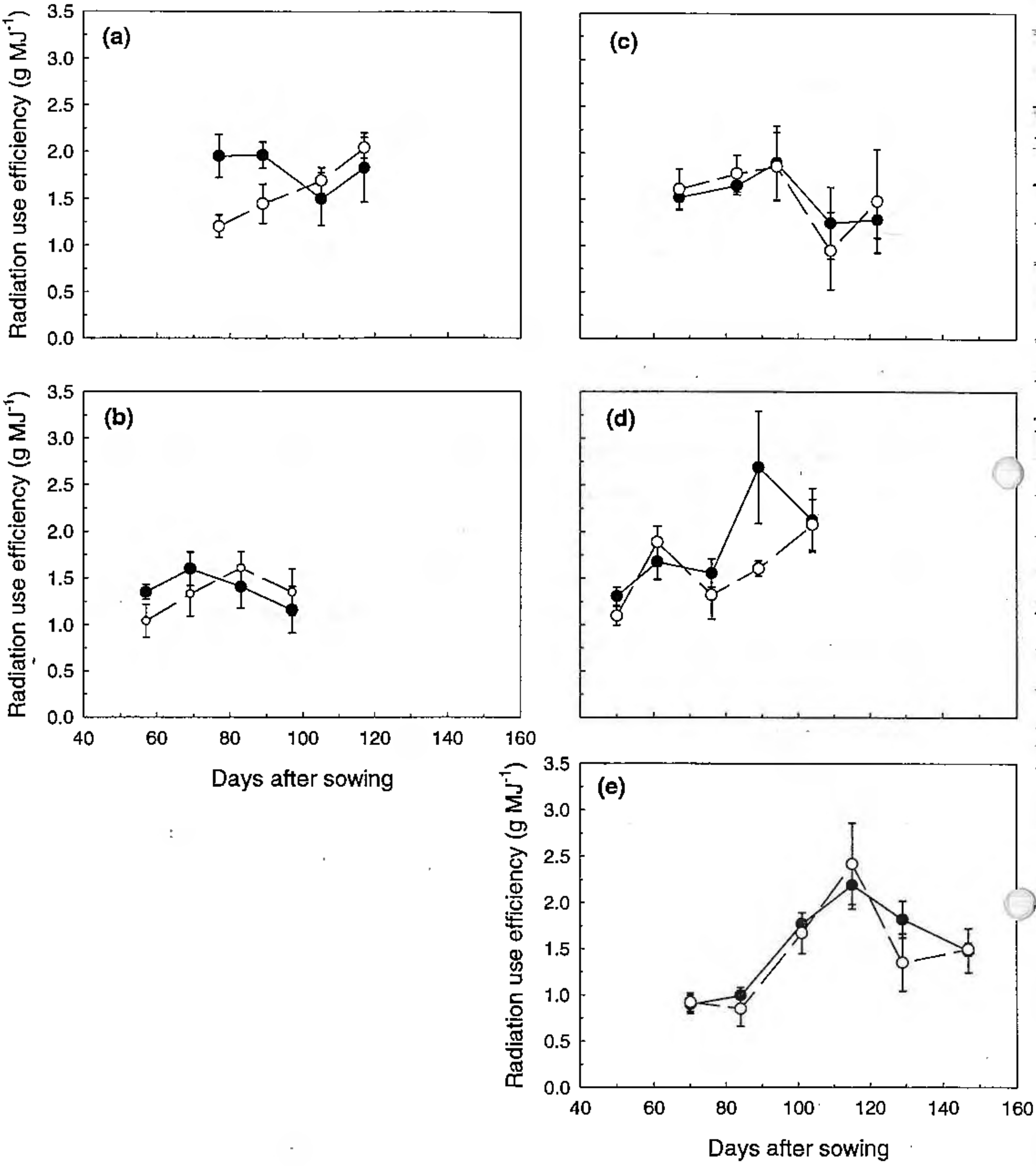
Fig. 2. Fruit development for cultivars ● S324 and ○ L22 across two sowings of experiment 2 and experiment 3. Error bars are one standard error of the mean.

Fig 3. Total dry matter and fruit dry matter production adjusted for glucose equivalents for cultivars ● S324 and ○ L22 across all experiments.

Fig. 4. Leaf area index development for cultivars ● S324 and ○ L22 across all experiments. Error bars are one standard error of the mean.

Fig. 5. Radiation use efficiency (RUE) on a glucose equivalent basis during crop development for cultivars ● S324 and ○ L22 across all experiments. Error bars are twice the standard error of the mean.

Fig. 6. Change in specific leaf nitrogen over time for cultivars ● S324 and ○ L22 for: (a) sowing 1, (b) sowing 2, and (c) sowing 3 for experiment; and (d) sowing 1 and (e) for sowing 2 experiment 2. Error bars are one standard error of the mean.


(a)
(b)
(c)
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(e)
Radiation use efficiency (g MJ^{-1})
0.0
0.5
1.0
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3.5
40
60
80
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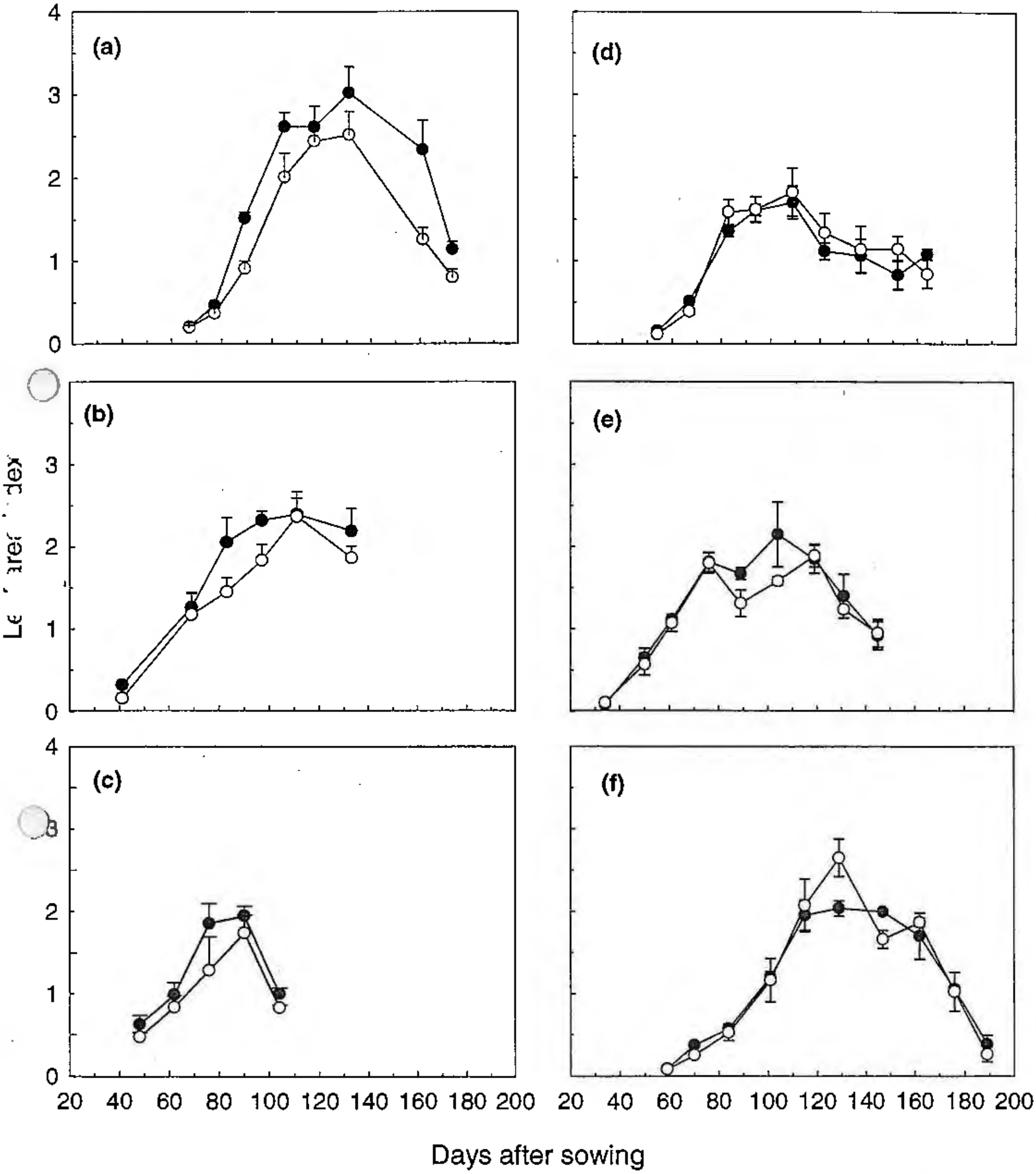
120
140
160
Days after sowing

Figure 5.


(a)
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Le ' are ' dex
0
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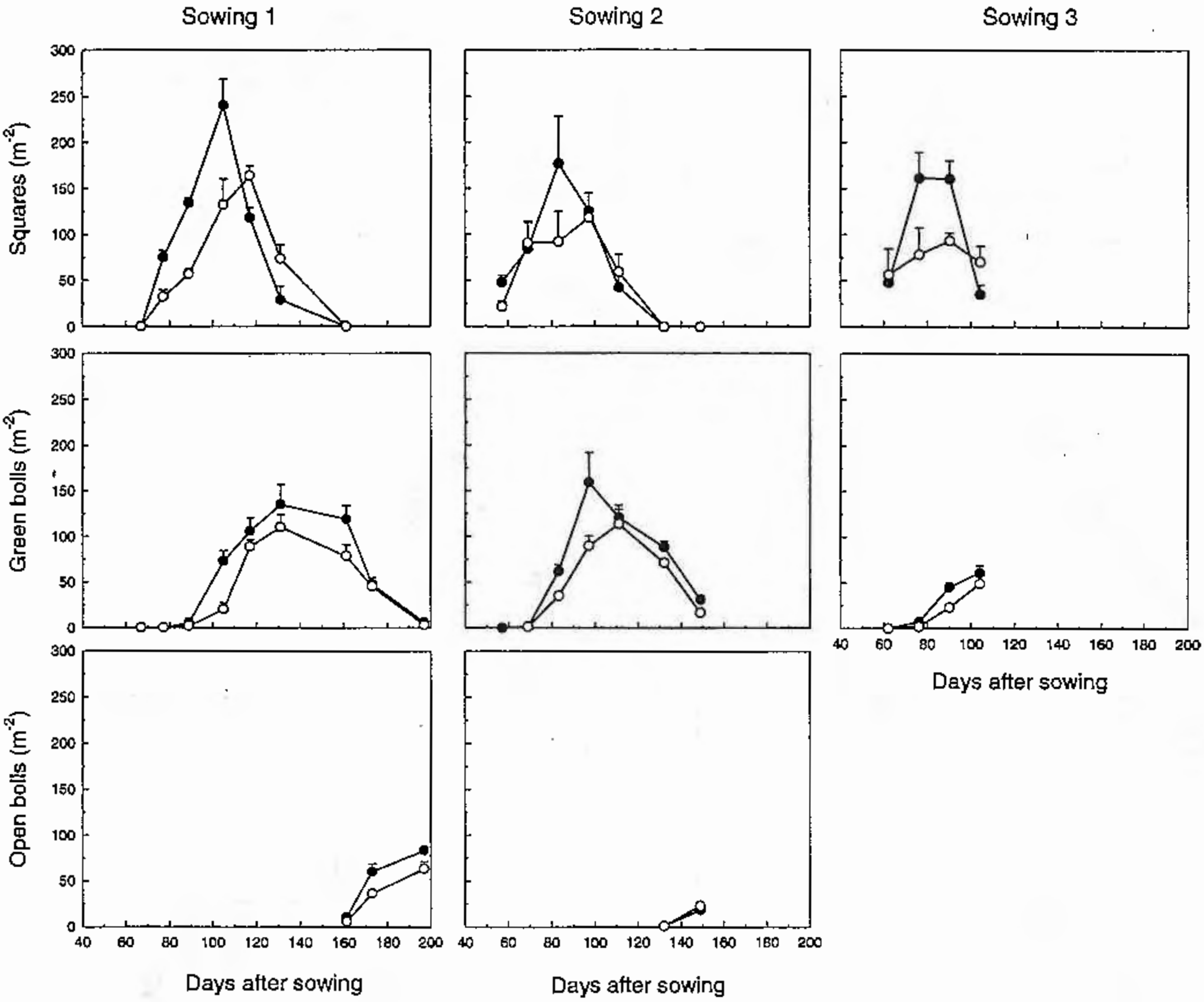
140
160
180
200
Days after sowing

Figure 4.


Sowing 1
Sowing 2
Sowing 3
Squares (m^{-2})
Green bolls (m^{-2})
Open bolls (m^{-2})
0
50
100
150
200
250
300
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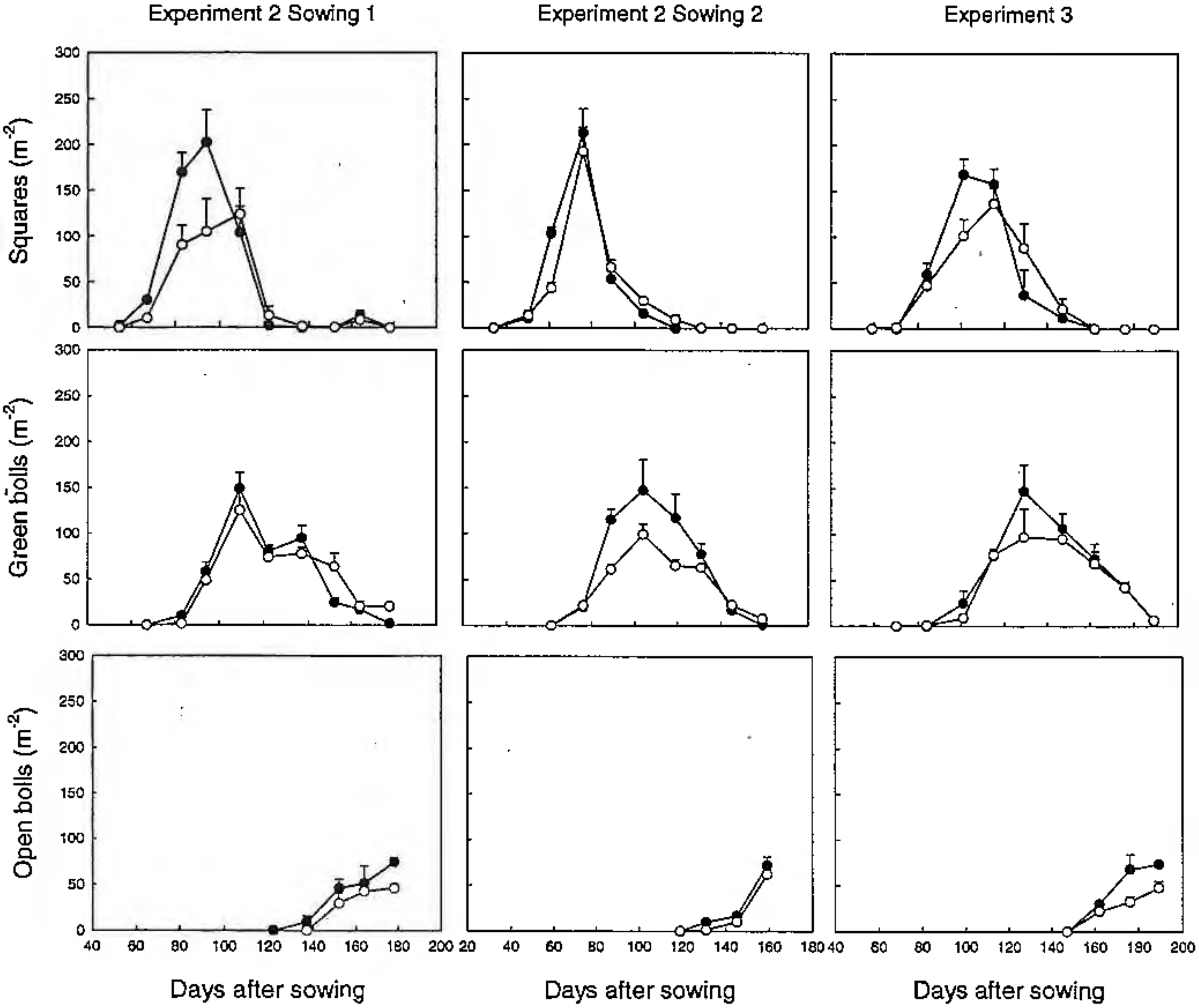
80
100
120
140
160
180
200
Days after sowing
Days after sowing
Days after sowing

Figure1.


Experiment 2 Sowing 1
Experiment 2 Sowing 2
Experiment 3
Squares (m^{-2})
Green bolls (m^{-2})
Open bolls (m^{-2})
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200
20
Days after sowing

Figure 2.

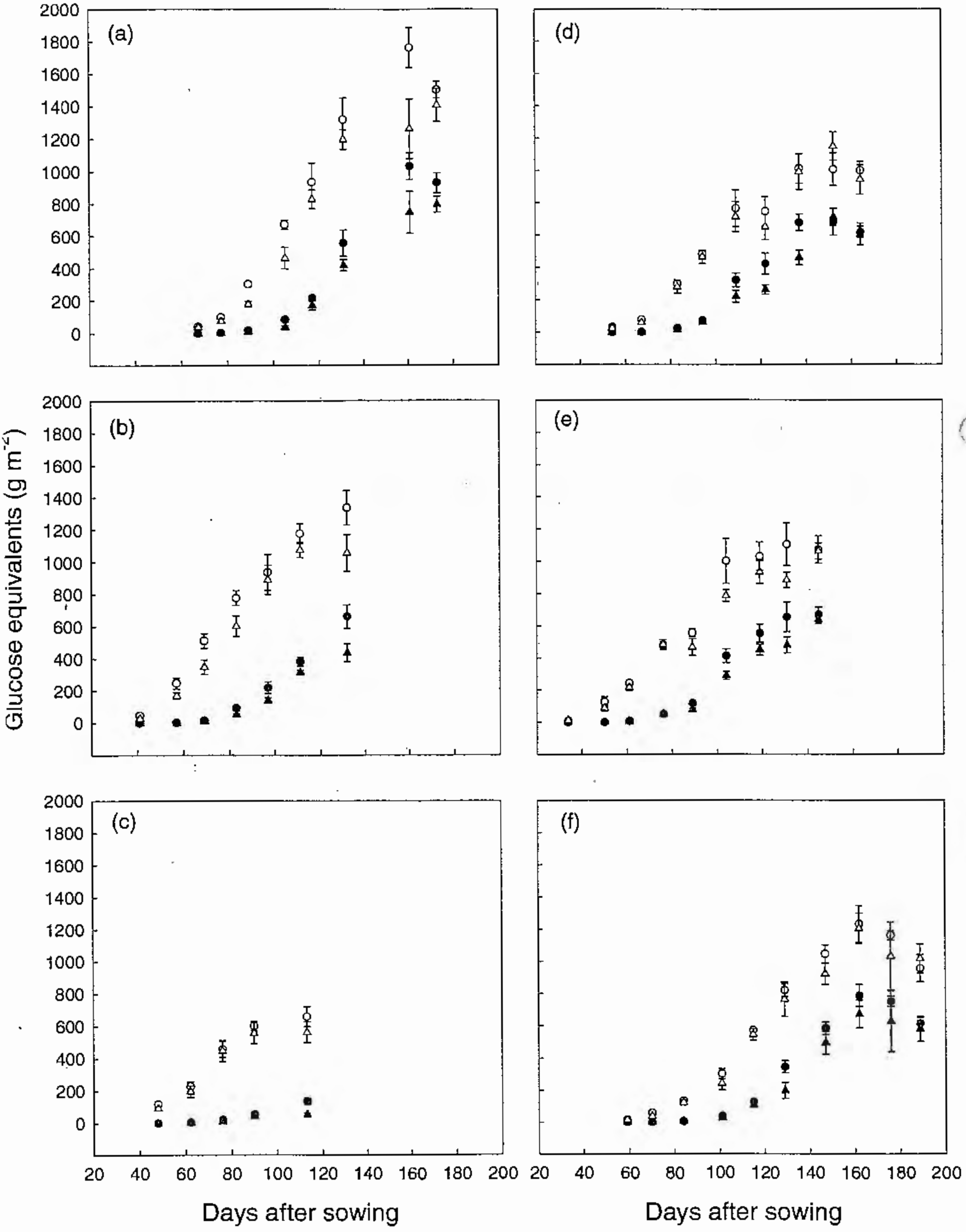
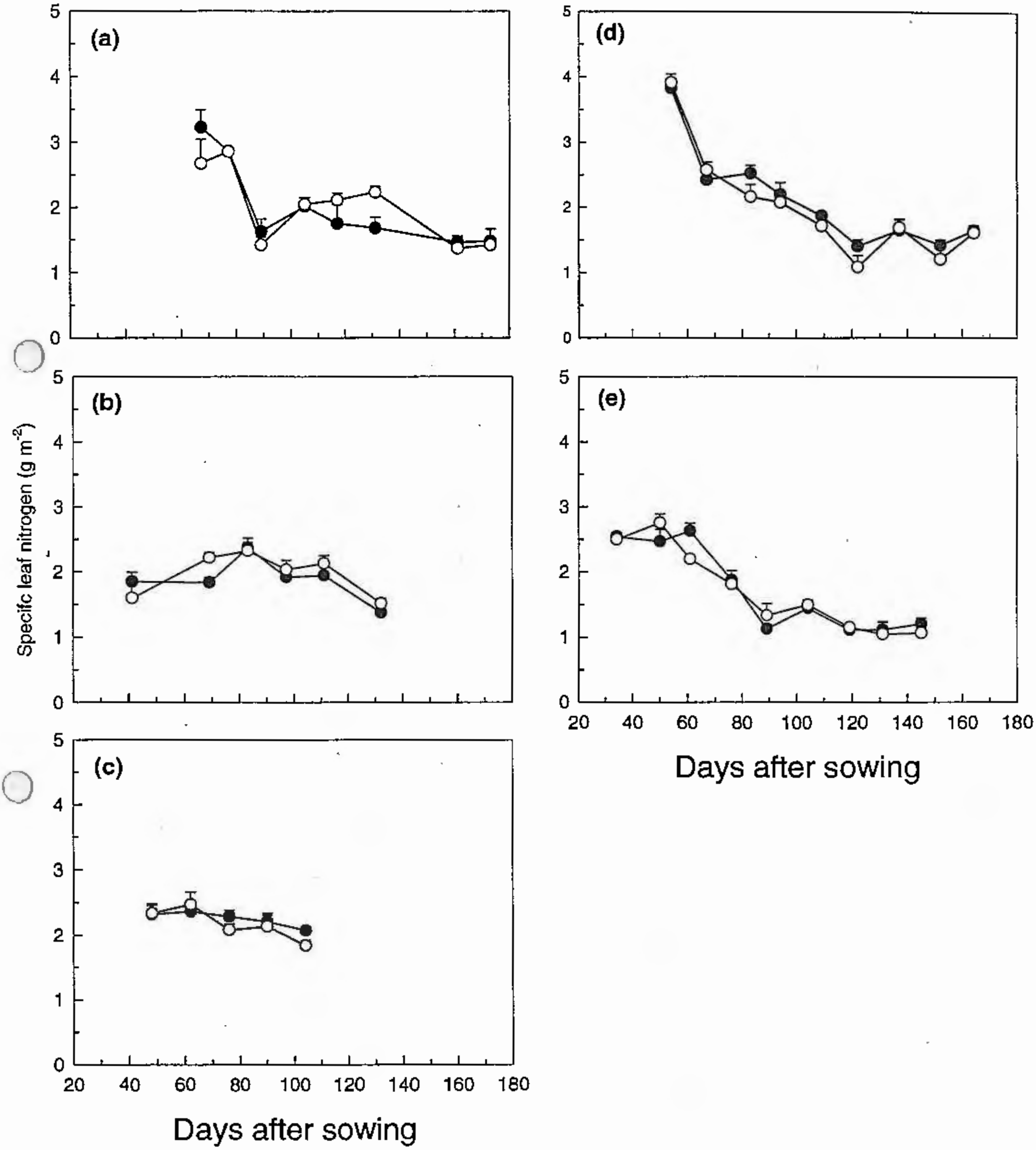

(a)
(b)
(c)
(d)
(e)
(f)
Glucose equivalents (g m⁻²)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
20
40
60
80
100
120
140
160
180
200
Days after sowing
Days after sowing

Figure 3.

(a)
(b)
(c)
(d)
(e)
Specific leaf nitrogen (g m^{-2})
0
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160
180
Days after sowing
Days after sowing

Frgure 6.

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Document 4

Proceedings of the 9th Australian Agronomy Conference, Wagga Wagga, 1998, pages 415-416.

Growth analysis of short and long season cotton cultivars

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Abstract

According to the nutritional hypothesis, the timing of crop maturity in cotton is affected by when the fruit that are already growing monopolise resources and prevent the crop from producing new fruiting sites. Maturity can therefore be influenced by either the supply of resources to the fruit or the level of demand generated by the fruit. Growth analysis was used to examine the supply of resources, in terms of the production and partitioning of dry matter, of an early and a late maturing cultivar grown in two fully irrigated field experiments. The two cultivars did not differ in peak leaf area index, above ground dry matter production or in allometric partitioning between the fruit and the rest of the shoot. Differences were however, found in light interception, canopy light extinction coefficient and radiation use efficiency in one experiment but not in a way that explain the differences in maturit

Key words: Extinction coefficient, *Gossypium hirsutum*, light interception, partitioning, RUE.

Cotton is an indeterminate species. The timing of crop maturity is not governed directly by temperature and photoperiod. Rather, according to the nutritional hypothesis, the timing of crop maturity is determined by when the fruit that are already growing monopolise resources and prevent the crop from producing new fruiting sites (1). Usually, the crop then finishes maturing the fruit that are already set. Crop maturity can therefore be affected by either the supply of resources to the fruit or the demand the fruit are generating in terms of their number or growth rate. In this paper we use growth analysis to examine the supply of resources in terms of the production and partitioning of dry matter, of an early and a late maturing cultivar.

Methods

An early maturing (Siokra S324) and late maturing (Siokra L22) cotton cultivar were studied in two field experiments grown on a uniform grey clay at Narrabri, NSW. The crops were sown on a 1 m row spacing with 10 plant/m^2. Full irrigation and commercial insect control were used and N was applied as anhydrous ammonia six to eight weeks prior to sowing. Experiment 1 was sown on 10 Oct, 1995, and received 150 kg/ha of N. Plots were 175 m by 4 rows and a completely randomised design was used with three replicates.. Experiment 2 was sown on 11 Oct 1996 and received 113 kg/ha. A randomised complete block design and four replicates were used. Plots were 75 m by 4 rows. Starting just before first square, 1 m^2 samples were taken on a fort-nightly basis and leaf area index (LAI) and dry weight of fruit, leaf and stem determined. The proportion of photosynthetically active radiation intercepted (PAR) by the canopies was measured weekly.

Results and discussion

The aim of this experiment was to determine whether differences in the dry matter production or partitioning could have contributed to the differences in crop maturity of a late and an early cotton cultivar. Differences were found between S324 and L22 in Experiment 1 in terms of accumulated light interception and radiation use efficiency (RUE) as measured over the whole period of measurement but not in a way that explained their maturity (Table 1). No differences were measured in Experiment 2. The difference in light intercepted be- tween cultivars in Experiment 1 was due to a higher light extinction coefficient (k) and not greater canopy size (Table 1).

According to the nutritional hypothesis, a greater assimilate supply for the production of fruiting sites should result in prolonged fruit production and delayed maturity. The combination of the higher cumulative light interception and the higher RUE of S324 might suggest that S324, the early cultivar, would have the greater supply of photosynthate for the production of new fruiting sites. However, since the allometric partitioning (2) of the resources did not differ between the

Table 1: Comparison of peak LAI, cumulative PAR, k, total dry matter (TDM) and RUE for the two cultivars in the two field experiments. (n.s.d. - no significant difference).

Variable	Experiment	Cultivar S324	Cultivar L22	Pooled SE	Significance
LAI	1	3.02	2.52	0.30	n.s.d.
	2	1.70	1.82	0.27	n.s.d.
PAR (MJ/m^2)	1	1024	976	12*	($P<0.05$)
	2	626	599	20	n.s.d.
k	1	0.64	0.77	0.03*	($P<0.05$)
	2	0.62	0.65	0.03	n.s.d.
TDM (g/m^2)	1	870	811	47	n.s.d.
	2	621	582	22	n.s.d.
RUE (g/MJ1)	1	1.07	0.89	0.03*	($P< 0.05$)
	2	1.03	1.00	0.03	n.s.d.

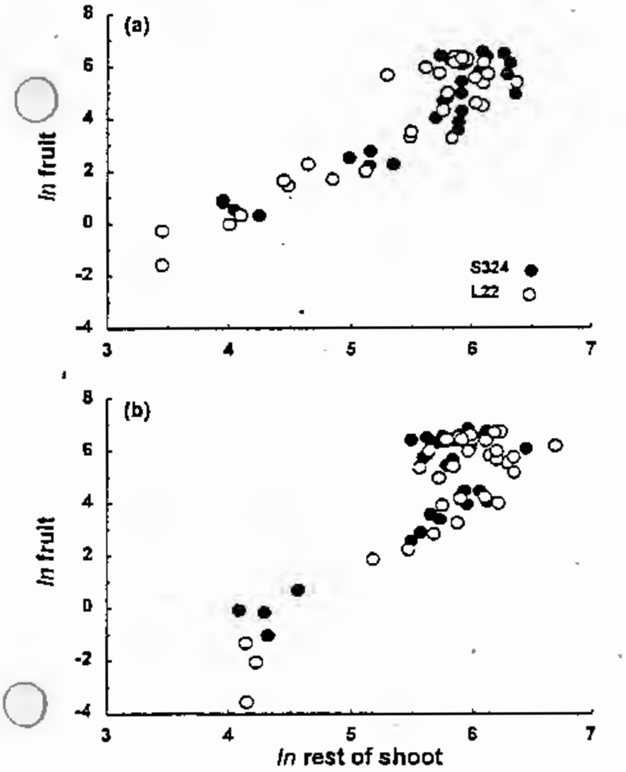

Figure 1: Comparison of the allometric partitioning of the two cultivars in the two field experiments.

cultivars the greater supply of dry matter should lead merely to a larger plant in S324 (Fig. 1). In either case, the differences do not explain why it is the earlier cultivar. Further studies are considering within season variation of growth and partitioning, demand for resources by fruit, and are including a greater range of growth conditions.

Conclusions

The late and early cultivars did not differ in peak leaf area index, above ground dry matter production or in allometric partitioning between the fruit and the rest of the shoot. In one season differences were however, found in light interception and canopy light extinction coefficient. The short season cultivar also had a significantly higher radiation use efficiency, but this does not explain why it matures earlier.

Acknowledgments

Thanks to the CRDC and the CRC for Sustainable Cotton Production for financial support of this work.

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(1) Hearn, A.B. 1981. *Field Crop Abst.* 34, 11-34.

(2) Pearsall, W.H. 1927. *Ann. Bot.* 41, 549-556.

Document 5

Assessing Effects of Canopy Nitrogen and Light Distribution on Radiation Use Efficiency of Cotton.

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Abstract

As a surrogate for photosynthesis, biomass accumulation at the crop level can be estimated from the product of the amount of radiation intercepted and the amount of dry matter produced per unit of radiation intercepted (radiation use efficiency, RUE). The cotton crop simulation model CERCOT uses this approach and modulates RUE in response to canopy nitrogen status. However, the response of RUE of cotton to its nitrogen status is uncertain. Using a previously reported approach to scale from leaf photosynthesis to canopy RUE, we explored the significance of developmental changes in the vertical distribution of canopy N and canopy light interception characteristics on the response of RUE to nitrogen status. Tested against a field experiment, the framework performed reasonably well for high observed RUEs but over-estimated low RUEs. A number of avenues are being explored to improve its performance. A sensitivity analysis with the framework suggested that RUE in cotton was not effected by developmental changes in the vertical distribution of canopy N or light interception characteristics, but this needs to be tested in cotton crops with larger canopies where these effects are likely to be more important.

Introduction

The cotton crop simulation model CERCOT has been developed for use in research and to assist in tactical and strategic decision making. In CERCOT, biomass accumulation by the crop is estimated from the product of the amount of radiation intercepted each day and radiation use efficiency (RUE, the amount of dry matter produced per unit of radiation intercepted). RUE for a given day is modulated according to the canopy nitrogen status. However, changes in either light interception properties or the vertical distribution of N within the canopy can effect RUE for a given canopy N status (Hirose and Werger, 1987; Pons *et al.*, 1989). Developmental changes in both these factors have been observed in cotton (Sadras, 1996; Milroy *et al.*, 1998) and could effect the relationship between the canopy nitrogen status and RUE over the development of the crop. This would have implications for models which use RUE to simulate biomass production.

To explore the importance of these developmental changes for RUE in cotton, we used a simple framework developed by Hammer and Wright (1994) that scales from leaf photosynthesis to RUE which accounts for, amongst other factors, both the vertical distribution of N and the light interception characteristics of the canopy. The framework estimates the photosynthesis of sunlit and shaded leaves at each of the specified layers in the canopy as a function of their light receipt and N status. The photosynthesis of leaves in all the layers are totaled and adjusted for respiration to calculate a whole canopy photosynthesis. In this paper we aim (1) to test the suitability of the framework of Hammer and Wright (1994) for estimating RUE of field grown cotton crops and (2) use it to explore the predicted effects on RUE of average canopy N, the vertical distribution of N and the canopy light interception characteristics.

Materials and Methods

A field experiment was conducted at the Australian Cotton Research Institute Narrabri (30°S 150°E), a semi-arid environment in north-western New South Wales, Australia. The soil was a grey-clay. Cultivar Sicala V-2*i* was sown on 14 October with two nitrogen treatments; nil and 150 kg ha^{-1} of N applied as anhydrous ammonia. The crop was grown using full irrigation and commercial insect control methods. A completely randomised design was used with four replicates. Plots were 75m by four rows spaced at 1m. Incident solar radiation was measured throughout the experimental period at a meteorological station 3 km from the site.

From about the time of first square, 1 m^2 destructive plant samples were taken each fortnight. On each occasion, the canopy was cut in four successive strata of equal vertical thickness. For each layer, the leaf area (hence LAI) was measured using a planimeter and the leaf material dried and weighed. The total dry matter (TDM) in the sample was also measured. Leaf N concentration (g N/g DM) was determined using a near infrared refractometer or a Leco high temperature combustion system, both calibrated against the Kjeldahl method. The stratified cuts continued until boll growth was completed and the crop was approaching maturity, giving five samplings. Two additional samples were taken, one before the first and one after the last stratified cut, for TDM and N only. The proportion of photosynthetically active radiation (PAR) intercepted by the crop was measured using a ceptometer at approximately weekly intervals. Readings were taken above and below the canopy in each plot at around noon under clear conditions.

Instantaneous canopy light extinction coefficients (k), vertical specific leaf nitrogen (SLN, g N/m^2 of leaf) gradients within the canopy (henceforth referred to as SLN gradient) and average canopy SLN were calculated for each harvest date. The coefficient k was based on total global radiation and calculated from the light intensity above (I_o) and below (I) the canopy and LAI using the equation: $k = ln(I/I_o)/\text{-LAI}$. The SLN gradients were calculated from the regression of SLN in a given layer against cumulative LAI (LAI_{cum}) from the top of the canopy to the mid-point of that layer.

RUE was calculated for each date when a stratified harvest was taken by using data from three consecutive sampling dates centred on the date of interest. For each date RUE was calculated from the linear regression of accumulated biomass on cumulative intercepted PAR over the three dates. The proportion of light intercepted by the crop canopy over the day (Q) was estimated from the proportion of interception measured around noon (Q_n) using the equation of Charles Edwards and Lawn (1984): $Q = 2.Q_n/(1+Q_n)$. In calculating biomass, the high synthesis cost of cotton fruit relative to vegetative growth was taken into account by adjusting the reproductive biomass by the ratio of the biosythethic production costs (g glucose per g dry matter) of reproductive and vegetative tissues using the conversion factors of Wall *et al.* (1994). That is, the RUE is equivalent to that for the production of vegetative tissue.

The performance of the framework was tested by comparing the derived RUE's to those measured for each sampling date. For this purpose, the LAI for each layer, actual incident radiation, average canopy SLN, canopy SLN gradients and k as measured at each sampling date were used as inputs to the framework. A limitation was the lack of a field based response of leaf photosynthesis (Pn) to SLN. The response equation used was based on that of Hammer and Wright (1994) but with a maximum Pn of 1.5 mg CO_2 m^{-2} s^{-1} at high SLN based on Australian cultivars grown in the field at Narrabri (Warwick Stiller CSIRO, unpublished data).

Results and Discussion

In the field experiment, RUE varied between 0.6 and 2.1 g MJ^{-1}. These values compare well to published data for the production of vegetative tissue by cotton which range between 1.2 and 2.1 g MJ^{-1} (Rosenthal and Gerik, 1991; Sadras 1996). Significant relationships were found between SLN in a layer and cumulative LAI from the top of the canopy ($P<0.05$). The negative slope of the relationship (ie: the SLN gradient) varied between the sampling dates and between nitrogen regimes ($P<0.05$, Fig. 1). Average canopy SLN also varied between treatments and sampling dates ($P<0.05$, Table 1), but k only varied significantly between sampling dates ($P<0.05$, Table 1). The k values in Table 1 appear low relative to previously published values for cotton (eg. Constable, 1986; Sadras, 1996) because they are based on total global radiation not PAR. On a PAR basis, the observations ranged from 0.51 to 0.81

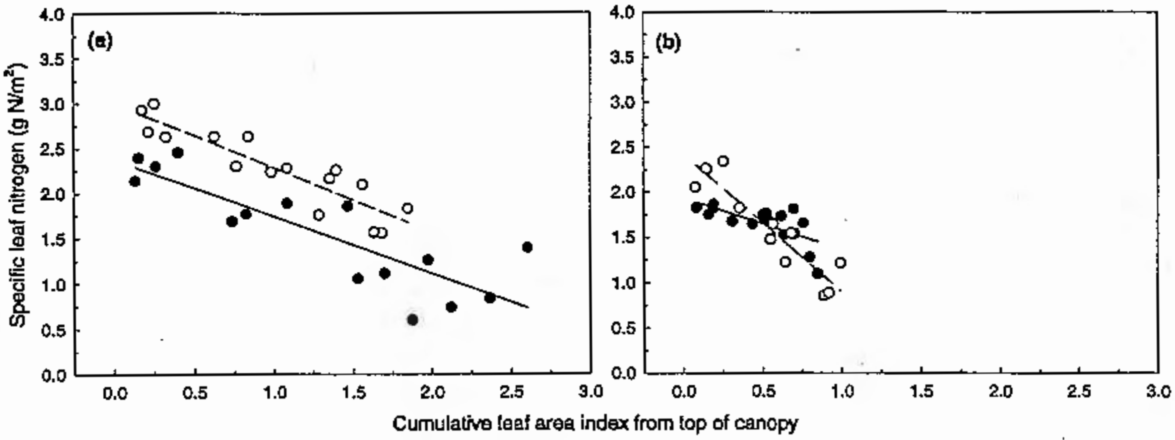

Fig. 1. Examples of the relationship between SLN and cumulative LAI for (a) the high N treatment and (b) the nil N treatment. Open symbols and broken lines are for 77 days after sowing (DAS), closed symbols and solid lines are 128 DAS.

Table 1. Observed values for the canopy light extinction coefficient, SLN gradient, total LAI and average canopy SLN for cotton crops grown under nil (LN) and high (HN) nitrogen for different sampling dates (DAS = days after sowing) and used as inputs to the framework.

DAS	Extinction Coefficient (k)		SLN Gradient		Total LAI		Average SLN (g N/m^2)	
	HN	LN	HN	LN	HN	LN	HN	LN
64	0.50	0.57	0.72	0.58	0.57	0.36	3.05	2.11
77	0.36	0.44	0.72	0.58	1.65	0.75	2.46	1.73
94	0.47	0.47	0.82	1.17	2.33	0.91	2.31	1.46
113	0.42	0.47	0.31	1.03	2.64	1.01	1.90	1.29
128	0.51	0.51	0.59	1.60	2.41	0.96	1.67	1.71

The RUEs calculated for the field experiment using the framework were plotted against the observed values (Fig 2a). The calculated RUEs were approximately correct for the higher observed values but were over estimated at moderate to low observed values, particularly for the nil N treatment. Part of the reason for the lack of response to low N supply is most likely due to the function used for the response of Pn to SLN. The function had been derived for peanut but was modified for cotton by changing the asymptotic maximum Pn rate. Although Reddy *et al.* (1979) have developed a relationship of this kind for cotton, it only used a limited range of SLN and was developed in a controlled environment. Significantly higher rates of Pn than the maxima reported by Reddy *et al.* (1979) or Constable and Rawson (1980) have been observed in the field (Warwick Stiller CSIRO, unpublished data). Leaf age may have also contributed to the over-estimation of RUE for the nil N treatment late in the season. The nil N treatment cut out earlier than the high N treatment and thus from this point onward the leaves at the top of the nil N canopy were older than those in the high N treatment. Thus, although they had only a slightly lower SLN (Fig. 1) they would have had significantly lower Pn rates (Constable and Rawson, 1980). Work is continuing to explore the response of Pn to SLN in the field and the interaction of leaf age and also light acclimation with this relationship. Non-linear canopy gradients (Hirose and Werger, 1987) may also have contributed to the scatter of the calculated RUEs. Research is continuing to quantify the importance of these aspects to the performance of the framework for cotton.

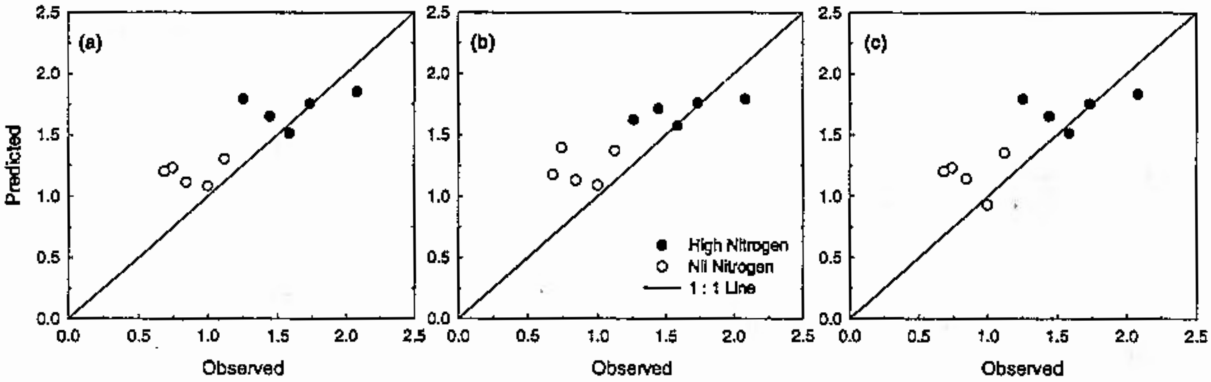

Figure 2: Derived versus observed RUE for the different dates in the field experiment using: (a) k and SLN gradient as measured for each date, (b) measured SLN and a common k calculated by pooling all the data and (c) measured k and a common SLN gradient.

To assess the significance of the observed developmental variation in k on the calculated RUE, we substituted a k derived across all dates and treatments in place of the actual k for each date. This had only a limited effect on the estimated RUE (Fig 2b). This was surprising given that a sensitivity analysis showed that the calculated RUE from the framework varied by 15% over the range of k values observed in the field trial (with SLN gradient = 0.61 and average SLN = 3.0). The small effect on the calculated RUEs for the field trial was presumably because, while there was statistical variation between the observed k values ($P<0.05$), most of the values lay near the overall value of 0.46. Thus only a few of the calculated RUE's where altered by using a common k.

When we tested the significance of the observed variation in SLN gradient by substituting an overall gradient in place of those specific for each date, it had even less effect than using a common k (Fig 2c). This was at least partially due to the low LAIs developed in the experimental crop. The analysis of Hirose and Werger (1987) indicated that canopy photosynthesis responded more strongly to SLN gradient at higher LAI; at an LAI of 2.12 the response was negligible. The highest LAI recorded in these crops was only 2.6 even though a yield of 2100kg ha^{-1} was obtained in the high N treatment.

The stability of the predicted RUE with changes in either k or canopy SLN gradient over the range observed in this study is promising for the development of a response of RUE to SLN which could apply through out the development of the crop. However, higher SLN gradients are likely with higher LAI (Sadras *et al.*, 1993) and also the consequences of variation in k or

SLN gradient are greater with higher LAI (Hirose and Werger, 1987). Therefore, it will be necessary to assess their importance in cotton crops which develop larger canopies than those in this study. This is the focus of ongoing experimentation.

Conclusions

The calculated RUE derived from the framework needs to be improved. This may be achieved through developing an appropriate field based response function for Pn versus SLN. Other aspects of the framework will also be examined to reduce the variability of the estimated RUE. The importance of developmental changes in SLN gradient and k for RUE in cotton needs to be quantified in crops with higher LAI than observed here.

Acknowledgments

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Document 6

Characterising the Fruiting Dynamics of Commercial Cotton Varieties

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Summary: This paper reports the results of an experiment to quantify the fruiting characteristics of eight cotton varieties to enable crop simulation models to more accurately reflect yield and maturity of current varieties. Characteristics measured were time to first square, square period, and boll period, and their subsequent effects on crop maturity. Thermal time to first square and boll period were correlated to the maturity ranking of the varieties. However, differences in the length of these periods compared with other reports indicates the need to pursue better methods to quantify these characteristics.

Introduction

Crop simulation models can be used to evaluate risks of management decisions before substantial investment has occurred. Variety selection for yield and its maturity (earliness) is an important decision, particularly in marginal areas or under conditions of late planting. In order to simulate the maturity of a particular variety, the processes that change between varieties must be identified and then related to an environmental factor such as temperature, so that they can be reliably predicted. This paper presents the results of continuing studies to update models to ensure that they reflect the fruiting patterns of current varieties.

Experimental Design and Management

A field trial was conducted at the Australian Cotton Research Unit in the 1995/96 growing season. Eight varieties were sown twice in a split-plot experimental design with three replications using conventional techniques. The two sowing times were 11th October and 29th November. The eight varieties are presented in Table 1 along with their maturity ranking. These varieties include six current commercial varieties and two which have just been released for the coming season.

The node of the first fruiting branch, the time of 1st square and 1st flower open were recorded on each plot. To determine boll period, in each plot, fifty new flowers were tagged on a single day in the middle of the flowering period, and were monitored daily when bolls began to open. The date on which bolls were open and suitable for picking was recorded. In addition when bolls began to open, a maturity pick was conducted on 1 m of row twice weekly to determine date of crop maturity. Just prior to a machine picked harvest, cotton was hand picked and bolls counted from 1 m of row in each plot to determine seed cotton mass per boll.

Table 1: Varieties used in field experiment and there respective ranking of maturity, where 1 is the earliest and 8 is the latest (Constable pers. comm).

Variety	Maturity ranking
CS 8S	1
Siokra S-101 (replaces S324)	2
CS 50	3
Siokra 1-4	4
Siokra V-15	5
Siokra V-2	6
Siokra L-23	7
Sicot 189 (replaces CS189+)	8

Boll period was only derived for the crop sown on the 11th October. Boll opening in the second sowing was accelerated by the effects of low minimum temperatures, and therefore, boll periods were excluded from the analyses.

Results

Yield: Machine picked yield in the first sowing was not significantly different among varieties (mean = 6.3 bales/ha). There was also no difference in number of bolls per m (mean 77 bolls), however, significant differences in seed cotton per boll (boll weight) were found (LSD 0.67).

Table 2: Yield parameters for varieties grown in 1995/96 season. Values followed by the same letter are not significantly different ($P < 0.05$) for seed cotton per boll.

Variety	Yield bales/ha	Open Bolls per m^2	Seed Cotton (g) per Boll
CS 8S	6.1	86	4.07 ac
Siokra S-101	6.5	85	3.93 ab
CS 50	5.9	85	3.75 a
Siokra 1-4	7.5	79	4.63 c
Siokra V-15	6.4	69	4.84 de
Sicala V-2	5.6	74	5.09 e
Siokra L-23	6.6	70	4.53 bc
Sicot 189	5.8	71	4.38 acd

Nodes to First Fruiting Branch: Nodes to first fruiting branch varied from 8 to 11 nodes and differed significantly ($P < 0.05$) between sowings (sowing 1 mean 9.85, sowing 2 mean 8.98, LSD 0.7) and among varieties (LSD 0.8). The differences among varieties was not consistent between the two times of sowing (significant interaction, $P < 0.05$, LSD 1.2) (Table 3).

Table 3: Nodes to first fruiting branch for varieties sown in field experiment in the 1995/96 season

Variety	Sowing 11th Oct	Sowing 29th Nov
CS 8S	8.2	9.0
Siokra S-101	10.3	8.7
CS 50	9.1	8.5
Siokra 1-4	10.7	9.4
Siokra V-15	10.7	9.1
Sicala V-2	9.8	9.4
Siokra L-23	10.8	9.1
Sicot 189	9.0	8.7

Time to First Square: Thermal time to first square was longest in Sicala V-2 and Siokra V-15, while CS 50 and CS 8S were shortest (Figure 1) and there were no significant differences ($P < 0.05$) between sowings . The correlation coefficient was 0.66 between the thermal time to first square and the maturity ranking of the variety.

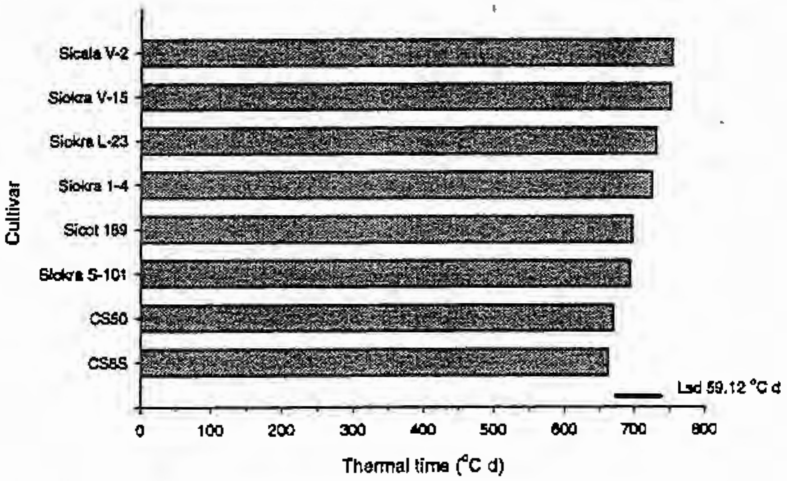

Figure 1: Thermal time to first square for varieties during 1995/96 season.

Square and Boll Period: Square period differed significantly ($P < 0.05$) among varieties (Figure 2) but not between sowings. CS 8S had the longest square period while Line 114 had the shortest. There were no significant differences between sowings, and no correlation was found between maturity ranking and square period.

While Figure 2 shows that there were no significant differences ($P < 0.05$) in boll period found among varieties in the first sowing, there was however, a correlation coefficient of 0.65 when compared to the recommended maturity ranking.

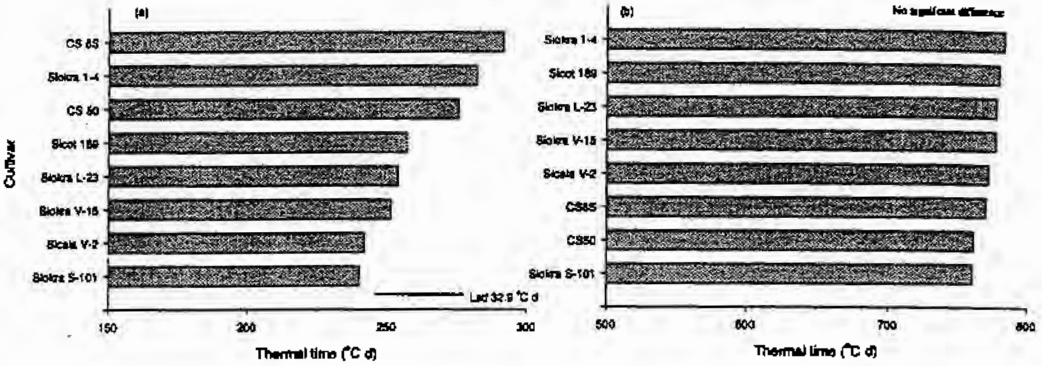

Figure 2: (a) Square period for both sowings and (b) boll period for the first sowing in 1995/96 season.

Crop Maturity: Days from sowing to 60% of bolls open was not significantly different among varieties in the first sowing. Maturity dates varied from 177 to 186 days after sowing and had a correlation coefficient of 0.55 when compared with the maturity ranking (Table 4).

Significant differences ($P < 0.05$) in fibre length were found among varieties where Siokra L23 had the greatest and CS 8S had the shortest (LSD 0.035). Later maturing varieties had greater length (correlation coefficient 0.64). There were no differences in micronaire.

Table 4: Maturity and quality parameters for varieties grown in 1995/96 season. Values followed by the same letter are not significantly different ($P < 0.05$) for fibre length.

Variety	Maturity Date (Days after sowing)	Fibre Length (inches)	Micronaire
Siokra S-101	178	1.18 c	3.67
Sicot 189	186	1.18 c	3.00
CS 8S	177	1.12 a	3.67
CS 50	184	1.14 ab	3.67
Siokra V-15	183	1.16 bc	3.67
Siokra 1-4	179	1.19 c	3.33
Siokra L-23	182	1.20 c	3.00
Sicala V-2	177	1.17 c	3.33

Discussion

Crop yields were variable and generally depressed, probably due to cool temperatures and waterlogging problems experienced during this season. Greatest yields were measured in Siokra 1-4 which generally had a longer thermal time to first square and boll period. Fibre length was greatest for Siokra L-23 and 1-4, and was also related to maturity.

Measured crop maturity found in this experiment was not correlated with time to first square, square period, and boll period, as maturity in this experiment was probably effected by cool temperatures effecting boll development. Time to first square and boll period were however, related to the recognised maturity ranking of the varieties. These two periods have an effect on maturity via their effects on carbon supply. A shorter time to first square places a demand on carbon supply earlier, whereas a shorter boll period places a greater demand on resources because each boll is trying to grow faster. Square period is not so important because the demand for carbon of developing squares is small in comparison.

The duration of all the periods were different to those found by Wells (1994). He also found that the thermal time for these periods differed across times of sowing and between years. The results in this experiment in conjunction with his data indicate that the methods for measuring fruit development traits requires further exploration. Further studies are investigating in more detail the quantification of fruit development traits and the interaction of these traits and carbon supply on crop maturity.

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Document 7

Using systems models in farm management

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Introduction

> "*We're getting a better understanding of the science behind (them) and it's giving us confidence to make decisions using the information. We're getting a handle on the situation rather than functioning on gut feeling.*" Farmer
>
> "*Advantage is that you know where you are likely to be going in six months time, this gives 'hindsight in advance', and farming with hindsight is much easier*" Farmer
>
> "*It influenced my advice: cropping and rotations, planting and nutrition*" Agribusiness consultant
>
> "*There are not too many opportunities that come along that can deliver major outcomes to farmers and (this) is clearly one such*" Industry reviewer
>
> "*The evaluation process provided strong evidence that (it) was having a positive impact: on learning within each participant group, attitudes, decision-making and practice.*" Researcher

These quotes explicitly address the topic of this paper - the application of simulation models in assisting the management of commercial farming enterprises. The need to begin this paper with such statements of support is because many readers, whether they be growers, consultants, extension officers or researchers, would have contrary or, at best, non-committal views on the usefulness of models in commercial agriculture.

Scepticism on the applicability of models is not due to their rarity nor lack of exposure. A recent survey of models targeted at farm production and catchment management (Hook, 1997) recorded over 90 models or computerised decision support systems (DSS) developed and/or supported in Australia. The compilation included models relevant to the cotton industry, the OZCOT and CERCOT cotton models and the now defunct SIRATAC DSS. It would be safe to assume that there are probably many more such products than those listed in this report. Yet, in Australia (Cooke, 1994) and world-wide (Plant, 1997), farmer acceptance of models and decision support systems has been disappointingly low.

In this paper, our objective is to relate our experiences of how some farmers and consultants have benefited from the application of systems models in their farming operations. We argue that this recent effort in applying models within industry has important distinguishing features from past efforts on decision support systems and that the current market pull for commercial access to systems models may be sustainable. We conclude with proposed plans to progress towards commercial delivery of systems simulation to farmers in the northern cropping region.

Why simulate?

A simulation model is simply a mathematical representation of an aspect of the real world. The case for simulation modelling as a scientific research tool needs not to be argued here. To be able to quantitatively explain biological and physical phenomenon and predict outcomes under different environmental stimuli is the goal of much of science. Nor would one argue with the widespread application of models in engineering and other real-life professions. One doesn't build bridges nor put people on the moon using trial and error when models can accurately predict consequences of different designs and actions. Likewise, in our everyday life, simulation is becoming ever more relevant –one can now assess mortgage loans at our banks via a loan repayment simulator. The awareness and acceptance of simulation as a legitimate form for generating information is undoubtedly increasing due to its wider exposure within the general public.

Simulation models are a means of easily and efficiently achieving understanding and gaining "experience". Maybe one doesn't have to live through 50 years of farming experience to gain some insight if one can simulate in minutes what would have happened in each of those 50 years. In this sense, a farming systems simulator could be used akin to a flight simulator – where one can learn from successes and mistakes of implementing actions without suffering the consequent pain and cost of real-life experience.

So, will farming systems simulation ever get to the point where real-life experience is no longer required for learning? Unfortunately, the answer is a definite no. Biological systems are not as predictable as physical systems, with no two organisms being nor behaving exactly the same - well, except perhaps for clones like Dolly the sheep. Where Newton's physical laws allow accurate prediction of mass and state in engineering, biological relationships are based on observed performances of populations of plants and animals. Nevertheless, we can say with some confidence, for instance, that a cotton plant will produce 1.5 g of matter for each megajoule of radiation it intercepts (Rosenthal and Gerik, 1991), or that a cotton crop will take close to 780 degree days to first flower appearance (Constable and Shaw, 1988). By combining such relationships into a simulation model such as the OZCOT cotton model (Hearn, 1994), the performance of cotton crops can be predicted under different environmental and management conditions.

The questions remain, however, as to how well simulation models perform in relation to commercial agriculture and how can industry make use of these tools?

What is FARMSCAPE?

FARMSCAPE (*Farmers, Advisers, Researchers, Monitoring, Simulation, Communication And Performance Evaluation*) is an acronym we have employed to represent a participatory R&D approach that explicitly addresses the question of relevance of systems models to commercial farming. It involves research to explore whether any farmer or adviser could gain benefit from tools such as soil characterisation and sampling, seasonal climate forecasts and, in particular, simulation modelling and, if so, how such tools could be delivered cost-effectively to industry.

FARMSCAPE has been based on the key elements identified in its name:

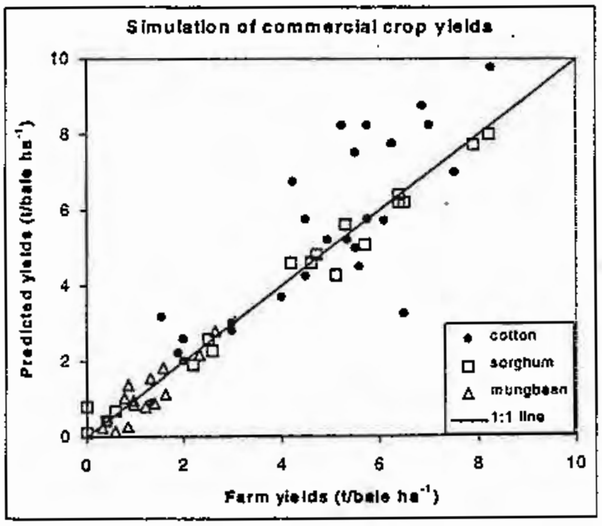
(i) the close collaboration of farmers, their advisers and researchers in discovering together how best to explore management options;
(ii) the implementation of research on commercial farms, especially incorporating improved soil monitoring to gain better knowledge of actual soil water and nitrogen in individual paddocks;
(iii) the application of a well-developed capacity to simulate systems using the APSIM systems model (McCown et al 1996) linked with the OZCOT cotton model (Hearn, 1994) with a requirement that simulations be credible against real-world experience;
(iv) the broader communication of project outcomes not only through public extension activities but particularly through agribusiness client services, and
(v) the continual assessment of project activities and impacts via formal evaluation processes.

Since 1992, FARMSCAPE has encompassed on-farm research and farmer group activities conducted from Capella in Central Queensland to Breeza in northern NSW, with most emphasis having been on the Darling Downs. The focus of FARMSCAPE has almost exclusively been on dryland farming systems. We have established direct working relationships with over 200 farmers and 15 advisers who have influenced research direction and provided strong support for continued evolution of the FARMSCAPE tools and techniques.

Are simulation models relevant to the real world?

Over the past 6 years, a number of commercial dryland crops have been monitored and used to test APSIM and OZCOT simulations. Figure 1 presents results for cotton, sorghum and mungbean, while other crops such as wheat and chickpea have also been tested. In most cases, these tests have confirmed that the models are able to simulate commercial crop production – in Fig 1 they accounted for 87% of observed variation over 59 crops (70% for the 30 cotton crops). For most of those crops where predictions were significantly different, we have been able to determine the reasons for the discrepancies – most are due to impacts of factors not accounted for in the models (eg. severe pest damage). For many farmers and consultants, APSIM and OZCOT have proved credible enough to be relevant to commercial cropping practices and now want to use them in benchmarking the performance of their own crops and in exploring alternative management strategies.

Fig. 1: Predicted yields versus commercial crop yields



How can systems models be used?

(i) Scenario exploration

A common and useful application of simulation is to explore new options or environments as general scenarios that are broadly relevant to a region or group of farmers. In this light, we were asked recently to investigate the returns and risks of dryland cotton by a group of farmers located near Spring Ridge on the Breeza Plain, NSW. The farmers in this group have been primarily growing wheat and sorghum in rotation after long fallows, with the occasional sunflower crop. While the farmers were comfortable with their present cropping systems, they did raise the question of whether alternative crops should be considered.

The OZCOT cotton model was run with inputs generated by the farmers and a local consultant in order to generate risk analyses and gross margins for dryland cotton assuming a full profile of soil water (300 mm available water) at sowing time (Table 1). The resultant predictions were mostly consistent with the expectations of the both a neighbouring cotton farmer and the consultant. The average gross margin was calculated as $1100/ha for cotton (yield 3.7 bales/ha; $560/bale) compared with $630/ha for sorghum (yield 6.2 t/ha; $120/t). While there was a risk of not breaking even, the farmers considered the risk in crop failure was not much greater than that for other crops. The group discussed offsetting this risk by limiting the area of cotton in relation to their other summer crops. Their farmers also confirmed that there were better chances of making higher gross margins than for either sorghum and sunflower.

The farmer group also asked for simulations to investigate the risks of dryland cotton starting with half a profile of soil moisture (average 3.23 bales/ha; Table 1), the effects of sowing time and different rates of nitrogen. Subsequent to undertaking these analyses, three of the farmers have decided to grow cotton for the first time in the 1998/99 season as part of their summer crop program. It is important to note that this simulation exercise did not make the decision for the farmers, but merely provided them with another source of information to assess the returns and risk of a new farming option.

Table 1: Risk analyses generated for dryland cotton production at Spring Ridge (Breeza Plain).

Outcome	Probability of Achieving Outcome (%)	
	Full Profile Soil Moisture	Half Profile Soil Moisture
≥ 1.70 bales/ha (0.7 bale/ac breakeven)	84	78
≥ 2.47 bales/ha (1.0 bale/ac)	63	53
≥ 3.71 bales/ha (1.5 bales/ac)	43	34
≥ 4.94 bales/ha (2.0 bales/ac)	32	22

≥ Greater than or equal to

(ii) Benchmarking past crop performance

Whether a crop has performed to its potential is often of great interest to farmers. Given actual seasonal climate and management inputs, models can predict what a crop should have yielded in the absence of extraneous factors, thus providing a benchmark against which actual crop yield can be assessed. Fig 2 demonstrates a benchmark simulation of a sorghum crop at Kupun, Qld. In this case, the simulated and actual yields were very close and so the farmer could conclude that his crop yielded close to its potential. However, by re-running this benchmark simulation, but using a higher plant density and fertiliser rate, the model also suggested that the farmer could have produced even higher yields than that achieved - the crop did not reach its environmental potential in that season

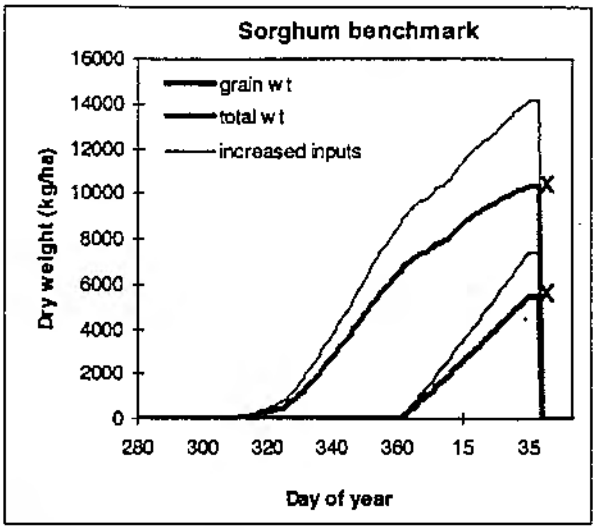
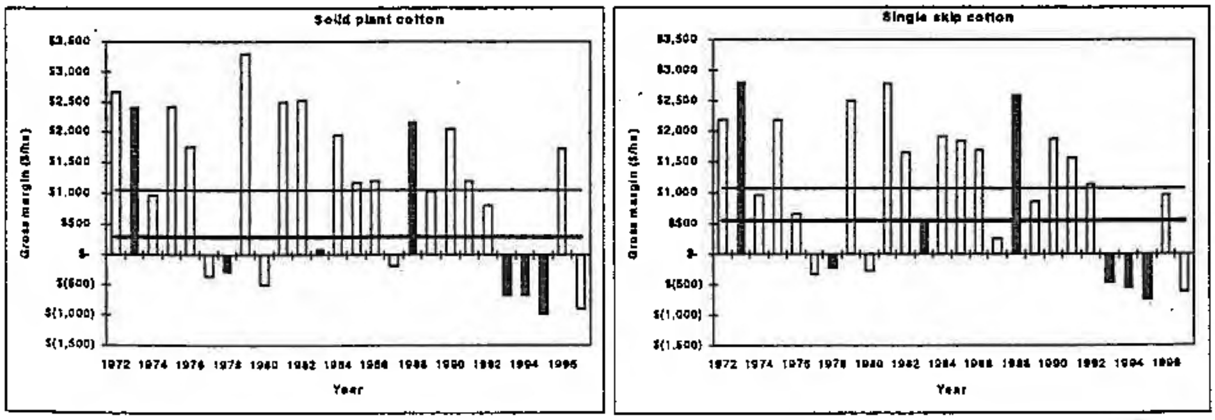


Fig. 2: Simulated daily increase in sorghum grain and total dry weight – X signifies actual weights at crop maturity

(iii) Tactical crop management

The APSIM or OZCOT models can be used in planning for the current or upcoming crop. Decisions on crop choice, varietal selection, fertiliser rate, sowing date, plant population, row configuration and so on can be assessed based on knowledge of pre-plant soil water, soil chemical analysis and seasonal climate outlook. Based on this information, the models can provide an assessment of expected crop performance in the upcoming season by simulating what would have happened under these same conditions in past years for which rainfall records exist - Fig 3 presents an example for cotton planted as either solid or single skip under low starting soil water conditions. The grower for whom these simulations were undertaken, changed to single skip cotton in the 1997/98 (*El Nino*) season rather than his normal solid plant configuration.

Fig. 3: Predicted gross margins for solid and single skip cotton crops grown at Brookstead when sown on 40% soil water profile. Solid bars represent *El Nino* seasons, the average for which is represented by the horizontal thick line, whereas the thin line is the average over all seasons.



(iv) Planning strategic crop rotations

A significant advantage of APSIM is that it is a model of a cropping system, able to simulate the production and environmental consequences of different crop rotations. This capability has been used by farmer collaborators in FARMSCAPE to explore cropping rotations suited to their own farming operations. It has also been used as a research tool to explore the prospects for innovative design of cropping systems. For example, the degree to which the efficiency of dryland cotton systems could be improved if they became more flexible through an opportunity cropping strategy has been recently explored by Carberry et al (1998). In a simulation case study, a standard dryland rotation of long fallowing from sorghum to cotton was compared to alternative fixed rotations and to a rotation influenced by a seasonal climate forecast based on the Southern Oscillation Index (SOI). The decision point is the October after sorghum harvest where the manager can choose to proceed with the standard summer fallow or plant sorghum or cotton in that season with the intention in all cases of planting cotton in the following summer. These three fixed rotations (fallow-cotton, sorghum-cotton, cotton-cotton) are compared to a SOI-influenced strategy – where the rotation chosen each year was determined by the phase of the SOI in October – using APSIM and OZCOT to simulate system performance over the 100 yr climate record for Dalby Qld.

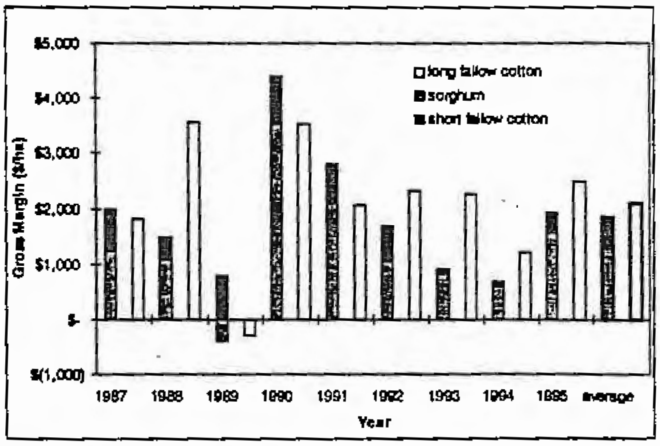
This simulation case study demonstrated that SOI could contribute some skill in improving management decisions over a two year rotation. By changing between fallow-cotton, sorghum-cotton or cotton-cotton rotations based on the SOI phase in the August-September period preceding the next two summers, average gross margins for the two year period increased by 14% over a standard fallow-cotton rotation (Table 2). At the same time, soil loss from erosion was reduced by 23% and cash flow was improved in many years because an extra crop was sown. The SOI strategy did however increase the risk of economic loss from 5% of years for the standard fallow-cotton rotation to 9%, but this risk was considerably less than the 15% for sorghum-cotton and 19% for cotton-cotton rotations.

Table 2: Average performance of three fixed rotations and a flexible rotation based on an SOI seasonal climate forecast (from Carberry et al., 1998).

	Fallow-Cotton	Sorghum-Cotton	Cotton-Cotton	SOI
Gross margin ($/ha/2 yr)	1482	1605	1691	1683
Risk (% yrs GM < $500)	5	15	19	9
Cash flow (year 2)	-56	380	820	405
Soil loss (relative to fallow)	1	0.49	0.72	0.77

The scenario described above is similar to that of a farmer collaborator at Bongeen, Qld, in late Nov. 1995 when his doubled cropped wheat after sorghum failed. He was faced with a decision on whether to continue with essentially a bare fallow through to cotton 10 months hence or plant sorghum at that time and follow with a short fallow through to the intended cotton crop. The simulation of the two rotations showed only a slight gross margin advantage to long fallowed cotton (Fig. 4). The farmer planted sorghum to gain stubble cover for soil protection and was still able to follow with a cotton crop in 1996/97.

Fig. 4: Gross margins for either sorghum-cotton or fallow-cotton rotations simulated at Bongeen Qld.

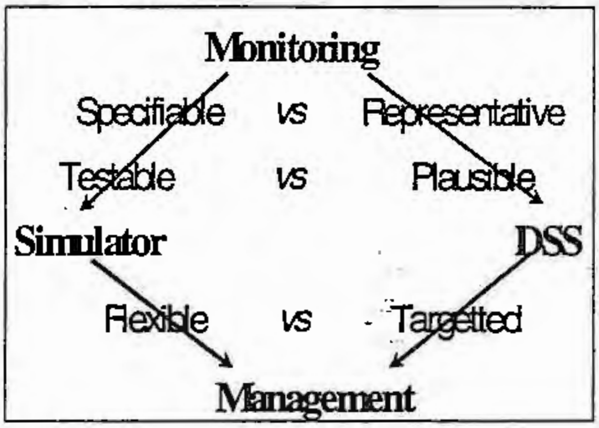


What have we learnt?

FARMSCAPE is a research activity that recognised early on that, if we wanted to explore ways in which farmers could better manage their farms, then these farmers needed not just to be consulted on the design of what should be done, but they also needed to participate in the implementation of the research and the interpretation of its outcomes. In other words, instead of using our scientific models to build derivative tools which we scientists believed could help farm managers, for instance a computerised Decision Support System (DSS), we took these base models out onto farms and asked farmer and adviser collaborators to design and test applications for their own situations. What emerged has been confirmation of the benefits of farmers gaining better knowledge of their water and nitrogen resources through increased intensity of soil monitoring and the discovery of a role for systems models in assisting the management of cropping systems.

FARMSCAPE has helped demonstrate that the key to farm managers valuing simulation is the positioning of these simulations in the context of their own farming situation. A simulator enables information to be specified to an individual paddock, its results can be tested against one's own crop performance and a simulator such as APSIM can be used to explore a whole range of issues. In contrast (Fig. 5), many DSS packages, (eg. WHEATMAN; Woodruff, 1992), provide generic or representative information for a district, they depend on plausible answers (as many of their assumptions cannot be tested using one's own data), and many DSS are generally targeted at single or few issues.

Fig. 5: Schematic comparison of a simulator versus a decision support system (from McCown et al, 1997).



An important distinguishing feature in our use of a simulator with farmers is that, while the simulator provides information that may be useful in making a decision, in the end, the farmers have to decide what would be best for their own situation. In contrast, many DSS packages have been designed to provide recommendations on what decisions should be taken. In leaving the interpretation up to the farmers, a simulator provides a means of learning about the farming system.

Where to next?

Developing the FARMSCAPE approach and tools to the point of commercial delivery is a logical next step for this R&D activity. A market now exists for timely and high quality interactions based on soil monitoring and simulation amongst a significant sector of the farming community. Formal evaluation of the current FARMSCAPE project has demonstrated impacts on participating farmers and advisers. The demand for simulations has increased rapidly to the point where we can not meet that demand, nor justify providing a "commercial" delivery service. Our intention is to do all we can to transfer to agribusiness the capability to deliver FARMSCAPE-based interactions.

Our preferred delivery mechanism is to establish an Accredited Adviser Network for delivering simulation and related products such as soil monitoring, seasonal climate forecasts, analysis of relevant management scenarios and "what-ifs, analysis and discussion" to farmer clients in the northern cropping region. Our proposal is that a number of agribusiness and private consultants be accredited and supported in implementing the FARMSCAPE approach within their business practices. Due to the high demands of training and support required, accreditation training and support initially could only be provided to a limited number of collaborating companies.

Finally, on the research front, we intend to continue exploring the role for simulation, expanding our interests to include irrigated cotton production systems and the agribusiness service sector. In the latter case, bank lending policy and agribusiness advice were definitely affected by recent *El Nino* events. Whether better information on seasonal climate forecasting and cropping prospects can improve institutional decision making (eg. bank leading policy, crop insurance policy, product inventory, marketing advice, etc.) is an emerging area worthy of further exploration.

Acknowledgements

The work described in this paper has been undertaken in collaboration with colleagues in APSRU, CRU and DPI, many farmer and adviser collaborators, and particularly with the assistance of the staff of IAMA Limited and Michael Castor and Associates. FARMSCAPE has received funding support from CRDC and GRDC.

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Document 8

Farming Systems Research - dryland cotton

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CSIRO Tropical Agriculture
Mike Bange, Cotton Research Unit, CSIRO Plant Industry

CRDC Project (CSP67C): Improved cotton management through the application of cropping systems models

The Farming Systems Research (FSR) approach employed in this project is aimed at identifying opportunities for and resolving constraints to implementation of more profitable and sustainable dryland farming systems through participatory on-farm research where farmers, advisers, and researchers are part of the research team. The main areas of activity are:

Negotiation of grower and adviser involvement

Farmer groups working within the project are functioning on the Brigalow Flood Plains (2 groups), at Dalby, Brookstead, Goondiwindi, Moree, Edgeroi and Breeza. Group facilitators include Nevin Olm, Mike Lucy, Mick Castor, Chris Lehmann and agronomists from Primac and IAMA-Seed and Grain Sales (multiple groups).

Issues being addressed include fallow water storage, cotton water use efficiency, soil fertility management, row configuration, cropping sequence, soil water conservation and soil erosion.

Monitoring climate, soil and crop performance

More than 30 soils in the cotton growing regions from Capella to Breeza have been characterised for water holding capacity, bulk density, background fertility (OC%) and subsoil salinity.

A network of 20 automatic and manual weather stations (measuring rainfall, max/min/ground temperatures, radiation, relative humidity) are providing daily data for locations from Emerald to Croppa Creek.. These are additional to the existing network of Cotton CRC weather stations.

As part of negotiated on-farm trials, a number of cotton and other crops (wheat, barley, mungbean, chickpea, sorghum) have been monitored for each farmer group. Data on the pre-plant and post-harvest soil water and N status, and crop yield of each paddock are being collected.

Testing model capabilities

Through collaboration with Brian Hearn, the OZCOT cotton model has been extended to deal with skip row configurations and cool temperatures during establishment.

The APSIM systems model (incorporating OZCOT) has successfully predicted commercial dryland yields for cotton and other crops grown in a range of systems.

Example applications addressing industry issues

Issues that have been addressed through crop and soil monitoring include quantifying the water holding capacities of different soil types, the fate of early applied N fertilizer, the relative extraction of deep soil N by sorghum and cotton, soil water storage after heavy May 1996 rains, etc.

Issues that have been addressed through simulation include comparison of long versus short fallow cotton systems, the impact of different cotton planting dates, sorghum versus cotton production systems, cotton in rotation with mungbeans, cotton yield forecasting in January, etc.

On a number of occasions, simulation results concerning pressing issues have been undertaken for local consultants and growers on a request basis.

Document 9

The potential value of seasonal climate forecasting in managing cropping systems

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Summary

There is considerable interest in exploring the value of seasonal climate forecasts in assisting farmers manage cropping systems, not only for short-term tactical decisions but also longer-term strategic decisions. This paper reviews a range of applications for climate forecasts, especially systems issues that would benefit from long lead-time forecasts. A specific case study is used to demonstrate the potential for using the Southern Oscillation Index in assisting the incorporation of opportunity cropping into dryland cotton production systems.

In the case study, the standard dryland cropping rotation of long fallowing from sorghum (through a subsequent summer fallow) to cotton is compared to alternative fixed rotations and to a rotation influenced by an SOI forecast. The decision point is the October after sorghum harvest where the manager can choose to proceed with the standard summer fallow or plant sorghum or cotton in that season with the intention in all cases of planting cotton in the following summer. These three fixed rotations (fallow-cotton, sorghum-cotton, cotton-cotton) are compared to an SOI-influenced strategy using APSIM to simulate system performance over the long-term climate record for Dalby, Qld.

The simulation case study demonstrated that SOI contributed some skill in improving management decisions over a two year rotation. By changing between fallow-cotton, sorghum-cotton or cotton-cotton rotations based on the SOI phase in the August-September period preceding the next two summers, average gross margins for the two year period increased by 14% over a standard fallow-cotton rotation. At the same time, soil loss from erosion was reduced by 23% and cash flow was improved in many years because an extra crop was sown. The SOI strategy did however increase the risk of economic loss from 5% of years for the standard fallow-cotton rotation to 9%, but this risk was considerably less than the 15% for sorghum-cotton and 19% for cotton-cotton rotations.

In conclusion, there are many decisions in the management of dryland cropping systems that would greatly benefit from climate forecasts with persistence in skill out to two years in duration. The case study used in this paper demonstrated some skill in using the SOI in choosing a cropping rotation of two year duration. Such applications are the obvious next frontier both for the development of enhanced forecasting schemes and for their application within the cropping systems of northern Australia and possibly elsewhere.

Introduction

In managing cropping systems, farmers make decisions that are influenced by many factors. Certainly economic returns are of primary importance, but decisions will also be made based on perceived risk of economic loss, cash flow, weed and disease control, the risk of soil degradation, and lifestyle among a long list of influences (Blacket, 1996). The fact is that there are not many decisions in farming that are simply based on a single factor nor are they made in line with a purely tactical response to current information. In most cases, management decisions have to fit within a whole farm strategic plan such that many decisions are planned months ahead and their consequences seen months afterwards. This characteristic of managing cropping systems, the requirement for a long lead-time between deciding on a course of action and realising its results, is the subject of this paper. Can seasonal climate forecasting provide a long enough lead-time to contribute to the strategic management of cropping systems in northern Australia?

Just as the general public are becoming increasingly aware of events such as *El Niño*, managers of cropping systems are increasingly utilising climate forecast information in making management decisions (Meinke and Hochman, 1998). The Southern Oscillation Index (SOI) is widely promoted as a forecast of seasonal outlook, providing probabilities of achieving above or below average rainfall in upcoming seasons. While the SOI is proving useful to managers, to date its application to cropping systems has been largely for tactical decisions involving short lead-times (Hammer and Muchow, 1996; Meinke et al., ??; Meinke and Hochman, 1998). Even though SOI persistence in prediction skill declines beyond a 3 to 6 months lead-time (Stone ??), its application to management decisions requiring longer lead-times is worth exploring.

The objective of this paper is to explore the potential value of seasonal climate forecasting in the management of dryland cropping systems in northern Australia. While a range of applications for seasonal climate forecasting are reviewed, a specific case study is employed to both demonstrate and assess the potential for using the SOI to aid a management decision, the consequence of which is realised over a two year period.

Management of cropping systems

Cropping systems, in their simplest sense, are defined by the sequence of crops grown in a rotation and by the agricultural commodities they produce. However, while most farmers see production as a primary goal, the management of cropping systems is done within the context of economic, natural resource, capital and labour, political, marketing and lifestyle influences (Blacket, 1996). How farmers manage their cropping system depend on their own objectives within these varying and at times conflicting factors.

The cropping systems of the northern grain region of Australia are characterised by the opportunity to produce a wide range of cereal, pulse, oilseed, forage and fibre crops. Both summer and winter crops are grown, with yields largely determined by water supply from either in-season rainfall or storage in the soil prior to planting. While the diversity in crop choice and planting time can be seen as advantageous, the high variability in seasonal rainfall (Hammer ??) means that the prospects for any one crop is often risky. Fallowing the soil between crops in order to build up soil moisture storage is a recommended management strategy to offset the risk of low in-season rainfall. However, fallow lengths of up to 18 months result in low cropping frequencies and, in some locations, may be contributing to resource degradation through increased soil erosion or salinisation (Freebairn, 19??; Hayman, 1996). As an alternative to rotations of fixed fallow length, opportunity cropping represents the practice of planting a crop whenever a planting opportunity is triggered, based usually on the accumulation of a minimum level of soil moisture storage and a planting rain.

A rotational farming program, whether based on long fallowing or opportunity cropping, needs to not only contain a profitable combination of enterprises but also be able to maintain soil structure and fertility, facilitate control of insect, weed and disease pests, allow for timely field operations and spread the requirements for labour and machinery. These longer-term strategic considerations need to be balanced with and considered alongside the short-term tactical decisions. For example, the application of some residual herbicides (eg Atrazine) can restrict the opportunity to plant some crops for up to 18 months after application. Likewise, dryland cotton is generally planted in long fallows after preceding sorghum or wheat crops, the stubble of which is desirable protection from soil erosion during the fallow and cotton crop. Thus, decisions such as applying residual herbicides or planning for dryland cotton generally form part of farmers' strategic management of their cropping system.

For this northern region, Wylie (1996) proposed five important aspects to successful farm business management:

1. Optimum enterprise mix
2. Optimum crop yields
3. Efficiency in resource use
4. Marketing
5. Making it happen (management skill)

There is obvious potential for seasonal climate forecasts to impact on at least the first four of these requirements for managing cropping systems. A number of analyses have already demonstrated value in seasonal climate forecasting on improving tactical agronomic management of crops to optimise yields (Hammer and Muchow, 1996; Meinke et al., ??; Meinke and Hochman, 1998). Chapman et al. (1998) has also explored whether climate forecasting can impact on marketing strategies. However, there has been little attention to date on exploring the potential of seasonal climate forecasts in the more strategic management decisions regarding crop rotations and resource sustainability.

The potential to utilise climate forecasts to improve enterprise mix or resource use requires forecasts of sufficient persistence to extend beyond a single crop into the subsequent fallow and even as far as the next crop. This will require forecasting skill out beyond 12 to 18 months from the time of forecast. If this was the case, one may be able to tradeoff length of fallow, and consequent soil moisture storage, for improved prospects of future rainfall. Reduced fallow lengths from opportunity cropping have been suggested as advantageous not only in terms of profitability but also for resource use efficiency and sustainability (Keating, 199?; Hayman, 1996; Wylie, 1996). However, opportunity cropping is riskier - in some seasons one may be sacrificing an assured good crop after long fallowing for two mediocre crops. The prospect of climate forecasting being able to reduce this risk is an appealing objective.

Analysis of cropping systems

Assessing the value of a climate forecast in a cropping system is difficult to achieve through experience alone. Experiments just can not be run for sufficient duration to sufficiently sample the distribution of seasons experienced in the northern cropping region. Alternatively, crop simulation models combined with the historical climate record have been used to analyse the value of seasonal climate forecasting for tactical decision making (Hammer and Muchow, 1996; Meinke et al., ??; Meinke and Hochman, 1998).

The ability to assess the value of a climate forecast in a cropping system requires an ability to simulate the key components of the relevant system. The Agricultural Production Systems Simulator (APSIM) is a simulation model designed to simulate the production and resource consequences of agricultural systems, including fallowing and cropping sequence (McCown et al., 199?). APSIM has been specified for and it's simulations tested against a range of farming systems (Carberry et al., 199?; Carberry et al., 199?; Turpin et al., 1996; Probert et al., 1998). Such testing has also demonstrated that APSIM is suitable for simulating commercial yields in the northern cropping region (Foale and Carberry, 199?).

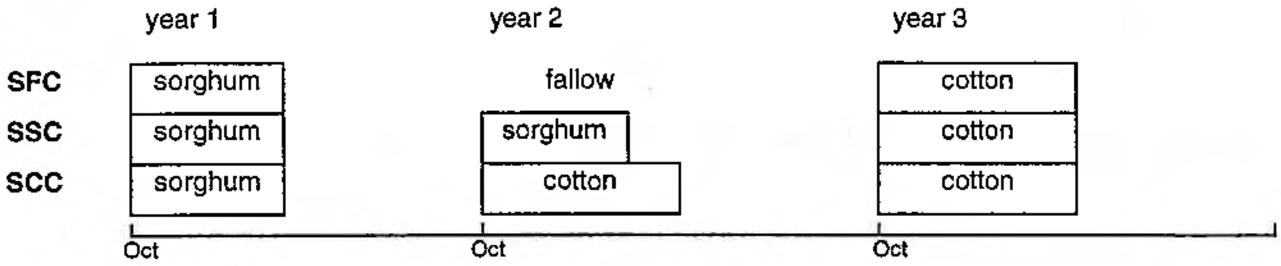
In the following case study, APSIM is used to explore the potential for using a climate forecast in influencing management that has consequences beyond the yield of a single crop.

A case study: cotton in an opportunity cropping system?

Dryland cotton production in northern Australia is a high return, high risk cropping option. For this reason, farmers who to decide to grow cotton generally become dedicated cotton growers, with grain production a secondary priority. Other crops are grown as rotation crops with cotton, usually to provide stubble cover to protect against soil erosion or as a disease break. Because of its high production costs and high risk, the recommendation for dryland cotton is for planting after long fallowing from either sorghum or winter cereal (QDPI Crop Management Notes, 199?). Thus, the decision to produce dryland cotton is usually made 6-12 months ahead of planting time and income received 6-8 months thereafter. In many years long fallowing will improve yields and reduce risk of crop failure. But in other years, the soil water profile may have been full long before planting time or in-crop rainfall may have been sufficient to discount the value of pre-plant moisture storage. The degree to which the efficiency of dryland cotton systems could be improved if they became more flexible through an opportunity cropping strategy has not previously been explored.

In this case study, three set crop rotations (Figure 1) are compared with an opportunity cropping rotation. The recommended sorghum-long fallow-cotton rotation (SFC) is compared with the option of planting sorghum (SSC) or cotton (SCC) in the second year of the rotation and short-fallowing through to cotton in the third year. All three rotations are committed to sorghum in year 1 and cotton in year 3 based on the rationale that the farm is geared for cotton production in terms of infrastructure (machinery, labour), markets (futures trading) and rotation of farm strips. While this degree of rigidity may not be completely realistic, it is assumed for the purpose of this case study.

Figure 1: Schematic representation of the three crop rotations.

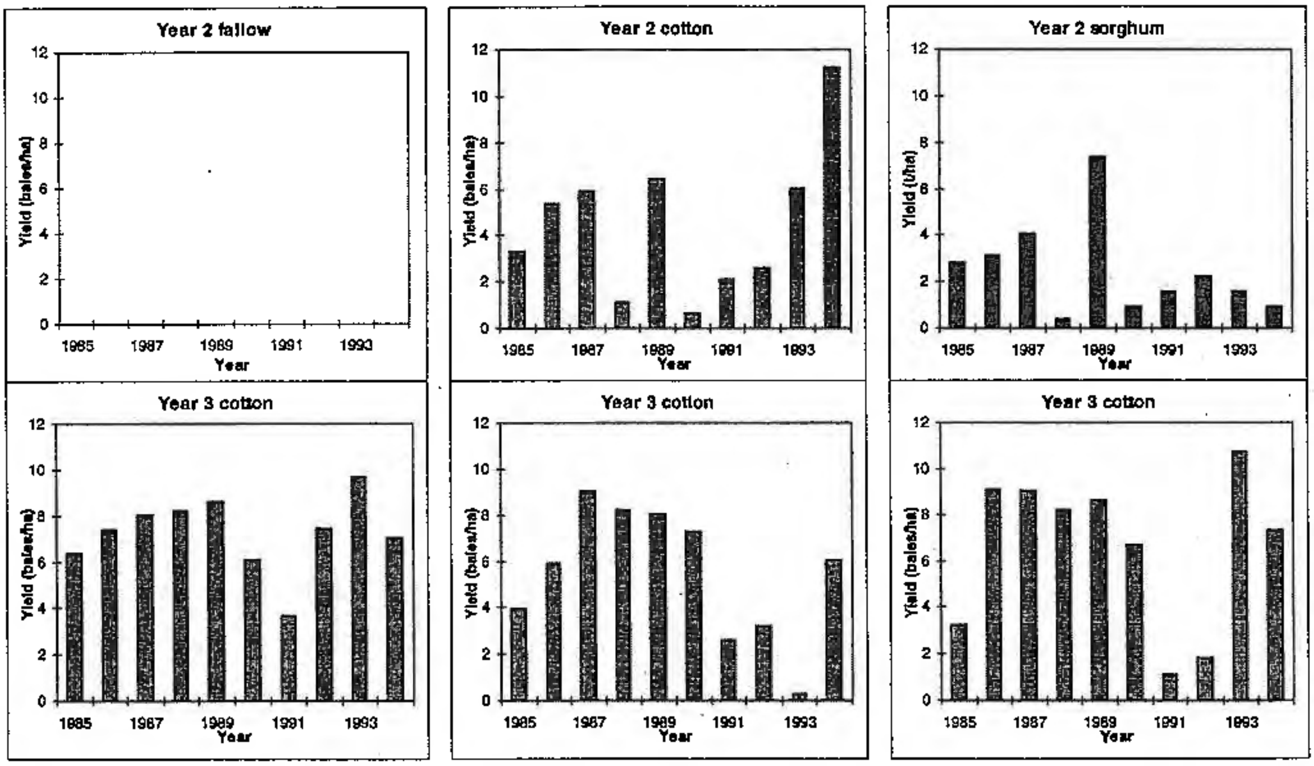


In order to simplify the comparison of the three rotations, subsequent analyses assumed that the decision point is the 1st October in year 2. That is, the farm manager has come out of sorghum in year 1 and is faced with the question of which of three rotations to select given known soil resources. At this point, the manager has the option of planting a sorghum or cotton crop or of fallowing through to the set cotton crop in year 3. This case study is thus considering a tactical decision for a given decision point and one set of soil water and nitrogen values. A more strategic consideration of this decision would need to accommodate a range of decision points and soil resource conditions.

APSIM version 1.40 was configured to simulate crop rotations grown on a Brigalow soil type at Dalby (lat. ??) over the historical climate record between 1887 and 1997. Over the 100 years, the simulations were run continuously with the system's status reset every two years - soil water was reset to 122mm available soil water, representing a 47% full profile to 1.8m depth. The three rotations, fallow-cotton, sorghum-cotton or cotton-cotton, were simulated with the initial sorghum or cotton crops planted on 1st October and the final cotton crop planted based on a sowing criterion of receiving 25mm rainfall over a 5 day period between the 1st October and 25th November. For sorghum, the cultivar Buster was sown at 100,000 plants/ha. For cotton, a Siokra-type variety was planted in single-skip configuration (two rows planted followed by one missed row) at 12 plants/m row. Both sorghum and cotton crops were fertilised with 150kg N /ha. Each simulation run was repeated a second time with the starting year offset by one in order to enable the crops in rotation to be represented in all years.

As can be seen in the example output of simulated yields for the three rotations in Figure 2, fallowing in year 2 resulted in some guarantee in cotton yields in year 3. Planting sorghum or cotton in year 2 dramatically affected subsequent cotton yields in some years, whereas there are other years where there was little or no effect. Lower year 3 cotton yields were a consequence of the previous crop reducing the soil water available to the following cotton crop. This effect of a preceding crop was reduced in those years where pre-season or within-season rainfall was adequate to produce good yields for the cotton crop in year 3. Interestingly, there are a number of years when a preceding crop resulted in increased cotton yields due to a reduced incidence of waterlogging.

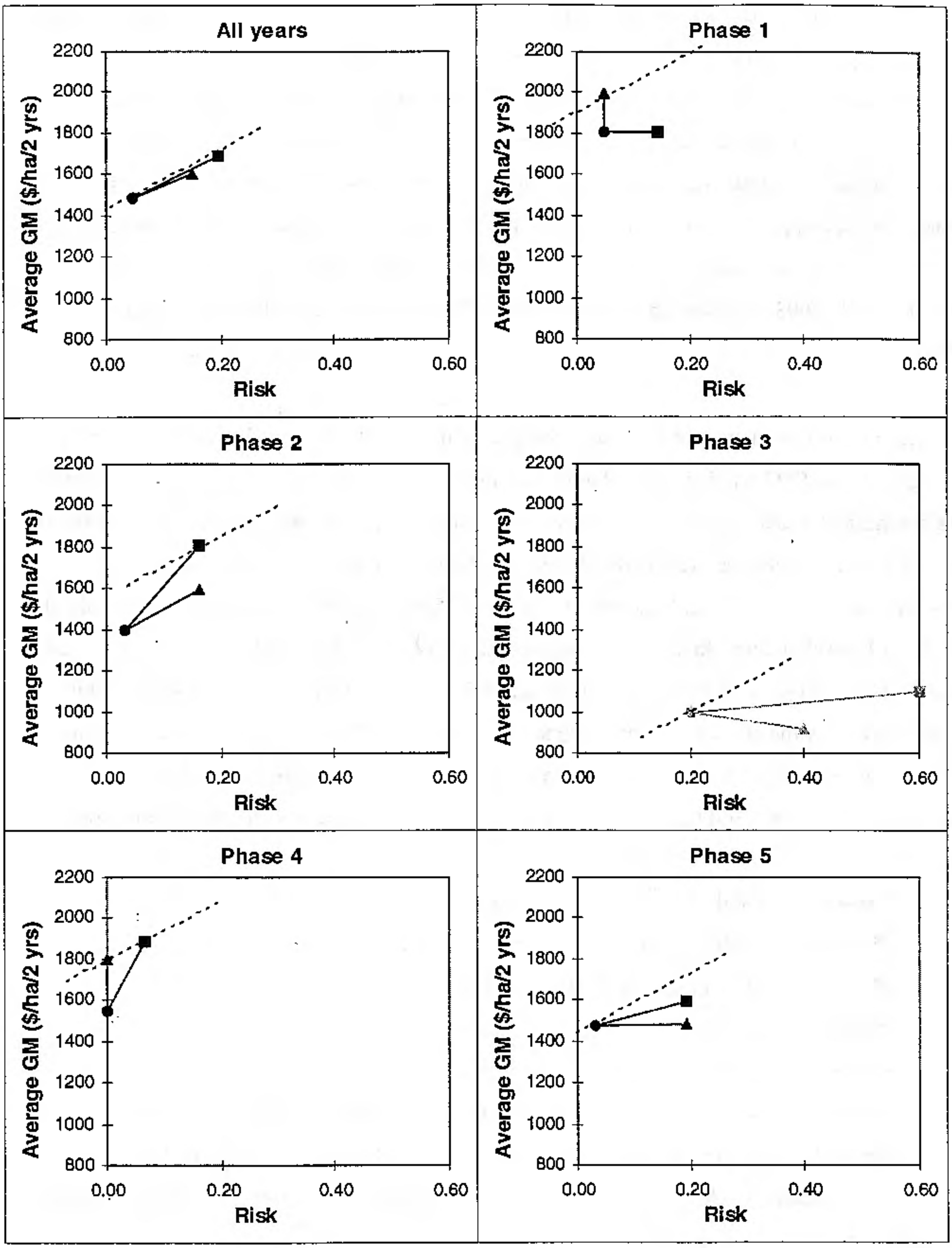
Figure 2: Simulate yields for the three rotations for the period 1985-1994. Yields are plotted against the year in which the decision point was made (i.e. year 2 of the three year rotation).



At the decision point of 1st October in year 2 of the rotation, the manager can either select the same rotation every year or choose to opportunity crop, i.e. select a different option (SFC, SSC or SCC) each year based on knowledge of his system status at that point in time. Given in this case study that soil resources are set to the same nominated value at this point in time, this decision can be based solely on a forecast of future climate. In this case, the five-phase SOI system of Stone (??) is employed whereby the value of the August-September SOI phase determines which of the three rotations will be chosen in an opportunity cropping situation.

The selection of a rotation for each SOI phase is not straight forward as there is no clear advantage of any one rotation in the analogue years consistent with each SOI phase. Therefore, the choice between any rotational strategy would depend on a manager's attitude to returns and risk. In order to select a preferred rotation for each SOI phase, average gross margin is plotted in Figure 3 against

Figure 3: Average gross margin ($/ha/2 years of rotation) for the SFC (●), SSC (▲) and SCC (■) rotations plotted against a measure of risk (defined as the proportion of years where the accumulated 2-year gross margin was less than $500/ha) for all years and for each SOI phase. The dashed line represents the nominal farmer utility function adopted for this analysis.



a measure of economic risk for each of the three rotations to create a return-risk tradeoff space over all years and for each SOI phase. The assumption is that risk-efficient strategies dominate others by higher mean gross margin return at a given level of risk. Choice between rotations in this return-risk space depends on attitude to risk of individual decision-makers, which can be expressed as an utility function. Within this return-risk space, iso-utility or indifference lines can be drawn tangential to the points of highest return or lowest risk. A horizontal indifference line tangential to the strategy of highest mean return would represent the choice of a risk-neutral farmer. Indifference lines of increasing slope depict increasing aversion to risk, culminating in a vertical indifference line of a highly risk-adverse farmer tangential to the strategy of lowest risk. This depiction of return-risk tradeoff and the application of iso-utility or indifference lines has been successfully employed by in a number of previous studies (Barah et al., 1981, McCown et al., 1991, Keating et al., 199?, Carberry et al., 1993, Muchow and Carberry, 19??, Parton and Carberry, 1995 and Hammer et al., 199?).

In dryland cotton production regions, the recommended strategy is to long fallow into cotton, analogous to the SFC rotation. Accordingly, the slope of the indifference line depicted in Figure 3 was determined as that required to select the SFC strategy marginally ahead of the next best rotation over all years. The rationale for choosing this slope for the indifference line was to depict a decision-maker whose current preference is for the recommended SFC rotation but who would also not be far from choosing a higher return, higher risk strategy (eg SCC). In fact, over all years, the three fixed rotations are close to forming a linear efficiency frontier (SSC is slightly below this frontier) whereby the chosen indifference line would find it difficult to discern between the three rotations. Nevertheless, by using an indifference line with this same slope within the return-risk tradeoff space for each SOI phase (Figure 3), a preferred rotation can be selected in each case, namely:

Phase 1 (SOI negative) = SSC
Phase 2 (SOI positive) = SCC
Phase 3 (SOI rapidly falling) = SFC
Phase 4 (SOI rapidly rising) = SCC
Phase 5 (SOI near zero) = SFC

By selecting the rotation corresponding to the SOI phase at the time of the decision point in year 2 of the rotation, a SOI-responsive tactic (SOI) can be determined for each year of the simulation analysis. Gross margins calculated for the 100 year climate record based on this SOI-responsive strategy are presented in Figure 4.

The performance of the three set rotations and the SOI-responsive tactic can be compared using a number of criteria. In this case, performance criteria included:

(i) gross margin accumulated for the simulated two year period (years 2 and 3 of the rotation);

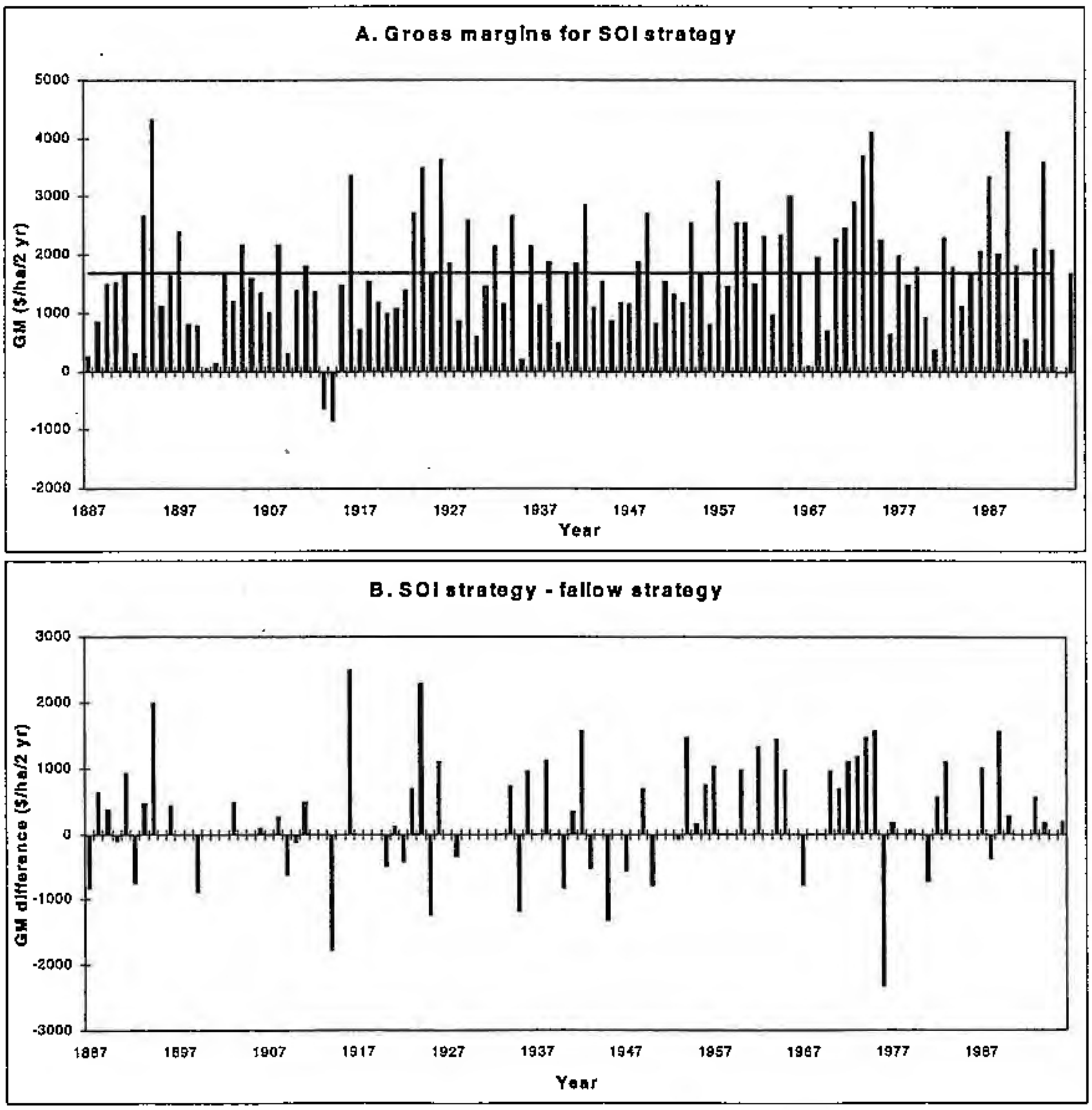
(ii) the risk of economic loss, quantified as the percentage of years when the accumulated gross margin for the two year simulation period was less than \$500/ha/2 years (an estimate of the fixed costs required to maintain a typical cotton farm at Dalby);

(iii) cash flow, quantified as the gross margin attained at the end of year 2 in a three year rotation; and

(iv) relative soil loss, quantified as the simulated soil erosion loss for each rotation relative to the simulated soil loss for the recommended SFC rotation (set to 1.0).

A final assessment of the four rotational systems is to compare their performance against a rotation where the choice at the decision point in year 2 is determined by future knowledge of the rotation in each year that produces the highest gross margin (criterion (i) above). This rotation is termed "perfect knowledge" (PK) as is an indicator of the potential performance of the farming system.

Figure 4: (A)Gross margins calculated from simulated yields for ?? and (B) the difference in gross margin ??



A summary of the average performance of the three set rotations, the SOI-responsive rotation and the rotation based on perfect knowledge is given in Table 1. Long fallowing into cotton (SFC) clearly produced the highest average cotton yields in year 3 of the rotation. It produced a high expected gross margin with the lowest risk of economic loss. However, long fallowing performed poorly in other performance criteria in having negative cash flow in year 2 of the rotation and the highest risk of soil erosion. Rotations where sorghum or cotton replace the summer fallow (SSC or SCC) reduced final cotton yields, on average by 13% and 28% respectively. However, the compensation for lower final cotton yields was the increased overall productivity of the SSC and SCC rotations due to the additional crops planted in year 2 of these rotations. The SCC rotation increased average gross margin by 14% and SSC by 8% relative to the recommended SFC rotation. While cash flow and erosion risk were also positively affected by these more intensive rotations, a significant downside was the large increase in risk of economic loss, increasing from 5% of years when SFC would have failed to 19% and 15% of years when SCC and SSC respectively would have resulted in economic losses. So, while each set rotation performed best in at least one performance criterion, no one rotation was best overall. In fact, using the farmer indifference line nominated in Figure 2, the lower return but lower risk outcome for the recommended SFC rotation would result in its preference over the other two set rotations.

Table 1: Average performance of five systems.

	SFC	SSC	SCC	SOI	PK
Yields					
Year 2 (bale or t / ha)	0.0	3.2	4.2	-	-
Year 3 (bale / ha)	6.0	5.2	4.3	-	-
Gross margin ($/ha/2 yr)	1482	1605	1691	1683	2226
Risk (% yrs GM < $500)	5	15	19	9	3
Cash flow (year 2)	-56	380	820	405	578
Soil loss (relative to SFC)	1	0.49	0.72	0.77	0.65

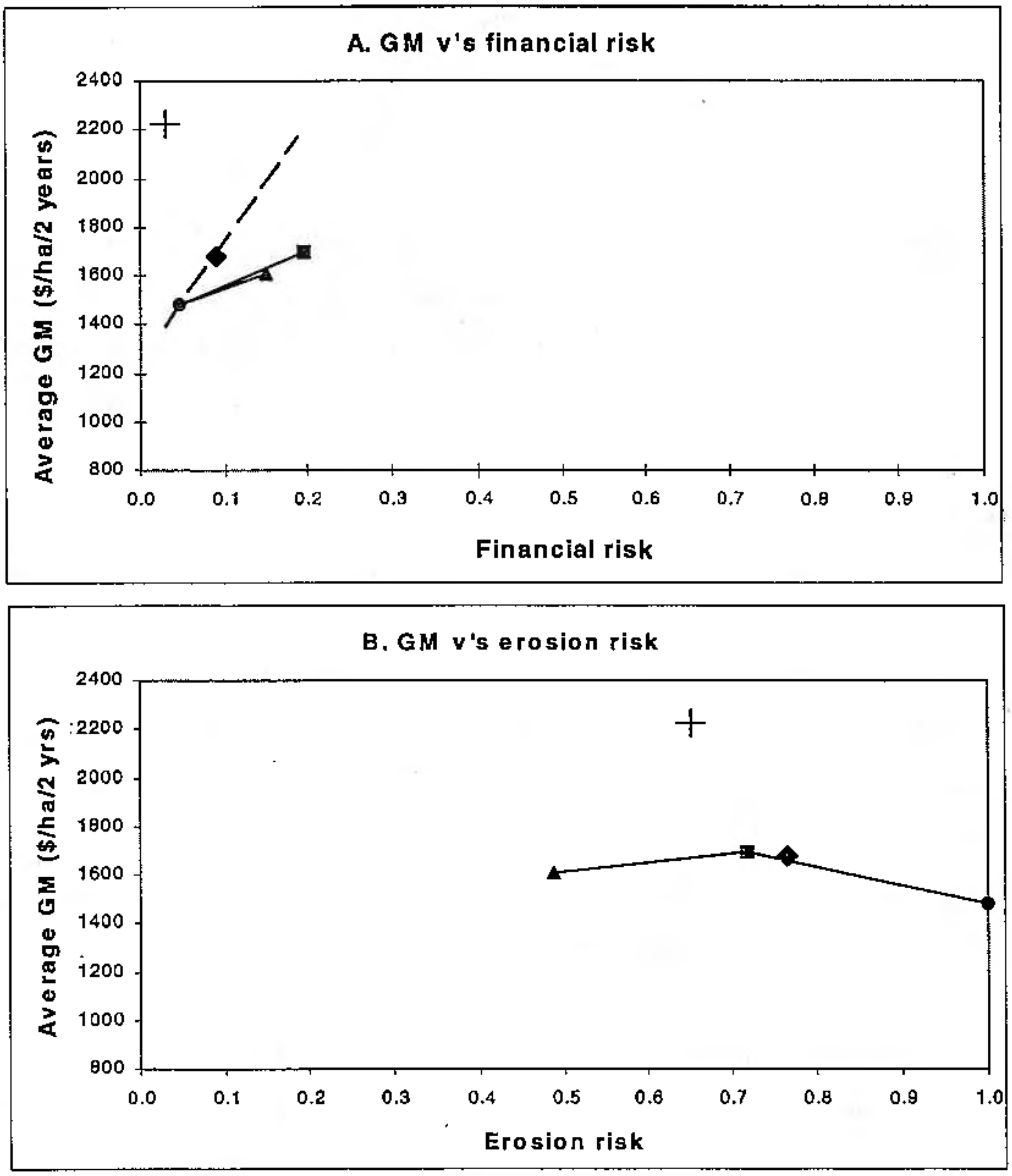
The opportunity cropping, or SOI-responsive rotation, performed well against the three set rotations yet it was not best in any one performance criterion (Table 1). It was significantly better than SFC in terms of average gross margin, cash flow and erosion risk, but it was also almost twice as risky on average. The SOI-responsive rotation produced very close to the average gross margin and soil loss values of SCC yet was considerably less risky and it was better than the SSC rotation in all but the soil loss criterion. Perfect knowledge produced significantly greater average gross margins at lower risk than any other of the management strategies. However, perfect knowledge, selected on a basis of maximisation of gross margins, did not produce the best outcomes for cash flow nor erosion. No one rotation, even including perfect knowledge, provided a best option for all selection criteria.

For a decision-maker with an indifference line used in Figure 2, the SOI rotation would be the preferred rotation based on a tradoff between gross margin return and risk (Figure 5A). For a decision-maker to not select the SOI rotation, the slope of the indifference line would have to increase by a factor of 3.3. It is important to note, however, that a number of decision-makers could remain indifferent to the SOI rotation if their attitude to risk is represented by an indifference line of slope greater than this value.

The previous analyses traded off gross margin return against risk of financial loss. However, other criteria may be of greater importance to some decision-makers. Figure 5B presents a tradeoff space for gross margin return versus erosion risk over all years for the three fixed rotations and the rotations based on SOI and perfect knowledge. Such a tradeoff space is relevant to a decision-maker wishing to maximise gross margin while minimising soil erosion. In this situation, there are only two risk-efficient strategies, SSC and SCC, which have equal or higher average gross margins at lower levels of erosion risk than the other rotations. Thus, a rotational system using a SOI seasonal climate forecast provided no advantage to such a decision-maker - the SCC rotation provided equivalent returns at a lower risk of soil loss. While the SCC rotation would be selected by a decision-maker who was indifferent to erosion, selection of the SSC rotation would only require a small increase in the slope of the indifference line away from the horizontal, suggesting that the SSC rotation would be a preferred rotation for decision-makers concerned with soil loss from erosion. In fact, some decision-makers who were extremely adverse to erosion risk would even select SSC in preference to a rotation that used perfect knowledge to maximise gross margin.

This case study examined the use of an SOI seasonal climate forecast in incorporating cotton into an opportunity cropping system. The example dealt with only one decision point and a given set of soil water and nitrogen values. Further analyses are obviously warranted for alternative decision points and soil conditions – values for soil water set closer to 0% or 100% would undoubtedly favour the SFC and SCC rotations respectively. And in reality, the assumed obligation to lock into cotton in year 3 could be reassessed prior to its planting, based on soil water and the SOI outlook at that point in time. Nevertheless, faced with the situation of 47% full water profile and a planting opportunity in early October, this case study was able to demonstrate that an SOI forecast at this time could be advantageous to making a decision with consequences seen 18 months thereafter. As the persistence in SOI forecast skill beyond 3-6 months is low, it is likely that the SOI forecast was providing an

Figure 5: Average gross margin ($/ha/2 years of rotation) for the SFC (●), SSC (▲), SCC (■), SOI (◆) and PK (+) rotations plotted against (A) financial risk, defined as the proportion of years where the accumulated 2-year gross margin was less than $500/ha; the dashed line represents the minimum slope of the indifference line required for preference of SFC over the SOI-based rotation, and (B) erosion risk, defined as the simulated soil erosion loss for each rotation relative to that for the SFC rotation.



indicator of soil moisture storage 6 months hence, which is turn provided a forecast of summer cropping potential 12-18 months after the original decision point. Soil moisture storage is a strong indicator of future crop yields (Hayman, 19??, other??).

Conclusions

Seasonal climate forecasts can undoubtedly assist farmers in managing cropping systems, either in short-term tactical decisions or long-term strategic decisions. This paper reviewed a range of applications for climate forecasts and concluded that there are a number of systems issues that would benefit from long lead-time forecasts. A specific case study was employed that demonstrated considerable potential for using the Southern Oscillation Index in assisting the incorporation of opportunity cropping into dryland cotton production systems. While this example dealt with only a limited situation, the suggested benefits derived from using SOI forecasts in selecting crop rotations clearly warrant further exploration.

The value of the SOI has often been assessed on crop performance within 3-6 months of a forecast. The results from the case study presented here demonstrated impacts on crop rotations ending 18 months after the initial forecast. Such impacts were mainly a consequence of the effects on soil water storage at the end this initial 3-6 month period. This telegraphing of a SOI forecast beyond 6 months via a soil water signal provides the opportunity to assess SOI as a longer-lead time forecast than has been explored to date in analyses that have considered correlation solely with seasonal rainfall.

This paper has demonstrated a significant point that should not be lost on those who are at the forefront of developing and extending new seasonal climate forecasts, namely that even a good climate forecast may still not be of value to decision-makers. The decision-analysis framework adopted in the case study indicated that the SOI-based rotation would not have been selected by the very risk adverse decision-makers (Figure 5A). Similarly, a decision-maker who would place soil erosion as a higher concern than financial risk would also not adopt the SOI strategy developed in this paper (Figure 5B). All decision-makers, including farmers, make decisions for a multitude of reasons and so, while a seasonal climate forecast may be of use to some, it may not necessarily be useful to all.

Finally, this paper introduced a decision-analysis framework to assess the value of the SOI against multiple criteria. This analysis framework proved useful in exploring tradeoffs between conflicting objectives in assessing the value of a climate forecast. This approach is subsequently used by Hammer et al (1998) to assess the relative skills of several alternative forecasting systems in assisting management of cropping systems.

Acknowledgments

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Evaluation Of Participative Approaches To RD&E: a case study of FARMSCAPE

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Abstract

This paper describes the evaluation framework and process developed and used for the FARMSCAPE project. It considers the impact of the evaluation on the RD&E process and its value/limitations in making meaningful statements/conclusions about the effectiveness of the participative RD&E project. Indicative results emerging from the evaluation about the FARMSCAPE project are presented. The paper concludes that the evaluation approach used was useful in providing benchmarks and teasing out the impact of the project on different participants. It also provided some evidence that the FARMSCAPE approach to developing and using decision support tools was useful in complementing farmer experience in dryland farming systems.

Key words:. Process evaluation, participative RD&E, farming systems research and extension.

Effective evaluation of Research Development & Extension (RD&E) projects and programs has been a difficulty faced by funders and project managers for many years. Adoption and cost-benefit studies have been plagued with the problems of measuring and then attributing changes to specific activities, and capturing impacts in extremely variable climatic and marketing conditions (1). Participative RD&E adds an extra level of complication: outcomes are often emergent rather than pre-determined; RD&E is enacted through interaction between a number of players; and impacts on all stakeholders are also critical rather than change in a single target group.

There is also a stronger need to provide ongoing input into project management in participative RD&E rather than a reliance on post project analysis. (2). The FARMSCAPE project, a participative RD & E project 'Farmer-Adviser-Researcher Monitoring, Simulation and Performance Evaluation for best dry land cropping practices', has these features and was the subject of this study.

Methodology

The evaluation sought to monitor and interpret the project through the eyes of the key participant groups: researchers; farmers; private consultants; and extension officers (both within and outside of the project) over the life of the project. At intervals throughout the project, interviews were undertaken with (approximately 30) representatives of these groups to capture learning and practice change as it happened and within the context of project activities and seasonal conditions. Interview data was collated and summarised from each participant group and returned to interviewees for checking that the information was correct. The project team received the summaries of all groups to provide an overview and stimulus for change in the project direction and activities. Insights gained were included in a project newsletter which was widely circulated.

Results and discussion

The iterative interviews and their analysis yielded strong, corroborated data about the impact of the project and its process on the key participant groups. Information gathered from each participant groups supported emerging conclusions. For example, follow-ing the mid-term (two years into the project) analysis of interviews with commercial advisers, an external evaluator, Van Beek (3), concluded that "... the inter-viewees in this group confirmed all the effects claimed by farmers: ... farmers have begun to think differently: more three dimensional: taking soil, water and nutrient balances down to 1.8 metres into account more long term; more strategically towards maintaining and improving resources; and taking economic aspects more into account." The iterative nature of the interviews also proved valuable in providing benchmarks of attitudes and practice. As Van Beek (3) observed...comparing last year's and this years notes... there is a substantially more positive attitude to FARMSCAPE products than a year ago. The evaluation process was flexible to fit in with key decision-making periods in the farming cycle, and to pursue data from new sources as their importance was established. For example, the mid-term interviews were broadened to include cotton growers and research managers. Some of the impact value of the evaluation was lost, however, because the data collection and its analysis took place within a sub-team rather than involving the whole team.

The analysis of interview data (developing and linking emergent categories and relationships - and using participants' direct quotes to minimise bias) indicated that those farmers directly involved in the project increased their use of soil testing; and explored crop simulations for: confirmation of current practices; use of alternative crops; and considering 'what-if' scenarios for the most efficient use of soil water. They did not embrace simulation outputs as expert knowledge to be adopted, but rather as an inquiry framework to test against their own experience. Commercial advisors used new soil monitoring techniques and simulation model outputs to enhance their advisory value to leading farmers. Model complexity and organisational changes limited the ability of commercial companies to directly and independently use the simulations - they relied on researcher support and input. On-going evaluation will monitor whether these farmers and advisors continue to use the tools and framework post the intensive phase of the project. Some extension officers claimed that they benefited from the project through an increased understanding about soil, water and crop management. Concern by others centred around the limitation of the approach to benefit the wider group of farmers and advisors, and the need to maximise the educational value of simulation, rather than focusing on its role in making recommendations. As a result of the evaluation process, researchers modified the model parameters and user interface, and changed the emphasis of the project from providing solutions to dryland farmers to providing a framework for farmer decision makers to test alternatives and complement their own experience.

Conclusion

The use of iterative interviews with different participant groups as an evaluation approach has proven to be very effective and robust in terms of capturing perceptions, learning and practice change in the stakeholder groups closely associated with the project. It has permitted a 'teasing out' of the value and impact of different project activities on participants, and provided a deeper understanding of the context and complexities operating within the project environment. The process could be strengthened by including the total project team in the analysis of collected data

The evaluation process provided some evidence that the project was having a positive impact on: learning within each participant group; attitudes, decision-making and practice. It highlighted the complexities in the management of dryland crops and the limitations of simulation aided decision making in providing expert recommendations. However, the evaluation has shown that simulation, adequately contextualised, was valued by participating farmers and advisers in: (a) gaining insights into production system function; and, (b) augmenting their farming experience in making judgements required in tactical responses and the evolution of improved production strategies.

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Leaf nitrogen gradients in cotton canopies vary with ontogeny and nitrogen supply

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Abstract

Leaf nitrogen (N) concentration usually declines with depth in plant canopies. For use in a framework to scale-up from leaf photosynthesis to canopy radiation use efficiency, we quantified the leaf N gradients in the canopies of three cotton crops. Stratified cuts were taken regularly, starting around the time of first square, and the leaf area index (LAI) and leaf N concentration in each layer determined. The slope of the regression of specific leaf nitrogen (SLN, g N/m^2 leaf) against cumulative LAI from the top of the canopy increased with ontogeny. It was also more marked under low N supply than high supply.

Key words: *Gossypium hirsutum*, leaf nitrogen, nitrogen distribution, ontogeny

Radiation use efficiency (RUE) of cotton crops varies with ontogeny and leaf N accounts for part of this variation (6). Hammer and Wright (2) have developed a framework which can be used to scale-up from leaf photosynthesis to canopy RUE. The framework allows for the leaf N gradients within canopies and calculates photosynthesis by leaves at different levels in the canopy as a function of their N status and light receipt. This paper presents canopy gradients of SLN for use within this framework with the aim of exploring the mechanism by which ontogeny and leaf N affect RUE. The final purpose is to improve the response to nitrogen within the CERCOT cotton crop simulation.

Methods

Measurements were made on two field experiments grown on a uniform grey clay at Narrabri, NSW. The crops were sown on a 1 m row spacing with 10 plants/m^2. Full irrigation and commercial insect control were used. In Experiment 1, cotton (cultivar Siokra L22) was sown on 11 Oct. 1995. On 9 Aug., 150 kg/ha of N was applied as anhydrous ammonia. Each plot was 175 m 5 4 rows and there were three replicates. In exp 2, two N treatments were established: nil and 150 kg/ha as anhydrous ammonia applied on 28 Aug. Cultivar Sicala V2i was sown on 14 Oct 1996. A completely randomised design and four replicates were used. Plots were 75 m 5 4 rows. Each fortnight, beginning around the time of first square, 1 m^2 destructive samples were taken. The canopy was cut in four successive strata of equal vertical thickness. The leaf area (hence LAI) in each layer was measured and the leaves dried and weighed. N concentration (g N/g DM) was determined using a near infrared refractometer or a Leco machine, both calibrated against the Kjeldahl method. Sampling continued until the period of maximum boll growth was over and the crop was approaching maturity. Seven stratified harvests were made in Experiment 1 and six in Experiment 2.

Results and discussion

In Experiment 1, pooling data across all samplings, a strong linear relationship was found between *ln* SLN and cumulative LAI from the top of the canopy (Fig. 1). The production of branches by the cotton plant means that at any height in the canopy there are leaves of a variety of ages. Nevertheless, clear N gradients were still apparent. This is consistent with the hypothesis that leaf N concentration is influenced by light receipt as well as age (3, 5). In Experiment 2 the gradient varied with ontogeny and became steeper (P<0.01) as the reproductive sink increased (Fig. 2). In contrast, N gradients in sunflower were more uniform in the reproductive than in the vegetative phase (7). This difference may be due to the indeterminate nature of cotton and/or the different distribution of reproductive sinks in the canopy. In Experiment 2, the gradient was greater for the low N treatment than for the high N treatment (P<0.001) (Fig. 1). A non-uniform N distribution in plant canopies results in higher canopy photosynthesis than a uniform distribution by maximising N in leaves which receive the most

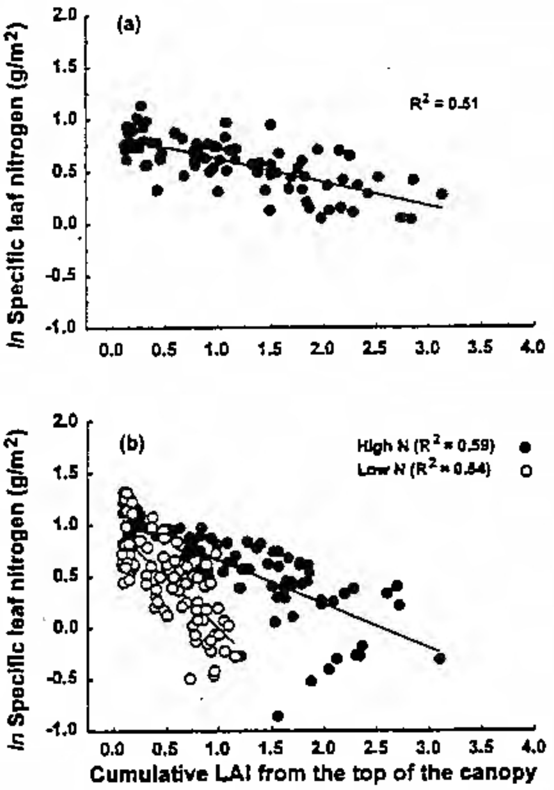

Figure 1: Relationship between ln SLN and cumulative LAI from the top of the canopy in (a) Experiment 1 and (b) Experiment 2, including data from all samplings.

light (4), although alternative reasons for the existence of gradients have been proposed (1). The greater N gradient in the low N treatment may reflect a mechanism that increases the efficiency with which limited N is used in photosynthesis. Investigations into the possible causes of ontogenetic changes in N gradients in cotton and their implications are continuing.

Conclusion

Leaf N gradients in cotton canopies were found to vary with N supply and ontogeny. In contrast to published data on other species they became steeper in the reproductive phase.

Acknowledgments

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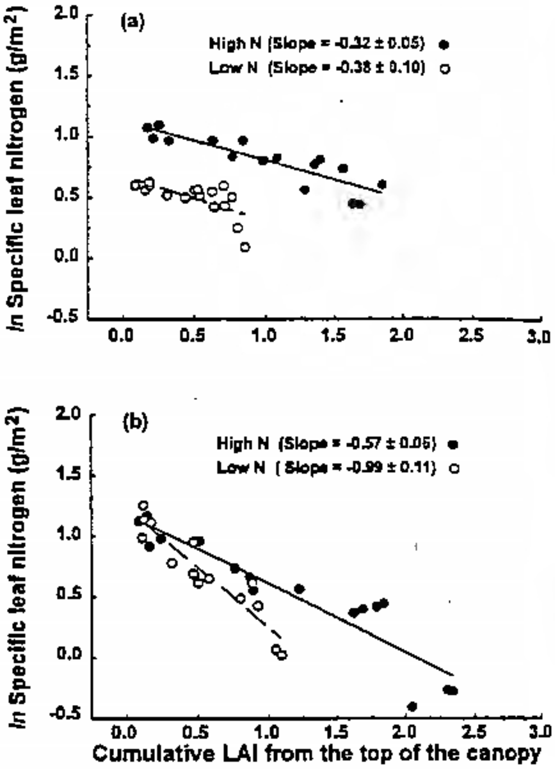

Figure 2: Relationship between ln SLN and cumulative LAI from the top of the canopy in Experiment 2 (a) near squaring (77 days after sowing) and (b) with a full boll load (141 days after sowing).

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Document 1d

Do Degree Days accurately describe rates of cotton development?

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Summary

Degree days are commonly used by industry and researchers to estimate expected crop development. This assumes that cotton's potential development is largely a function of temperature. Controlled environment studies show that the function currently used to calculate Degree Days does not accurately reflect the effect of high temperatures on development. Preliminary analysis of the data shows that the inclusion of an optimum temperature in the degree day function in addition to the base temperature of 12°C can make more consistent predictions of cotton development. Improving this function will enable better predictions of cotton development in a greater range of environments and seasons.

Introduction

The rate of crop development is controlled by temperature and the relationship is often described using the convenient concept of degree days (DD). This is essentially the average temperature on a given day minus a base temperature of 12 °C; the temperature at which development ceases. The present function used in the Australian cotton industry to derive DD12 is:

$$\text{Degree Days } (^\circ\text{C d}) = \frac{(\text{Tmax} - 12) + (\text{Tmin} - 12)}{2}$$

where Tmax and Tmin are daily maximum and minimum temperatures respectively. When Tmin is less than 12 °C, (Tmin - 12) is set to 0 (Constable and Shaw, 1988). Degree days can be accumulated over time to predict developmental phases or rates of cotton growth (eg. time to first square). In the cotton industry DD12 are used for a variety of purposes, such as comparing the performance of crops within and across seasons; nitrogen management (nutriLOGIC); pest management (entomoLOGIC); and the cotton crop simulations models OZCOT and CERCOT.

Since the DD12 function was derived from experiments which focused on the effects of early season development of cotton (Constable, 1976). The effects of low temperatures were the primary concern. Hence, this function describes the development of cotton ceasing when minimum air temperature drops below 12 °C. This minimum temperature for development is often referred to as the base temperature.

Recent studies into the effects of environment on crop development have highlighted some deficiencies in using this function to predict development. Constable and Shaw (1988) estimate that approximately 505 DD12 are required from sowing to first square. However, the measured DD12 for this period varied considerably (from 510 to 695 DD12) in a series of field experiments when calculated using the standard function (Table 1). Similarly, recent investigations of dry season cotton production in the Ord (North West Australia) where high daily temperatures are experienced early in crop growth have shown that the time to first square varied between 440 and 600 DD12 (Yeates pers comm). Such variation devalues the usefulness of DD12 in predicting development. Especially when very hot conditions can be expected.

Table 1: Degree days (base 12) calculated for the time to first square for cultivars S324 and L22 (there was no significant difference between cultivars).

Season	Sowing date	Degree Days (°C d)
1995/1996	10 October 1995	696
	20 November 1995	608
	5 December 1995	644
1996/1997	11 October 1996	510
1997/1998	16 October 1997	622

While variation in development can be caused by a number of environmental influences (such as waterlogging, pest attack, disease, cold shock), there is evidence to suggest that some of this variation may be caused by high daily temperatures. The DD12 function assumes that the rate of a process continues to increase as temperatures increase. However, at high temperatures many biological processes don't respond as markedly to temperature as they do at moderate temperatures.

Studies conducted by Wells (1994) have shown a tendency for the rate of progress toward first square to increase only gradually when average daily air temperatures exceed the mid twenties (Figure 1). Constable (1976) in his studies in early cotton crop development also indicated that there appeared to be a plateau in the rate of crop development when temperatures exceeded 23° C.

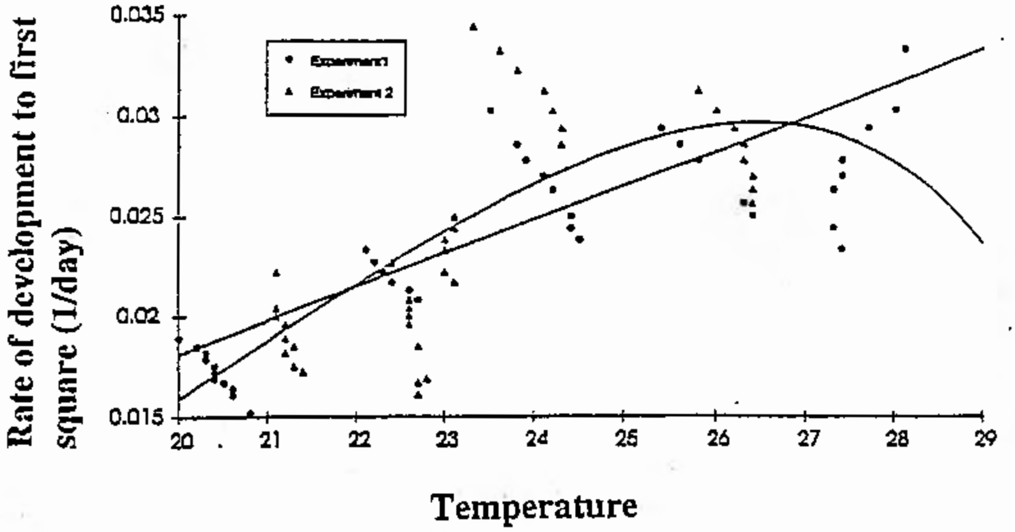

Figure 1. The rate of development to first square versus average daily air temperature (Wells, 1994).

Little work has been conducted to determine the effects of high temperature on the development of cotton. This paper outlines results from continuing studies to develop new functions that can be used to calculate DD that will account for both low and high temperature effects on cotton development.

Experimental Methods

To quantify the response of cotton development to temperature, specifically the time to first square and squaring rate, an experiment was conducted in a controlled temperature glasshouse under natural light. A short season (Siokra S324) and a long season (Siokra L22) cotton cultivar were sown on October 7 1996. Nine plants of each cultivar were grown under each of five maximum/minimum temperature regimes: 12/20, 18/26, 21/29, 23/31 28/32 °C (daily means of 16, 22, 25, 27 and 30 °C respectively).

Plants were observed three times per week and the date of appearance of the first square was recorded. The appearance of a square was defined as the date when the subtending leaf unfolded (Constable, 1991). From the appearance of the first square until one week after the opening of the first flower, the date of appearance of each square/site (sites analogous to new square production) was recorded for cultivar S324. This provides an estimate of the potential rate of squaring before the effects of increasing boll load could be expected to slow the rate of square production. Degree Days (DD12) were calculated using the function presented previously.

Results and Discussion

Rate of development calculated using the present cotton industry function (DD12) appeared to decrease as average daily temperature increased, in other words the apparent duration to first square in DD12 for both cultivars increased as average temperature increased (Figure 2). Degree Days to first square for cultivar S324 increased from 356 DD12 at 22 °C average daily temperature to 415 DD12 at 30 °C. This means that the DD12 calculation may not be adequately allowing for high temperatures. A better function would give similar estimates of developmental rate at all temperatures. A similar response was seen for cultivar L22, only the calculated DD12 were greater for each average temperature. No squares were produced in the 16 °C average daily temperature treatment in the experimental period.

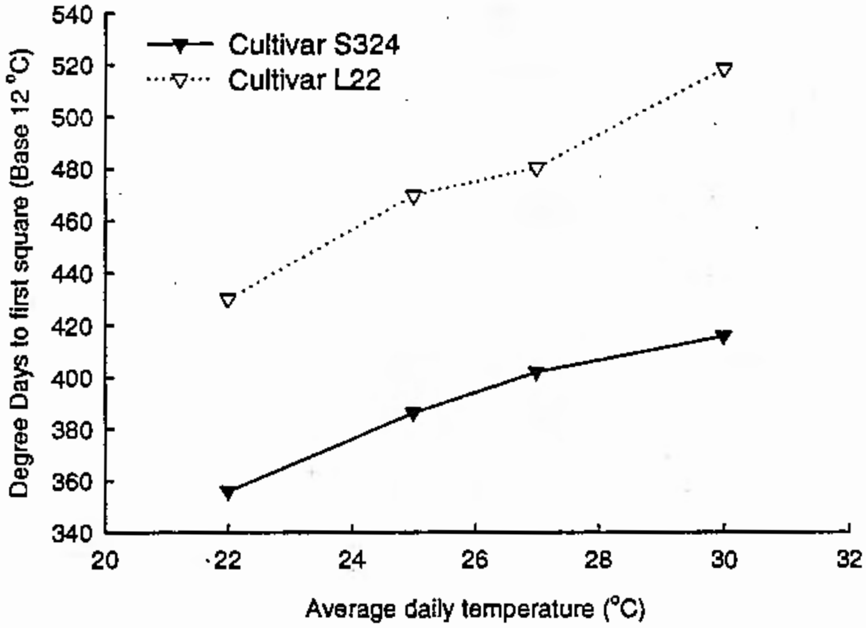

Figure 2. Degree Days (calculated using present industry function) to first square versus daily average temperature (°C) for cultivars S324 and L22.

After first square the rate of site production can be described by the squaring constant. The constant indicates the rate of square production as a function of temperature. It is a characteristic of the cultivar and should be constant across temperatures. Cultivars with a greater squaring constant have a higher rate of square production. The squaring constant for cultivar S324 calculated using the conventional DD12 function decreased as average temperatures increased (Figure 3). So again it would appear that the function did not adequately reflect the effects of high temperature.

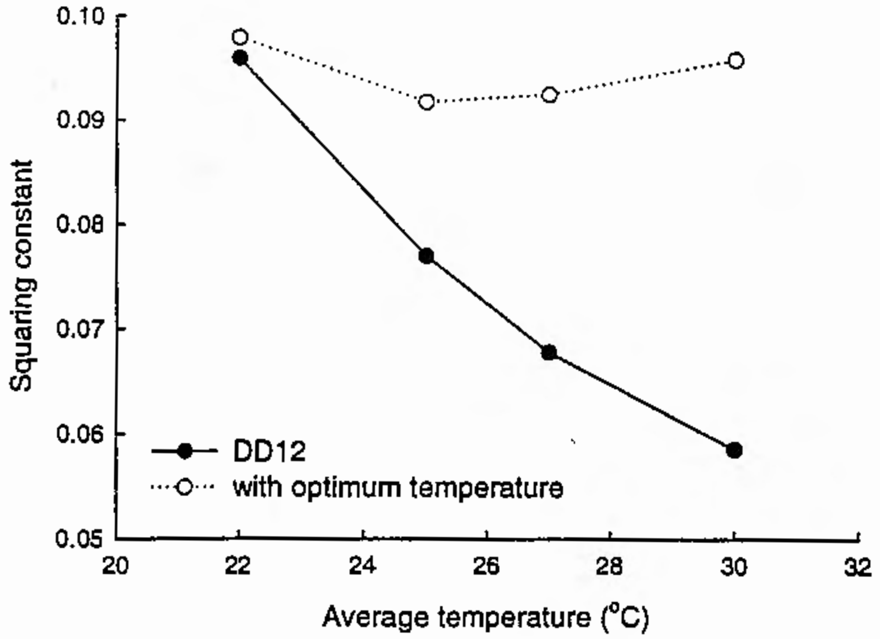

Figure 3. Squaring rate for cultivar S324 versus daily average air temperature (°C) calculated using the present cotton industry function (DD12) as well as a function that includes an optimum temperature.

These results demonstrate that the present function to calculate DD does not account for the effects of high daily temperatures. The addition of an optimum temperature in the DD function, in the same way as a base temperature of 12 °C, may allow for more consistent predictions of developmental rates. Figure 3 shows that a more reliable squaring constant can be estimated when an optimum temperature is included in the DD function. The functions are still being explored, particularly for the development to first square.

Improving the function that calculates DD by including an optimum temperature will enable better prediction of cotton development in a greater range of environments and seasons. Continuing work is concentrating on developing the response over a greater range of temperatures and for different developmental processes in cotton growth, as well allowing for differences between cultivars. The new temperature functions are also being tested using field grown crops.

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Document 13

Reproductive Allocation of Cotton in Response to Plant and Environmental Factors

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We measured the responses of cotton reproductive allocation (reproductive dry matter/total shoot dry matter) to environmental and plant factors in five field experiments. A wide range of growing conditions were generated by manipulation of sowing date, nitrogen fertilizer, and plant density. Plant factors that varied included phenological development (short- *vs.* long-season cultivars), and leaf morphology (normal- *vs.* okra-leaf types). We quantified the relationships between reproductive dry matter and shoot dry matter using allometric analysis, and calculated the daily rate of increase in reproductive allocation. Shoot dry matter ranged from 4 to 235 g per plant, and reproductive dry matter from negligible to 138 g per plant. Within these ranges, the linear regression between $\log_e$- reproductive dry matter and $\log_e$- shoot dry matter had an $r^2 = 0{\cdot}81$ ($P = 0{\cdot}0001$). Differences among experiments were significant, but they accounted for only a small proportion of the variance of reproductive dry matter (8 %). The dynamics of reproductive allocation followed a logistic pattern. The rate during the linear phase of increase in reproductive allocation was fairly stable across experiments ($\approx 0{\cdot}006\ \mathrm{d}^{-1}$). The effect of experiments was significant, but it accounted for only 7 % of the variance in the rate of reproductive allocation increase. Analysis of treatment effects on both allometric coefficients and on the rate of increase in reproductive allocation showed that: (*a*) few of the sources of variation included in these experiments caused significant changes in reproductive allocation; and (*b*) when significant changes occurred, their magnitude was comparatively small. The relative stability of cotton reproductive allocation suggests that for some applications simple models can be developed on the basis of a fixed rate of increase in reproductive allocation.

Key words: *Gossypium hirsutum* L., cotton, reproduction, allometry, harvest index, allocation, nitrogen, plant density, okra leaf, phenology.

INTRODUCTION

Reproductive allocation (reproductive dry matter/total shoot dry matter) is an important component of plant fitness (Bazzaz *et al.*, 1987). Chiarello and Gulmon (1991) examined the responses of reproductive development to environmental stresses and highlighted the strong coupling that exists between the reproductive and vegetative growth of plants. As they pointed out, the coupling is implicit when reproduction is viewed as a form of resource partitioning.

Reproductive allocation is also a major determinant of economic yield in seed crops (Gifford *et al.*, 1984). Increased partitioning of dry matter to reproductive organs accounts for much of the progress in breeding for high yield potential in wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), oat (*Avena sativa* L.), rice (*Oriza sativa* L.), maize (*Zea mays* L.), and sunflower (*Helianthus annuus* L.) (Slafer, 1994).

In grain crops, harvest index (seed dry matter/total shoot dry matter) is a measure of reproductive allocation. In reviewing the concept of harvest index and its application in plant breeding and crop physiology, Hay (1995) pointed out that in the absence of severe stress, major environmental factors have little influence on harvest index. Hay (1995) also emphasized the high heritability of this trait in several species. The dynamics of harvest index have usually been described with a logistic function and a number of studies have concentrated on the stability of harvest index increase during the linear phase of seed growth. Effects of genotype and/or environmental conditions on the rate of harvest index increase during this phase have been investigated in soybean [*Glycine max* (L.) Merr.] (Spaeth and Sinclair, 1985), sorghum [*Sorghum bicolor* (L.) Moench] (Muchow, 1990), barley (Goyne *et al.*, 1996), wheat (Moot *et al.*, 1996) and sunflower (Chapman, Hammer and Meinke, 1993). The relative stability of the rate of harvest index increase found in some of these studies implies that 'grain yield accumulation can be estimated from crop biomass at any stage of grain growth without knowledge of grain number or the rate of grain growth' (Muchow, 1990). For some applications this simple approach to modelling crop yield could be useful, as illustrated by the models of Chapman *et al.* (1993) and Goyne *et al.* (1996).

Studies of reproductive allocation are therefore important in understanding both the adaptation of wild plants to their natural environments and the physiology of yield determination. Quantitative relationships to account for the effects of plant and environmental factors on reproductive allocation are essential components of crop simulation models. In cotton (*Gossypium hirsutum* L.), lint yield is closely related to fruit production (e.g. Hearn, 1975).

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The objective of this study was to evaluate the variation in cotton reproductive allocation caused by environmental and plant factors. A range of contrasting growing conditions was available through manipulation of sowing date, nitrogen fertilizer and plant density. Plant factors that varied included leaf morphology, *viz.* normal- *vs.* okra-leaf, and phenological development, *viz.* short- *vs.* long-season cultivars. The okra-leaf trait is linked with a high rate of flowerbud production (Thomson, 1995), and this could cause differences in reproductive allocation between normal- and okra-leaf types. Likewise, short season cultivars are expected to have earlier reproductive growth and/or greater rates of increase in reproductive allocation (Spaeth and Sinclair, 1985; Chiarello and Gulmon, 1991).

In this study we used two analytical methods: firstly, allometric analysis of the relationship between reproductive dry matter and shoot dry matter was used to separate changes in partitioning related to plant size or 'ontogenetic drift' (Evans, 1972) from changes in partitioning related to other sources of variation (Coleman, McConnaughay and Ackerly, 1994). Secondly, we calculated the rate of increase in reproductive allocation with time, a method that allows comparisons with other species.

MATERIALS AND METHODS

Crops and treatments

Five experiments were conducted at Narrabri, a semi-arid environment in NW New South Wales, Australia (30°13′ S, 149°47′ E). Crops were furrow-irrigated at approx. 14 d intervals; weeds were controlled with pre-sowing herbicides and manually through the season, arthropod pests were monitored twice weekly and controlled with chemicals following the guidelines in entomoLOGIC, a pest management package used in commercial cotton farms (McKewen *et al.*, 1994).

Treatments are summarized in Table 1. Experiment 1 compared two short season cultivars of different leaf morphology (Siokra S324, okra leaf *vs.* CS7S, normal leaf) grown under contrasting availability of resources: low, resulting from high plant density and no nitrogen fertilization; and high, resulting from low plant density and high nitrogen rate. No attempt was made to separate the effects of plant density and fertilization, which would have required a fully factorial experiment, but rather the treatments were designed to generate extreme growing conditions, as described in Sadras (1996). Experiment 2 compared two plant population densities. Experiment 3 combined two cultivars of contrasting leaf morphology (Siokra 1–4, okra leaf *vs.* Deltapine 90, normal leaf) and two rates of nitrogen application at high plant density. Experiment 4 compared normal and okra-leaf cultivars. Experiment 5 compared short- (Siokra S324) and long-season (Siokra L22) cultivars at three sowing dates.

All experiments included four replicates per treatment. Treatments were laid out in completely randomized blocks (expts 1, 2, 4 and 5) or a split-plot design with nitrogen rate as main plot and cultivar as sub-plot (expt 3). Individual plots comprised 5 rows × 17 m (expts 1 and 2), 6 rows × 17 m (expt 3), 6 rows × 25 m (expt 4), and 4 rows × 75 m (expt 5). In all experiments inter-row distance was 1 m.

Measurements

Dry weights of shoots and of reproductive organs (flowerbuds, green fruit and mature fruit) were obtained

TABLE 1. *Summary of treatments in five field experiments at Narrabri and reproductive allocation measured at the end of the growing season*

Experiment	Season	Treatment code	Sowing date	Cultivar*	Plant density (m^{-2})	Fertilizer (kg N ha^{-1})	Reproductive allocation ± s.e. (dimensionless)
1	1993/94	A	23 Nov.	Siokra S324	5	180	0·63±0·01
		B	23 Nov.	Siokra S324	12·5	0	0·66±0·01
		C	23 Nov.	CS7S	5	180	0·68±0·03
		D	23 Nov.	CS7S	12·5	0	0·70±0·02
2	1994/95	A	12 Oct.	Siokra V-15	5	120	0·68±0·02
		B	12 Oct.	Siokra V-15	10	120	0·66±0·03
3	1993/94	A	11 Oct.	Siokra 1–4	16	0	0·67±0·01
		B	11 Oct.	Siokra 1–4	16	105	0·62±0·01
		C	11 Oct.	Deltapine 90	16	0	0·64±0·01
		D	11 Oct.	Deltapine 90	16	105	0·55±0·03
4	1994/95	A	13 Oct.	Siokra 1–4	16	86	0·61±0·02
		B	13 Oct.	Deltapine 90	16	86	0·61±0·02
5	1994/95	A	13 Oct.	Siokra S324	8	120	0·60±0·02
		B	13 Oct.	Siokra L22	8	120	0·56±0·02
		C	30 Nov.	Siokra S324	8	120	0·48±0·03
		D	30 Nov.	Siokra L22	8	120	0·40±0·01
		E	21 Dec.	Siokra S324	8	120	0·20±0·03
		F	21 Dec.	Siokra L22	8	120	0·09±0·02

* Siokra S324, Siokra V-15, Siokra L22, and Siokra 1–4 are okra-leaf cultivars while CS7S and Deltapine 90 are normal-leaf cultivars. Siokra L22 is a 'long'-season, Siokra S324 and CS7S are short-season, and Deltapine 90, Siokra V-15 and Siokra 1–4 are medium-season cultivars (Constable, pers. comm.).

from samples taken from each replicate at approx. 14 d intervals. Samples were taken at random from the central crop rows and sample size varied between 0·5 m^2 (expts 1–4) and 1 m^2 (expt 5). No attempt was made to separate seed, fibre and other fruit components.

Data analysis

Using values of reproductive dry matter (y) and shoot dry matter (x), allometric relationships were investigated with least-squares linear regressions of $\log_e$-transformed variables (Coleman *et al.*, 1994). The slope of the regression, b, is an allometric coefficient or 'scaling factor' (Niklas, 1993*a*) that expresses the ratio between the relative growth rates of reproductive structures and shoots (Thornley and Johnson, 1990). Regression analysis was applied to the data pooled across experiments and differences in b among experiments were assessed using stepwise procedures (Sokal and Rohlf, 1981). Separate regressions were also calculated for each experiment and the effects of treatments within each experiment on b were assessed with stepwise procedures as before.

Reproductive allocation was calculated as the ratio between reproductive and total shoot dry matter. The time course of reproductive allocation followed a logistic pattern (e.g. Fig. 3A). Thermal time (Hodges, 1991) was calculated using a base temperature of 12 °C (Constable, 1976). The rate of change in reproductive allocation (y) with time (x_1) or thermal time (x_2) during the linear phase was calculated using least square regressions; points for inclusion in the analysis were selected as in Spaeth and Sinclair (1985) and Moot *et al.* (1996). Variation in the rate of increase in reproductive allocation among experiments and in the rate due to treatments within experiments was analysed statistically as explained above for the allometric coefficient.

To account for the oil-synthesis cost of the cotton seed, dry matter was converted to glucose equivalents using production values of fruit and vegetative organs given by Wall, Amthor and Kimhall (1994). The responses of reproductive allocation to environmental and plant factors, however, were unchanged by the method used in the calculations (i.e. dry matter or glucose equivalent) (see also Sadras, 1997). Thus, for simplicity, and to allow for comparisons with other studies, this paper presents results on a dry matter basis.

RESULTS

Allometric relationships

Shoot dry matter ranged from 4 to 235 g per plant and reproductive dry matter from negligible to 138 g per plant. Across these ranges, the linear regression of the $\log_e$ transformed variables had an r^2 of 0·81 (Fig. 1A). The experiment effect, i.e. the variation in b among experiments, was highly significant ($P = 0·0001$), and the inclusion of this effect in the model increased the coefficient of determination from 0·81 to 0·89.

The allometric relationship obtained in our experiments was compared with data from experiments of Hearn (1975) in a tropical environment (Fig. 1B). The plants of Hearn's experiments were initially well below the allometric relationship obtained for our plants, but differences diminished as reproductive growth progressed.

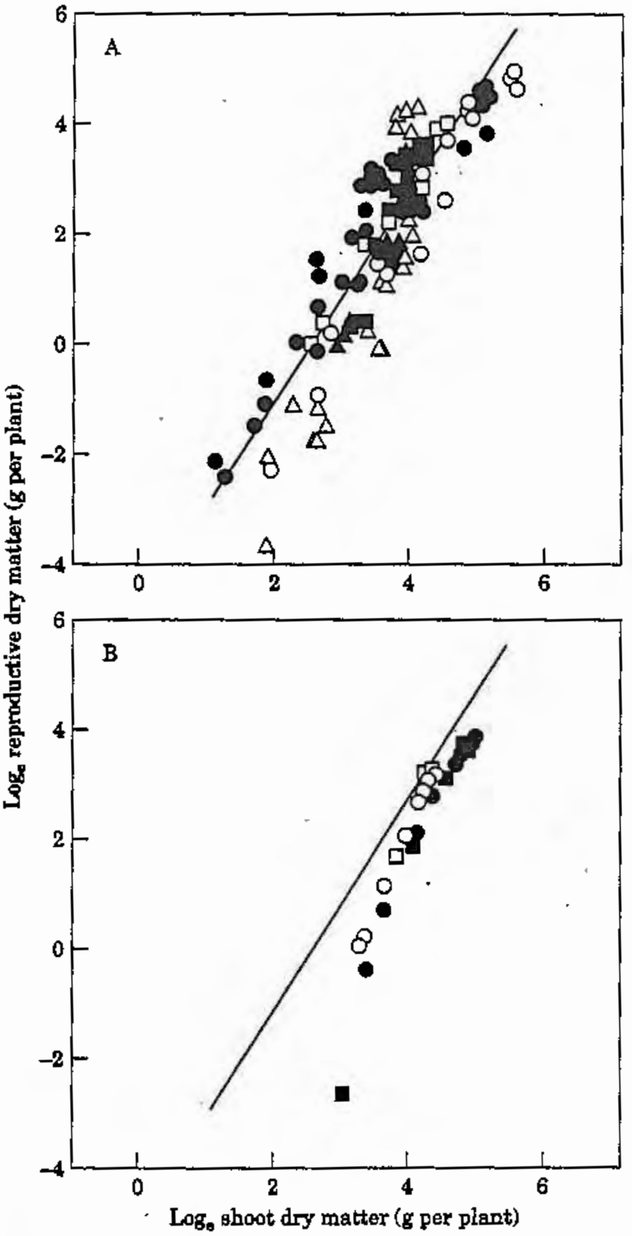

FIG. 1. A, Allometric relationship between reproductive dry matter and shoot dry matter in the five field experiments summarized in Table 1. (●) Expt 1; (○) expt 2; (■) expt 3; (□) expt 4; (△) expt 5. The fitted regression had a slope = 1·97 (s.e. = 0·085), $r^2 = 0·81$ ($P = 0·0001$). B, Comparison between the allometric relationship in Fig. 1A (——) and data from plants grown at Kununurra (15°29′ S, 128°43′ E). (○, ●) Fortnightly irrigation; (□, ■) 3-weekly irrigation; (○, □) 34 kg N ha^{-1}; (●, ■) 168 kg N ha^{-1}. Data from Hearn (unpub. res.) from experiments described in Hearn (1975).

Allometric analysis for the treatments in each experiment showed that plants growing under low availability of resources (low nitrogen supply, high density) had a significantly greater allometric coefficient than their counterparts grown under more favourable conditions (Fig. 2, expt

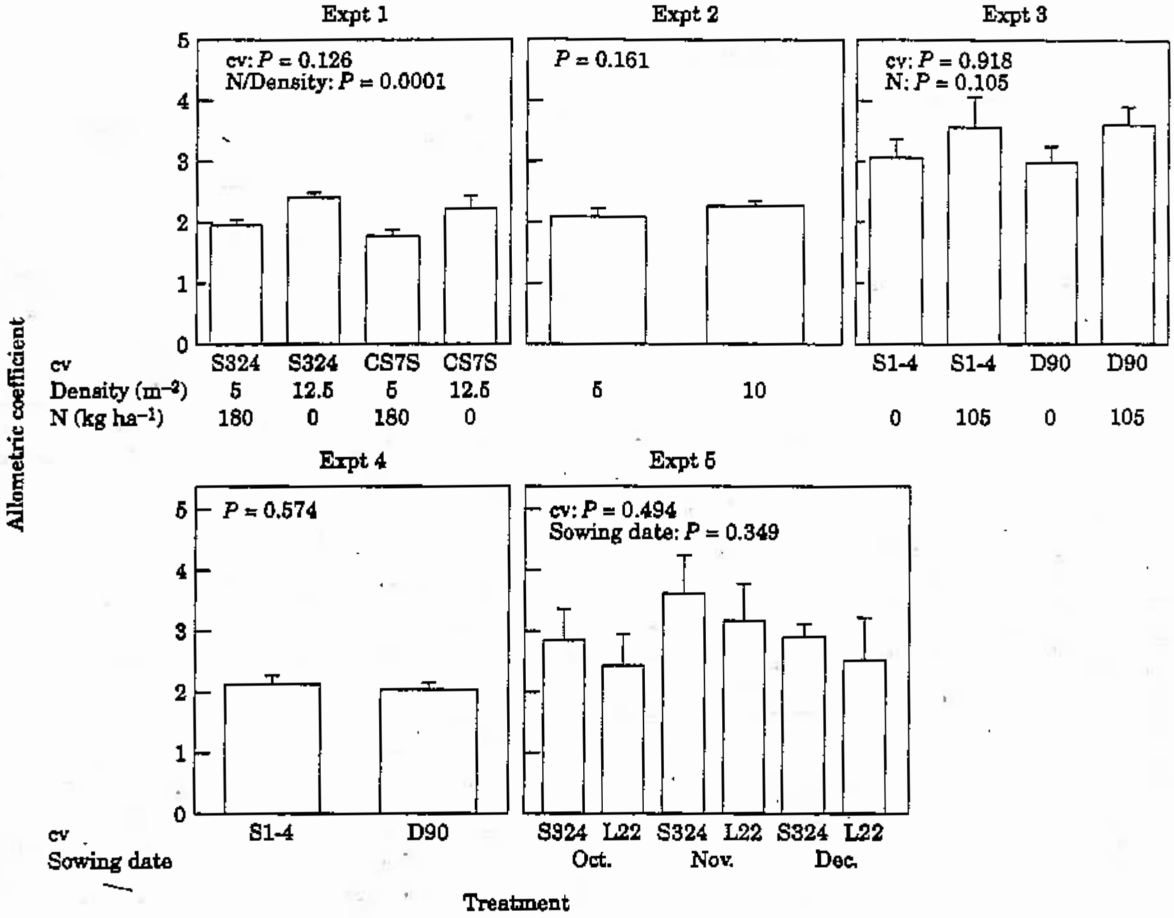

FIG. 2. Allometric coefficients (dimensionless) of cotton plants as affected by plant and environmental factors in the five experiments summarized in Table 1. Error bars are s.e.

1). Allometric coefficients were unaffected by (*a*) leaf type (expts 1, 3 and 4), (*b*) plant density (expt 2), or (*c*) phenological development and sowing date (expt 5) (Fig. 2).

Dynamics of reproductive allocation

Changes in reproductive allocation with thermal time followed a logistic curve, as shown in the example of Fig. 3A. The only exception to this pattern was the December sowing of expt 5 (Table 1) in which plants did not reach the linear stage of reproductive allocation increase due to low temperatures which terminated plant growth. Excluding this treatment, the pooled data for the linear stage of the five experiments is shown in Fig. 3B. A linear model with thermal time as the independent variable accounted for 88 % of the variation in reproductive allocation, a marginally better correlation than that obtained using time as the independent variable ($r^2 = 0{\cdot}82$). The average rate of increase in reproductive allocation was $5{\cdot}45 \times 10^{-4}$ (°C d)$^{-1}$ or $5{\cdot}98 \times 10^{-3}$ d^{-1}. The experiment effect, i.e. the variation in rate among experiments was significant ($P = 0{\cdot}004$) and the inclusion of this effect in the thermal-time model raised the coefficient of determination from 0·88 (Fig. 3B) to 0·95.

Analysis for the treatments in each experiment showed that in expt 1 plants grown under low availability of resources had a significantly greater rate of increase in reproductive allocation than their counterparts grown under more favourable conditions (Fig. 4). In expt 3, the rate of increase in reproductive allocation was greater in Siokra 1–4 (okra-leaf) than in Deltapine 90 (normal-leaf), but no significant differences between cultivars with different leaf morphologies were found in expts 1 and 4. Rates were also unaffected by plant density (expt 2), phenological development or sowing date (expt 5) (Fig. 4).

DISCUSSION

We used allometric analysis (Figs 1 and 2) and analysis of the dynamics of reproductive allocation (Figs 3 and 4) to explore the effects of plant type and growing conditions (Table 1) on the reproductive allocation of cotton plants.

Okra-leaf cultivars have a high rate of flowerbud production compared with normal-leaf types (Thomson, 1995). Although strict comparisons should include isogenic lines for leaf morphology, comparisons between okra- and normal-leaf types with different genetic backgrounds (e.g. Deltapine 90 *vs.* Siokra 1–4, expt 4) have often had the resolution to detect biologically meaningful differences (e.g. Wilson, 1994). Allometric analysis showed no difference

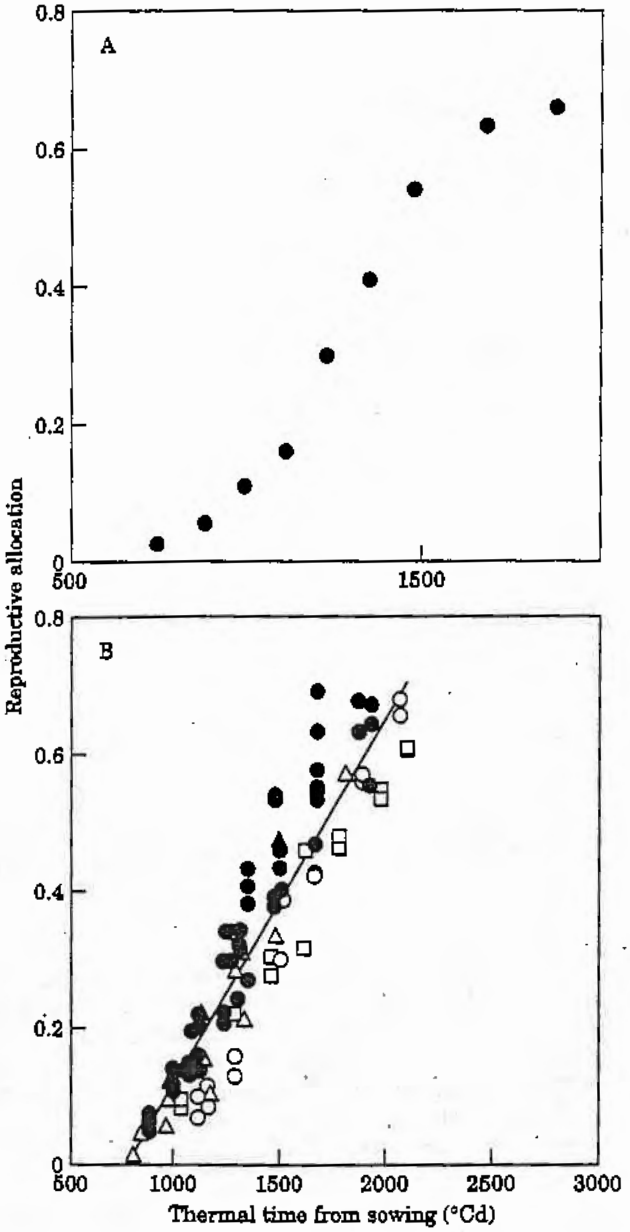

FIG. 3. A, Example of the pattern of change in reproductive allocation with ontogeny (expt 1, Treatment B). B, Reproductive allocation during the linear phase in the five experiments summarized in Table 1. The fitted regression had a slope = $5{\cdot}4 \times 10^{-4}$ $(°C\ d)^{-1}$ (s.e. = $2{\cdot}0 \times 10^{-5}$), $r^2 = 0{\cdot}88$ ($P = 0{\cdot}0001$). Symbols as in Fig. 1A. Reproductive allocation is a dimensionless variable.

between normal- and okra-leaf types in three experiments (Fig. 2), and the rate of increase in reproductive allocation was higher in the okra-leaf type in one out of three experiments (Fig. 4).

The rate of harvest index increase of Gokuwasechishima, an early soybean cultivar, was almost twice as high as the average rate of mid-season cultivars (Spaeth and Sinclair, 1985). Also, comparisons of plants grown in contrasting environments indicate that the stress of a shorter growing season may increase partitioning to sexual reproduction (Chiarello and Gulmon, 1991). In our study, a comparison of cultivars of contrasting phenology showed trends in the expected direction: i.e. the short-season cultivar (Siokra S324) had a greater allometric coefficient than the long-season cultivar (Siokra L22) in three sowing dates (Fig. 2, expt 5), and it also had a slightly greater rate of increase in reproductive allocation at two sowing dates (Fig. 4, expt 5). None of these differences, however, were statistically significant.

Plant density, ranging from 5 to 10 plants m^{-2}, did not affect reproductive allocation of well fertilized plants (Figs 2 and 4, expt 2). In contrast, plants grown under severe stress due to the combination of high population density and no fertilization had a greater reproductive allocation than their counterparts grown under more favourable conditions in expt 2 (Figs 2 and 4). This response is consistent with the high initial rate of fruit setting of nitrogen- and water-stressed cotton plants in comparison with well fertilized and frequently irrigated controls (Constable and Hearn, 1981). The responses of reproductive allocation to stress depend on (*a*) the resource(s) involved, *viz.* water, light, space, minerals, (*b*) interactions between stresses; and (*c*) plant type, e.g. perennials *vs.* annuals, wild *vs.* domesticated (Chiarello and Gumon, 1991). In general polycarpic perennials reduce their partitioning to sexual reproduction under low availability of resources, but there are many exceptions to this rule including the case of perennials that act as annuals under stress (Chiarello and Gulmon, 1991). In all four species of cultivated *Gossypium*, a genus of perennial shrubs, annual types have been developed under domestication (Evans, 1993) that retain some perennial traits (e.g. Sadras, 1996).

The small magnitude of the changes in reproductive allocation of the plants in our experiments contrast with the apparently high responsiveness of wild plants (Chiarello and Gulmon, 1991). This could be, in part, due to intrinsic differences between wild and domesticated plants. However, it could also be that some of the changes in reproductive allocation reported for wild species are not true changes in partitioning, but rather variations associated with plant size that require allometric analysis to be resolved (Coleman *et al.*, 1994). Using allometric analysis, Niklas (1993*a*, *b*) found a stable relationship between reproductive biomass and stem diameter for different species in each of three taxa (Pteridophytes, four species; Gymnosperms, six species; Angiosperms, two species). Likewise, allometric analysis showed that significant reductions in reproductive allocation of cotton plants caused by spider-mite (*Tetranychus urticae* Koch) infestation were not due to true changes in partitioning, but rather reflected the effects of mites on plant size (Sadras and Wilson, 1997).

We compared the allometric relationship obtained in our experiment (Fig. 1B) with data from the experiments of Hearn (1975). Hearn's experiments contrast with ours in three aspects: (*a*) they included an obsolete cultivar (Deltapine 16); (*b*) crops were grown in a tropical environment (latitude 15° S); and (*c*) they were unprotected from insects during the 'wet' season. The initial divergence between Hearn's data and ours is probably due to the relatively high vegetative growth caused by high temperature, and insect-induced fruit shedding (Sadras, 1995).

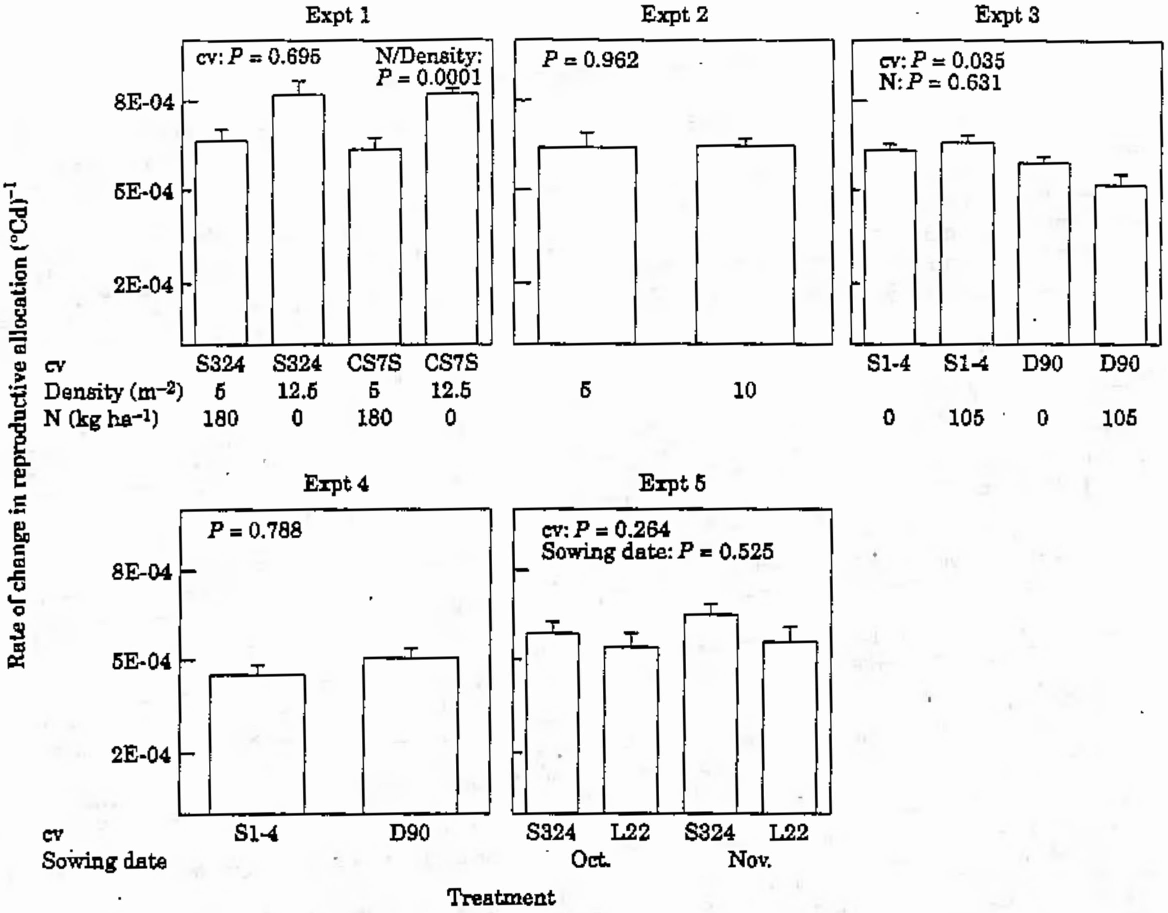

FIG. 4. Rate of increase in reproductive allocation during the linear phase as affected by plant and environmental factors in the five experiments summarized in Table 1. Error bars are s.e.

Once the plants were allowed to set fruit by protecting them with insecticides, they gradually reached allometric proportions similar to the plants in our experiments, which include current cultivars in a temperate environment.

Final harvest index depends on the rate of harvest index increase and the duration of the reproductive growth period. Previous studies with cotton indicate that final harvest index is fairly stable in relation to major environmental factors such as water availability, nitrogen supply and CO_2 concentration (Constable and Hearn, 1981; Orgaz, Mateos and Fereres, 1992; Kimball and Mauney, 1993). In our study reproductive allocation at the end of the growing season consistently showed relatively little variation except for expt 5, in which delaying the sowing date consistently reduced the final value of reproductive allocation (Table 1). This, together with the relative stability of the rate of change in reproductive allocation of cotton found in the present study (Fig. 3), suggests that significant changes in final harvest index are more likely to be found in cases when plant and/or environmental factors affect the duration of reproductive growth.

The stability of the rate of change in reproductive allocation of cotton is comparable to that reported for a number of cultivated species (see Introduction). The average rate of change in reproductive allocation in cotton found in this study ($\approx 0{\cdot}006\ d^{-1}$) is much lower than the rates reported for other species, which range from about 0·01 to 0·02 d^{-1} (soybean, Spaeth and Sinclair, 1985; sorghum, Muchow, 1990; barley, Goyne *et al.*, 1996; wheat, Moot *et al.*, 1996). Given that reproductive allocation in our study included flowerbuds and whole fruits, while only seed was considered in other studies, the differences between cotton and other species are still greater. The low rate of increase in reproductive allocation of cotton, in comparison to cereals, could be related to differences in growth habit: in determinate species there is usually little vegetative growth from shortly after anthesis, while significant vegetative growth is often observed during part of the post-flowering period of cotton. Comparisons between cotton and soybean (Spaeth and Sinclair, 1985), however, indicate that the low rate of increase in cotton reproductive allocation with time cannot be completely attributed to cotton's indeterminate growth habit. The lack of allometric analyses for other species precludes further comparisons.

In summary, few of the sources of variation included in these experiments caused statistically significant changes in reproductive allocation of cotton, and when significant changes did occur, their magnitude was comparatively small. The relative stability of cotton reproductive allocation suggests that for some applications simple models can be developed on the basis of a fixed rate of reproductive allocation increase.

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Document 14

SyTREC Pty Ltd
ACN 068 685 321

*Systems-based Consulting and Training
in Managing and Evaluating
Research, Development, Extension and Communication*

FACSIMILE MESSAGE

TO: Peter Carberry
FAX NO.: 076 881193
FROM: Peter Van Beek
DATE: 15 June 1998
No. pages (including this one): Eight

Dear Peter

I have written-up the findings from the extra interviews as a separate report. They stand out as such.

I would like you (and Bob) to read through it. If it is OK with you, I'd like to send a copy to the interviewees for three reasons. One is to validate the findings. The second is to start their learning that FARMSCAPE is more than extension, which is the way they see it now. The third is that there is a unique opportunity to compare the management of relevance of two projects. Some people in Narrabri were thinking in that direction. Needless to say that I'd love to do it.

Please contact me as soon as possible.

Yours sincerely

Peter Van Beek

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Adding value to management through systems-based consulting and training

THE FARMSCAPE PROJECT: Interviews with Cotton Researchers

By Peter Van Beek

1 Introduction

This report is part of a series of reports monitoring the impact of FARMSCAPE over a period of three years. Other reports are: *The FARMSCAPE Project: setting up the Evaluation Component' (1995); The FARMSCAPE Project: External Mid-Term Benchmarking (1996)* and *An Assessment of the Effects of Close Working Arrangements Between APSRU and IAMA in 1997.* The five interviews covered in this report were additional to the third, and last, set of interviews about the Evaluation of effects of FARMSCAPE.

This report is meant for clarification of data and as a contribution to ongoing management and does not contain conclusions and recommendations. These will be incorporated into the final combined report of those interviews.

FARMSCAPE has had a presence in Narrabri through group-work of Dr Mike Bange with dryland cotton growers. The five interviewees work in cotton research in Narrabri and included: two modellers, two program manager/leaders, one consultant/researcher. Four were not closely involved with FARMSCAPE.

2 Methods

The interviews were loosely structured around the interviewees' views of: FARMSCAPE; the interaction with farmers as part of FARMSCAPE; the effect of this interaction on farmers, the interviewees and their work; future developments; and any other FARMSCAPE-related aspects they cared to mention.

3 Data

3.1 APSIM in context

Several interviewees placed APSIM, the model at the core of FARMSCAPE activities, in context with cotton models: SIRATAC (a widely known earlier cotton model), Entomologic (a current Integrated Pest Management model) and OZCOT, the current cotton model which is also part of APSIM. SIRATAC had led to the Entomologic and OZCOT models.

Interviewees stated that SIRATAC was initially a research tool, to synthesise knowledge, and was not seen as a commercial tool. It was developed with feedback to research via technical officers. However, once industry saw it, they liked it. There was consultation with corporate growers and large organisations and SIRATAC was well adapted to their management structure. There were no consultants at the time, only chemical sellers. Development of SIRATAC paralleled the development of consultants.

Some interviewees said that SIRATAC was taken-up before it was ready, and the focus became servicing the industry. No research was done on, for instance, predator-prey interaction. There was mainly one line of technology and SIRATAC's Pest Management aspect got watered down. This aspect required counting of predators. However, commercial consultants were not paid enough to spend the amount of time required for counting predators.

Interviewees said that Entomologic has the same problem. (This was later confirmed during another FARMSCAPE interview by an independent consultant). Industry Development Officers in cotton now use it mainly as a platform for their experiments, not for extension. Entomologic is PC based and not aimed at growers, but at agronomists and consultants. It is now promoted as a package to extension agencies. There are no plans to do more than conducting training workshops, on-farm experiments and field days. One interviewee believed that 'There is nothing commercial to be done with this model'.

3.2 FARMSCAPE in context

The interviewee with direct experience with FARMSCAPE said he was 'In favour of the FARMSCAPE approach. However, our managers have reservations and feel it is not real science. Their opinion is partly influenced by experience with Peter Cox, who prejudiced people against this approach and had a negative influence on getting support for the principles. People are now coming around, judging by the way they are talking'.

He further believed that 'One problem in communication is that farmers and scientists use the same words, but put them differently. Scientists ask "How does cotton grow?" and farmers ask "How to grow cotton?" In FARMSCAPE these two questions meet. The simulation model provides a venue for both questions to be answered That is where the failure is in communications: not listening to the question. Each party needs to see the validity of the other's question'.

He continued that 'This is one more reason why we need teams, not just because we need different skills, but we also need different personalities and motivation. The questions motivate different people, commercial motivation and gut-level questions. The model has answers to both type of questions, not complete answers, but credible ones. It is a meeting point, a bridge. I also saw it in SIRATAC and other models, FARMSCAPE is just the most recent experience'.

3.3 Interaction with, and effects on, farmers

Some interviewees said they have little interaction with farmers. Others said they have normally a lot of interaction with farmers: 'A lot of us answer grower queries'; 'It is nothing new to us, only capital-city folk use that terminology. Farmer contact became intrusive in research; I try to pass-off computer applications to farmers which is a slow process, but as time goes on people get more comfortable with computers' and 'I have always had a clear understanding of what farmers want and do, but we were not necessarily successful in getting them to adopt. But I do not necessarily understand how farmers make decisions. I'd rather do research and leave that to farmers and consultants'.

One interviewee has worked with cotton Industry Development Officers 'Which would be a FARMSCAPE approach, once it is applied in irrigation areas on a wide scale. We found out what questions farmers ask. It showed gaps in our knowledge and also the relative unimportance of some issue'.

Another interviewee had seen interaction with farmers before, but not about a model: 'Not like FARMSCAPE, this is very good, it gets credibility for the model from the farmers'. The interviewee believed that farmers need to be convinced it is worthwhile using the model - the best thing to do on the farm'. 'The interaction provides a two way thing which provides credibility and solves problems. The grower gets benefits, and the scientist gets to see where the system (model) is falling down e.g. the need for including variety and skip-row versus solid set'.

An interviewee with little up-front farmer contact, thought that the 'Interaction of Mike with farmers is great, even if it is hard to figure out what is FARMSCAPE and what is interaction. I can see an enormous increase in perceptiveness of farmers and funders to using models for strategic ('can we plant') and tactical ('should we plant now') questions. I see a lot of value in sitting down with a group and develop their confidence before pushing results down their throats. I also see more readily acceptance of other science'.

One interviewee thought that 'Being in FARMSCAPE makes Mike's role more like extension, or a higher proportion of it. That has lots of implications: for instance we have no training in that aspect'.

3.4 Effects on interviewees

One interviewee stated 'I can see value in feedback to me of farmer-concerns. I am not a great advocate of Farming Systems Research, am concerned about the agenda being driven too much by producers and short term concerns, rather than pulling the system apart and analyse weaknesses. FARMSCAPE identified a number of shortcomings in our model, and identified issues the farmers were concerned about. These were not new, but were then not seen as priorities: skip-row and rates of development of cultivars. Including them did not make me feel less of a scientists. Another effect on me is encouragement in my work, because of acceptance, greater use and wider application than it would have achieved otherwise. That gives personal satisfaction'.

Another interviewee said he 'Had seen Mike become more confident in the value of models, judging by the positive feedback, interest and type of questions. Its outputs are seen as valuable and realistic, with farmer-pull for access to the model'.

3.5 Effects on the interviewees' work

Several interviewees said FARMSCAPE activities had helped to guide development of the cotton model. They mentioned the inclusion of skip-row versus solid set planting, differences between varieties, and seedling establishment. Some interviewees 'Were aware of these needs but had seen them as relatively unimportant'. One said it helped to show that 'Extremes are important, and so is avoiding the dry and using the wet'.

Some people saw value in FARMSCAPE because 'It gets access to farmers through agri-business and accredited advisers' and 'An issue for us is that we are not in other cotton areas, people outside this area often complain about not being involved, particularly in Central Queensland'.

One interviewee stated that his observations of the close interaction with farmers 'Did not influence the design of my work. I tend to do what I think is right. I would be reticent to include "noisy" (not fully tested) information, even if asked, unless it was on an one-to-one basis and I felt the other person could handle it. I would not put something which needs cautious interpretation and assessment of value in a package unless I knew it would always be handled by some-one who could explain it. This is in part protecting myself, even if I see value in it for a manager. I am cautious about things out there unaccompanied. We can provide many things which can be of higher value'.

One interviewee stated that 'We used to resent FARMSCAPE at first for the lack of recognition that we did modelling before they came on the scene. Now I see FARMSCAPE as a way to get our work out, breaking down barriers. FARMSCAPE is a good thing, and they have done it properly. They have a lot of resources, we have only one modeller, CRDC don't see modelling as necessary. If FARMSCAPE gets expanded we may see industry call for more modelling.'

Another interviewee said he 'Met farmers as part of other duties. They were enthusiastic about FARMSCAPE, never negative. But growers don't know about contributions to FARMSCAPE by others. This lack of recognition of work by others is serious, it effects funding to develop their work further. There is also a lack of recognition in some printed material, even though some APSRU people bent over backwards to try and avoid that. This lack of recognition is a real fear of managers in cotton research programs'.

When asked about the possible value of FARMSCAPE groups as, for instance, learning or research groups in the sustainable area, some interviewees said they 'Have not seen the "Learning together" aspects in FARMSCAPE'.

Another thought that there is 'Value in recognising the skills and knowledge of farmers, they have enquiring minds as well. But what about the rigour, and not drifting along? I think partnership is the word to use, we need to recognise the level of what is at stake. We could draw conclusions which are artefacts and could become part of the folklore without foundation. Partnerships need a different process to allow for the lack of control (-treatment). We need to be aware of the pitfalls when doing that type of work. We need a theoretical structure to allow for those pitfalls. Grower experience is not truly an experiment. However, when a grower makes a particular choice and gets results, we can run the model to test alternatives. That is useful in formulating what you might do in future, or for checking if the model is wrong'.

3.6 Changes in the use and design of modelling products

One interviewee 'Had seen a change in the use of models. OZCOT used to be strategic, now in APSIM it is also used for tactical decisions. I think it is great. It is disappointing that we can't get more people (working closely with farmers).' Another suggested that 'When working with FARMSCAPE, we use the cotton model as a risk analysis, tailored for different regions: sowing dates, N-rates specific for regions; when targeting irrigation growers: how big an area, time of planting'.

3.7 The future

Some interviewees can see further linkages of models: 'I can see APSIM as a core around soil and water, with crop models attached to it. We can bring to the farmer all the things we can offer in one package'; 'Next thing is to link APSIM, cotton and pest management models' and 'Linking cotton to APSIM opened opportunities for working on interaction between cropping system and pest, rather than between crop and pest, and compare options. Our focus for cotton here is on irrigation, dryland only comes in through APSIM'.

One interviewee expressed concern that 'Indian Ocean data is not in the model'.

When asked for suggestions about how to get the model used by a large number of growers, one interviewee said 'That is too scary for me, but I can see merit in commercialisation. While it must be available to the widest group, with littlest exclusiveness, I accept that some people want to get the benefits without spending time, and pay some-one. That person must be well trained and that needs QA. However, I believe that end-users should be involved in education too, not just the consultant. They need to appreciate limitations and assumptions, otherwise they dump all responsibility on the consultant. If they know a bit about it, they can support the consultant better. Growers need to be integrated in the education and know what is happening'.

Another interviewee said he 'Was concerned about exclusivity, otherwise commercialisation is OK. It is a change, I am so used to see science going out through the public domain for free, that it is difficult to accept that farmers may have to pay for extension officers visiting the farm'.

A third interviewee said that 'I only care about the cotton model, but I have real concerns about APSRU- IAMA closeness, that it could it exclude consultants and thus the main grower body. My main concerns are to: not deny access to any groups, and not link the model to pesticide and fertiliser sales'.

One interviewee saw a problem in that 'Research wants to develop the program further, while industry wants it now' Another comment was that 'We should take feedback not as negative, but as indicators where to do research next. Feedback and research both need to drive research. However, we also need research for understanding. That gets lost in funding bodies. The process of applying for money cuts this out, as they need tangible outcomes. On the other hand, maybe that is all they (the funding bodies) get in applications, and no basic research type stuff'.

One interviewee believed in 'Top-down modelling, keeping the model as simple as possible. That means starting with just as much information as is needed for a particular management application (KISS principle) and using fudge factors openly and empirical calibration when needed. Not bottom-up: collecting together all know relationships of a crop and integrating them is extremely complex. It defeats the purpose of modelling: simplifying the world to make sense of it'.

The interviewee believed that 'APSRU provides a context for using cotton models which benefits the cotton industry. APSRU could benefit from being seen as networkers, as credibility rubs off both ways. They can also help getting models out amongst users. Farmers are pragmatic and can influence modellers to make things work NOW, even if not all the information is there. They can make them answer the question: "What is the best we can do with the current information available to us now". Models can be hold back by a sense of perfection by the modeller'.

4 Discussion

4.1 Outstanding points

This discussion is preliminary only. A number of aspects stand out to me:

1. FARMSCAPE has influenced the content of models by changing perception of priorities;
2. FARMSCAPE has helped to widen the use of OZCOT across wider geographic regions and into dryland areas;
3. such adoption of research and modelling is seen as satisfying and motivating;
4. recognition of work done is important for ongoing funding, as well as for professional status and personal satisfaction;
5. APSIM was seen by some interviewees as a core onto which other models can be attached;
6. some interviewees saw a role for APSRU as a networker;
7. commercialisation of APSIM is acceptable to most interviewees provided it does not lead to exclusion of certain groups, or abuse to boost sales;
8. the approaches to, and uses of, modelling can appear to be conflicting:
   - bringing together all that is known (bottom-up) and identifying gaps,
   - simplifying reality as much as possible, so it can be better understood (top-down), and (found during earlier interviews with farmers participating in FARMSCAPE)
   - quantifying gut-feel and general principles by using locally-specific data and thus aiding in real-life decisions; and
9. FARMSCAPE was seen by all except one interviewees as extension - a way to get information to and from end-users - and not as something more, such as co-learning.

4.2 Relevance

The first four points are self-explanatory. Together they suggest that FARMSCAPE was seen by these five researchers as useful in making research relevant and rewarding.

4.3 Further integration networking and commercialisation

The fifth and sixth points indicate ways for, and recognition of benefits of, integrating future activities. The seventh point indicates that commercialisation is seen as a fact of life, even if not a particularly welcome fact.

4.4 Different uses for models

The eighth point about diversity of approaches and uses has been documented in other interviews in this series as well. This leads to the question 'As the underlying logic is the same for all three purposes, being based on physical relationships, are these conflicts real? Or can these uses be dealt with in one model through different formats of the model, or different entry points?' I understand that APSRU is already moving in the direction of entry and / or presentations at different levels.

4.5 Better articulation needed

Point nine may need further thought. One interviewee clearly saw FARMSCAPE as more than extension. He described it as a point where the different uses of models, and the different interests of scientists and farmers in science and modelling, can come together, learn from, and re-inforce each other. Another interviewee looked at these meetings as partnerships, and questioned if such co-learning should be called research or something else. The use of the word partnership appears to me to be useful as it avoids semantic arguments about what is, or is not, research.

Point nine suggests that the nature of FARMSCAPE, and the values it adds beyond traditional extension, may need to be still better understood and articulated, and more clearly presented. Other interviews in this series suggest that FARMSCAPE group interactions around APSIM are, at least in part, about bringing together scientific data and rigour with managerial and commercial data. This has led to increased mutual appreciation, co-learning, understanding of relevance, and direction setting, as borne out by earlier interviews and confirmed to some extend by these interviews.

4.6 An hypothetical application of the FARMSCAPE approach

While the FARMSCAPE interactions may, or may not, be science, the suggested benefits are potentially important for the management of science. This importance can be illustrated by the following questions:

- 'If Entomologic had been developed in a manner similar to APSIM, could this have resulted in, for instance, more research aiming at the development of commercially feasible methods of counting predators?'

If so:

- Could Entomologic then have become a routine management tool of considerable potential value, rather than remain restricted to being an experimental and demonstration tool?'

Given the funds spent on developing Entomologic, and the need for such a tool, this question is probably of more than hypothetical interest.

5 Suggestion

I suggest that a comparison be made between Entomologic and APSIM, focusing on how the actual and potential relevance of both projects has been established and managed. I believe that the learning of such a comparison will be of considerable benefit to the management of applied research in general.