Australian Government

Cotton Research and Development Corporation

Annual, Progress and Final Reports

REPORTS

Part 1 - Summary Details

Please use your TAB key to complete Parts 1 & 2.

CRDC Project Number:		**CSP139C**
Annual Report:	☐	Due 30-September
Progress Report:	☐	Due 31-January
Final Report:	☒	Due 30-September 2004 (or within 3 months of completion of project)

Project Title: Application of Crop Simulation within the Australian Cotton Industry

Project Commencement Date: 1/7/01 **Project Completion Date:** 30/6/04

Research Program: 4 Farming Systems

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1. Project background

Research involving the application of computer simulation and soil characterisation to assist with crop management decisions has been shown to be beneficial to growers within the cotton industry. The demand for this type of information for industry and research purposes has continued to increase in the past 3 years. Industry Development Officers and District Agronomists have had access the "user friendly" version of the OZCOT cotton model. These industry users have also provided a valuable feedback mechanism for future refinements and enabling crop management issues to be addressed in response to weather, field conditions or crop growth.

The direct benefits to the industry are twofold. Firstly, simulation enables on-farm risk assessments to be made about crop management decisions which can be combined with on-farm experience and experimentation to solve problems and maximise crop potential. Secondly, by providing extension and research staff and other industry personnel with a simulation capacity, the benefits to industry will be more widespread. Both irrigated and dryland growers have used the information generated by simulation technology to substantially refine their crop management strategies.

This project had 3 major components in the application of crop simulation to the cotton industry.

- Exploration of on-farm crop management scenarios using simulation in dryland and irrigated crop production. An exciting application to be investigated was the tactical in-crop use, where fruiting characteristics and climate forecasts are combined to assist growers with crop management in-season.
- Provision of support to extension staff, researchers and industry personnel in the use of the 'user-friendly' OZCOT. This would involve the application and evaluation of simulation in new areas and novel crop management strategies for these industry personnel. The maintenance of staff and core skills within the Cotton CRC and CSIRO was seen as crucial to this aim.
- Training in the FARMSCAPE accreditation scheme being undertaken by APSRU. This sought to maintain the validity of the simulation and training techiques used by the cotton industry, providing a proven framework for adoption.

Over the course of the project, an important evolution took place in the development of decision support tools for cotton growers, with the re-development of the OZCOT model. The re-development process has involved considerable effort in the areas of code writing, scientific content and modulisation. The HydroLOGIC irrigation management software is the first product of this evolution, which employs the OZCOT model to predict crop growth over a range of management scenarios.

2. Project objectives and achievements

Collaborative onfarm research involving investigations into applications of cotton modelling and delivery of simulation results.

This objective has been achieved through the following activities:

- During the first growing season (2001/02), research focussed on in-season application of the OZCOT model for decision making. Research activities were concentrated on 5 growers within the industry in an effort to gather quality information. The growers were selected from the existing grower groups, from the Darling Downs to Breeza. This geographical spread allowed model application in different growing environments and on a range of local crop management issues of importance. In addition this research activity gathered valuable experiences needed for future OZCOT and HydroLOGIC software development.
- Field validation trials testing the application of HydroLOGIC in the field, as compared with existing irrigation management, were conducted during the 2002-03 season. These were conducted in the Upper and Lower Namoi valley growing areas.
- Trials during 2003-04 season consisted of an intensive trial at Narrabri and field validation trials located in various valleys. An intensive trial at Narrabri demonstrated the clear benefits to irrigation scheduling using HydroLOGIC in low water allocation scenarios. The comparison trials were conducted in collaboration with local extension staff, and compared existing grower management with HydroLOGIC scheduling. Feedback from growers involved indicated clear benefits to using simulation to assist in crop management

Meeting the industry demand for simulations.
a) Provision of support services to the CRC Industry Development Officers and other industry pesonnel in the use of the OZCOT model.

This objective has been achieved through the following project activities:

- Since the distribution of the user-friendly OZCOT (UFO) software in February 2001, over 40 users, including 5 growers, have been trained. Support for the UFO software continued until January 2003, at which limitations in the design did not allow the latest version of the OZCOT source code to be used. Support to users until this point revolved around simulation procedure and analysis, and providing climate information on a regular basis, fortnightly or whenever requested. This climate information was generated using data provided by the SILO project and the Bureau of Meteorology, provided through the CRDC project CSP123C 'Enhancing access to weather and climate data'. In September 2003, HydroLOGIC replaced the user friendly OZCOT as the decision aid that would be provided to extension personnel.
- During the period of support for the UFO, issues that Industry Development Officers and other industry staff investigated include:
  - Comparisons between actual fruiting development and simulated fruiting potential during the season and after harvest. These comparisons generated discussion points regarding the crops actual performance and indicated limitations to crop growth where they occurred.
  - Exploring potential yield under reduced water allocations and strategies to maximize available water, such as stretching irrigation intervals and delayed timing of first irrigation.
  - Members of the water extension team have also used OZCOT to explore the impacts of reduced allocation and different irrigation scheduling on crop growth.

- OZCOT-generated information has been incorporated into presentations primarily to explain principles of water use efficiency, but also irrigation scheduling and implications of reduced water allocations.

Over 500 copies of the HydroLOGIC software have been produced and distributed for the industry, through the Cotton CRC Technology Resource Centre and local extension staff. During 2003 and 2004, regional training workshops were conducted by Dirk Richards and Sandra Deutscher, with over 200 growers and consultants trained.

b) Maintenance of a simulation capacity and skills within the CRC and cotton industry to enable growers and industry representative to access this technology.

This objective has been achieved through the following project activities:

- The simulation capacity within the CRC has been maintained through the project activities involving OZCOT and HydroLOGIC. A wide range of enquiries for information developed by simulation have been addressed, from industry researchers and extension staff. Some of these issues include:
  - Simulation of CSIRO Plant Breeding dryland trials in NSW and Qld from 1993-1998, to determine yield potential at these sites and ascertain the contribution to yields of in-crop rainfall.
  - Time of sowing responses in Emerald for seed increase crops, to determine the latest date which does not incur a yield penalty and to estimate the yield potential of later sowings.
  - Water and nitrogen yield response curves for irrigated cotton crops in the Gwydir Valley, for use in a Cotton CRC/University of New England ecosystem services project. This information developed knowledge of how production issues (i.e. changes in soil moisture and nitrogen over the season and the effects of seasonal climate) at a field scale contribute to the value of water on a whole-of-catchment scale.
  - Predictions of crop growth and yield over a range of soil types and irrigation strategies to produce general rule-of-thumb guidelines for irrigators facing reduced water allocations in the Upper Namoi.
  - A modified version of OZCOT was used to provide information to explore the impacts in changes in fruit retention (in a Bollgard II system). Some of this information has been used by the TIMS committee to generate guidelines for insect resistance management strategies.
  - Information generated by OZCOT has been used extensively in exploring row configuration options in dryland cotton. Much of this information has been used in workshops conducted by Cotton Seed Distributors and incorporated in the updated Cotton CRC Dryland Cotton Production Manual.
  - Information generated by OZCOT was used in the development of a decision aid for growers in the Macintyre Valley, to assess the value of water with changes in river flow associated with seasonal forecasts (Ritchie et al 2003).

Formalised accreditation in the FARMSCAPE participatory learning approach

This objective has been achieved with level 1 of the scheme finished in June 2001, and level 2 completed in June 2004. This training process will maintain the validity of the simulation and training techiques used by the cotton industry, and provide a proven framework for adoption. Accreditation also aimed to ensure the credibility of the project officer as a trainer for OZCOT and related software. Maintaining linkages with one of the major modelling groups in Australia (APSRU) is important for development of tools for industry and remain abreast of of new research approaches in this area.

Since enrolling in the accreditation program in July 2001, numerous workshops were attended to assist with the accreditation process. Several modules had direct relevance and implications for current research activities, including the process of benchmarking 3 dryland crops at Narrabri. These sites were characterised for water holding capacity, and subsequent simulation provided background for discussions on crop potential, crop choice and fertiliser strategies.

3. Research methodology

Collaborative onfarm research involving investigations into applications of cotton modelling and delivery of simulation results.

An on-farm participative research approach involving growers, consultants and researchers has been used over the previous three years to further the application of simulation on-farm. This approach has been crucial to the ongoing success and application of simulation technology on-farm, and the exploration of new applications. The collection of hard data from on-farm trials has allow an assessment of model and system rigour, while soft data has been very important in the refinement, development and design of new tools for cotton management. This soft data was obtained via group discussions, surveys and personal interviews, and remains as the primary feedback mechanism for simulation technology development to provide quality information for growers. An overview of specific OZCOT and HydroLOGIC trial methodology is provided below with further details in Appendix 1.

- Initial on-farm OZCOT research in 2001-02, was conducted at Jandowae and Dalby in Queensland, and at Merah North, Bourke and Breeza in New South Wales. Whole fields were selected and management strategies assessed during the season using OZCOT where appropriate. The one-on-one discussions over the season generated much of the direction for HydroLOGIC and their experiences in running the user friendly OZCOT re-enforced certain areas with potential for limiting this technology.

- Two trials in 2002-03 season compared standard management practice with HydroLOGIC management, with a prototype version of the software being tested.
  - In the Lower Namoi valley, a trial at Narrabri consisted of 4 treatments; standard management (14 day cycles), HydroLOGIC management with 8Ml/ha (Full) and 4Ml/ha (Limited), and a skip planted irrigated treatment.
  - In the Upper Namoi a trial was established on the Breeza Plain at Battery Hill in collaboration with Phillip Morgan. It consisted of 3 treatments replicated twice; HydroLOGIC scheduling; irrigation at 60mm deficit; and at 75mm deficit.

- Trials conducted in 2003-04 season included a trial at Narrabri and five comparison trials located at Emerald, St George, Moree, Wee Waa and Breeza.
  - The Narrabri trial was established at the CSIRO lease at Myall Vale, with three different water allocation treatments being imposed; 8ML/ha, 4ML/ha, and 2ML/ha, with timing of irrigations determined individually using HydroLOGIC.
  - The demonstration trials used split fields or paired fields side by side, allowing a direct comparison between the existing grower's irrigation management and field management using HydroLOGIC. A decision log was maintained by each co-

operator and recorded dates and crop stages where HydroLOGIC was used and other considerations at the time. These trials were located at:

- Arcturus Downs, Rolleston in collaboration with Toni Anderson
- Cubby Station, in collaboration with Greg Nichol and Steve Ginns
- Caroale, Moree in collaboration with Julie O'Halloran
- Drayton, Breeza in collaboration with Penny Van Dongen
- Togo, Wee Waa in collaboration with Anne Johnston

Meeting the industry demand for simulations.

a) Provision of support services to the CRC Industry Development Officers and other industry pesonnel in the use of the OZCOT model.

Support in the application and extension of information generated by the OZCOT model has been achieved through focussed workshops, support phone and email enquiries, and one-on-one discussions. Individual training sessions for user friendly OZCOT were conducted where appropriate for new Industry Development Officers and Queensland Rural Water Use Efficiency Initiative staff. Development of the HydroLOGIC irrigation management software began in 2002 to replace the user friendly OZCOT software, and was formally launched and released to the industry on the 15th of September 2003. Since the official release, training workshops have been held in all cotton growing valleys in 2003 and 2004. Other support initiatives include an Australian Cotton CRC summer scholarship appointed for 7 weeks beginning in January 2004.

b) Maintenance of a simulation capacity and skills within the CRC and cotton industry to enable growers and industry representative to access this technology.

To provide a simulation capacity to the industry, a range of delivery mechanisms were utilised to facilitate extension of information on crop potential. These included:

- Specific workshops and presentations to growers and consultants, including:
    - Limited Water workshops
    - WaterWise irrigation course
    - Cotton CRC annual reviews and CRDC Farming Systems Forums
    - Cotton Seed Distributors information
    - CGA meetings in the Upper and Lower Namoi valleys
- Contributions to extension staff newsletters in the form of crop potential over a range of soil, climate and management conditions.
- Publication of research findings and future decision support tools in scientific journals, conference, and industry publications such as WATERpak.

Formalised accreditation in the FARMSCAPE participatory learning approach

The FARMSCAPE accreditation program conducted by CSIRO Sustainable Ecosystems comprises six modules arranged into two levels of accreditation. These are:

Level 1 Accreditation
Module 1: Soil monitoring and data management
Module 2: Weather monitoring and data management

Level 2 Accreditation
Module 3: APSIM: the program and the science
Module 4: Simulation applications in farm management
Module 5: Analysis of simulation results and Quality assurance
Module 6: Flexible representation of results and communication with decision-makers

4. Project outcomes and research results.

Collaborative onfarm research involving investigations into applications of cotton modelling and delivery of simulation results.

To determine and quantify the advantages to utlising simulations for crop management decisions, a range of discussions, surveys and field validation operations were conducted during research activities. This collected knowledge allowed assessment in the following four criteria:

1. How rigorous and accurate was OZCOT?
2. How useful was OZCOT to assist with decisions?
3. How has HydroLOGIC performed?
4. How successful has uptake and delivery been?

OZCOT trials in 2001-02

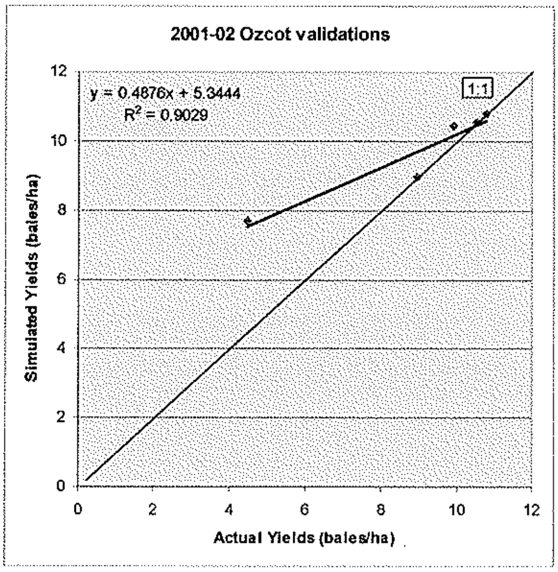
In collaboration with project staff, growers used OZCOT to compare their own crops fruiting development with the predicted square development, and to assist with the timing of first irrigations. All growers involved with the project were keen to use the model and looked forward to improvements in the interface following their suggestions. Three new soil characterisation sites were established on these properties involved with the research project, to fill drained upper limit knowledge gaps identified in August 2001. This information has value not only for users of OZCOT, but the remainder of the industry. During the season OZCOT was run where appropriate, although generally when the project officer was visiting the trial site and collecting field data. During these sessions the grower's attitudes and questions were recorded, with respect to OZCOT predictions and the trade-off with farm management constraints.

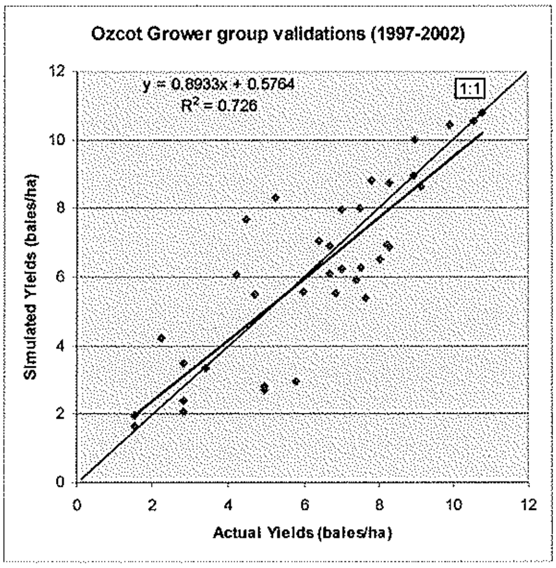
a) **How rigorous and accurate was OZCOT?**
Although the trials covered a wide range of growing conditions and soil types, the accuracy of yield prediction by OZCOT was consistent (as shown below).

Trial location	State	**Actual (bales/ha)**	**Simulated (bales/ha)**
Cardale	NSW	9.9	10.44
Waverley	NSW	10.54	10.56
Gebar	QLD	10.77	10.81
Prattenville	QLD	4.48	7.7
Battery Hill	NSW	8.95	8.98
Patricia Downs	QLD	not available	not available

The model was able to simulate crop growth during this season successfully, once accurate soil moisture (PAWC) and weather information was available. The exception was at Bourke (Prattenville) where root development and moisture extraction may have been limited by salt at depth. At all sites peak leaf area and fruit number was predicted within a small margin, at levels lower than within-field variability would suggest. Comparisons between simulated soil moisture balance and field measurements did reveal some differences, although difficulties with equipment calibration may have contributed more to this error than OZCOT itself. A comparison of actual by simulated yields for 2001-02 alone produces good correlation (R^2=0.90). The addition of these datasets to trial yields (actual vs. simulated) for the period

1997 to 2002 produces a good correlation with low scatter (R^2=0.72), indicating considerable skill in the model over a wide range of climate and cultural conditions.





Further details on the 2001-2 field validation summaries are provided in Appendix 1.

How useful was OZCOT to assist with decisions?
Grower experience and reflections on the use of OZCOT and the interface provided important information for future systems. These include:

- The usefulness of running OZCOT during the season was lessened by the inability to enter actual crop data into the model to correct predictions of crop growth. Future versions of this type of simulation software need this flexibility to parameterise the simulations to actual crop conditions. This functionality has since been incorporated into the HydroLOGIC software, allowing input of field specific information on fruit numbers, soil moisture deficit, and leaf area.
- The time taken to prepare and update climate files for distribution, and the subsequent installation on grower computers. This process has now been streamlined within HydroLOGIC through access to the SILO climate products and the ability to import on-farm weather information into the system.
- Discussions after harvest indicated that running the model during the season had significant time problems, partly due to the user interface and unfamiliarity with the software and simulation process. Considerable improvement needs to occur is the output reporting and interpretation area, before OZCOT can be successfully used for in-season decisions. Subsequent development with HydroLOGIC has focussed on aligning the user interface with existing CottonLOGIC functionality and design. The reporting component has been developed further using standard report generator concepts, although considerable scope exists to enhance this area further with season classification by climate forecasts.

How has HydroLOGIC performed?

2002-03 trials at Narrabri and Breeza

Narrabri
Timely water application ensured optimal plant growth and fruit development within the HydroLOGIC treatments, resulting in a harvest of 8.11 bales/ha under full allocation and 5.81

bales/ha under limited water allocation. These results compare favourably with the standard scheduling treatment which yielded 7.56 bales/ha. The results indicated that yield and maturity could be optimized using HydroLOGIC, under both full and limited water situations. The HydroLOGIC limited results demonstrated that in spite of reduced irrigation water, crop water use could be optimized to achieve similar water use efficiency as conventionally irrigated cotton with no impacts on fibre quality. (Refer to Appendix 1 for complete summary).

Breeza

On analysis of final trial yields, within field variation was apparent with low yield in the second replicate. This trial did demonstrate the importance of accurate soil moisture measurement for irrigation scheduling. Discussions with Phillip Morgan highlighted how management constraints such as siphon shifts and filling head-ditches on different occasions need to be balanced with HydroLOGIC predictions and current weather conditions.

2003-04 trial at Narrabri and demonstration sites

Narrabri

HydroLOGIC predictions were run on the 29th November to determine the first irrigation date in all scenarios, with only the 8ML/ha treatment to be irrigated on December 17th. Predictions continued to be assessed during the season and following rainfall (for actual irrigations dates please refer to Appendix 1).

As expected, yields increased with the frequency of irrigation and total allocation applied (Figure 3b), although boll size was not greatly different between treatments. The average boll sizes (seed cotton per boll) for the 2ML/ha, 4ML/ha and 8ML/ha treatments were 4.30 gm/boll, 4.45 gm/boll and 4.29 gm/boll respectively.

The results from this experiment demonstrated that HydroLOGIC can be used to effectively schedule in-season irrigations under limited water situations. The complementary nature of the software was also highlighted, with the information from soil moisture probes being value-added by HydroLOGIC to give predictions of the next irrigation date and crop growth. Work is continuing to evaluate the HydroLOGIC system under a range of growing conditions and scenarios. Future refinements to HydroLOGIC in response to requests include; the ability to assess years that have certain characteristics (e.g. hot seasons); seasonal climate effects; and use for overhead irrigation systems.

Demonstration sites

Although hot and variable growing conditions were experienced during the 2003-04 season, HydroLOGIC was able to provide useful information to assist with farm planning and scheduling. Two important variables existed within these trials; the existing level of irrigator knowledge, and the level of crop and soil monitoring; and the reporting of average crop potential within HydroLOGIC. To address the later variable, the refinement of HydroLOGIC output to deliver individual seasons or the average of climatically similar seasons will improve the accuracy of predictions and scheduling decisions. The characterisation of seasons by SOI phase and MJO are two such possibilities, with the potential to improve decision making as skills within seasonal climate forecasting improve.

How successful has uptake and delivery been?

Since the distribution of the user-friendly OZCOT (UFO) software in February 2001, over 40 users, including 5 growers, had been trained. Individual training sessions for user friendly OZCOT were conducted for 4 new Industry Development Officers and the Queensland Rural Water Use Efficiency Initiative staff (8). Evaluation of this training found that extension staff value the potential of the OZCOT model and have been using this software tool to answer limited water questions with their local growers after being approached. Support for the User Friendly OZCOT software continued until January 2003, following which the HydroLOGIC irrigation management software has addressed much of the industries demand.

Development of the HydroLOGIC irrigation management software began in 2002 to replace the user friendly OZCOT software. Development priority was placed on HydroLOGIC following user requests and the industry drive to improved water use efficiency. A test version was released to selected growers in December 2002, and training sessions conducted for 38 industry staff and growers in April 2003. Important feedback from this group assisted with development of the production version, which was formally launched and released to the industry on the 15th of September 2003. Over 500 copies of the HydroLOGIC software have been produced and distributed for the industry, through the Cotton CRC Technology Resource Centre and local extension staff. During 2003 and 2004, regional training workshops were conducted by Dirk Richards and Sandra Deutscher, with over 200 growers and consultants directly trained.

Conducting parallel research into methods for leaf area assessment, thereby allowing growers to rapidly assess leaf area and enter values into HydroLOGIC, has been important in the uptake process. This research developed a range of photo guides which has been distributed with software and is available via the Cotton CRC web page.

From June to November 2002, 7 Limited Water workshops were held at 7 locations in the industry. Formal evaluation before the meetings indicated the majority of participants had some knowledge of the processes involved with water stress and had heard of the OZCOT model previously. Topics which influenced knowledge changes in participants were the physiological response of cotton to water stress, the impact of reduced allocations, the implications of timing the first irrigation as predicted by the OZCOT model, and understanding the impact of stretching irrigation deficits during different crop stages. Many participants indicated they had changed their opinion on scheduling and 75 percent of attendee's indicated they would use an irrigation scheduling tool like OZCOT to help with irrigation decisions.

Research and simulation results were presented and discussed:

- At the CSD/CSIRO Research Review, Narrabri, on the 14th of June, discussing weather conditions during the 2000/01 growing season and crop growth indices.
- With the Cotton Water Use Efficiency Initiative Officers, 5th September, Narrabri, outlining areas of application for OZCOT within the water management area and other opportunities for use.
- At the CSD Summer Cropping Dryland meetings, September 2002, regarding dryland crop potential, fibre quality and the OZCOT software.
- At the NSW Agriculture Irrigation course, 21st Oct 2002, outlining applications of the OZCOT model, response curves for first irrigation and water allocation for the current season, and other potential uses.

- With a group of Bourke cotton growers on the 30th January 2003, outlining the HydroLOGIC trial at ACRI, key results to date, and the future potential of the HydroLOGIC software.
- At the Lower Namoi field day on the 20th Feb 2003, discussing the HydroLOGIC software, research results to date and other related irrigation research.

Whilst not formally connected with this project, the continuing efforts of APSRU in the FARMSCAPE area and Whopper cropper initiatives using OZCOT are of relevance. Project personnel have been involved with these initiative conducted by APSRU, providing cotton specific information and remain committed in supporting these initiatives. Maintaining contact with this group through the FARMSCAPE accreditation process has been important to achieving this collaboration. However, this CRDC project did directly address issues within irrigated cotton production that were not covered as part of the APSRU efforts.

4. Provide a conclusion as to research outcomes compared with objectives. What are the "take home messages"?

The collaborative on-farm research undertaken in this project has shown that crop simulation can make positive contributions to management decisions. The trial results demonstrate that yield and maturity can be optimized using modelling tools such as HydroLOGIC, under both full and limited water situations. The HydroLOGIC limited results demonstrate that in spite of reduced irrigation water, crop water use can be optimized to achieve similar water use efficiency as conventionally irrigated cotton with no impacts on fibre quality. Maximizing yield in the future will require optimum application of irrigation water and use of in-season rainfall. HydroLOGIC allows irrigators to make informed decisions, based on the predicted response in plant growth to moisture conditions and future irrigations. This project has been successful in meeting the general industry demand for simulations, with information developed and delivered through a wide range of mechanisms. Providing support and training for users of OZCOT and HydroLOGIC has been one of the key components in delivery of this technology. The accreditation of project staff in the FARMSCAPE participatory learning approach was important for application and development of these modelling tools.

This project has provided an important foundation for the building of human and technology capacity to maintain and expand the use of simulation technologies in the Australian Cotton Industry for current and future needs. We remain committed to refining the capabilities of existing tools such as HydroLOGIC and exploring better means of improved means of access to industry.

5. Detail how your research has addressed the Corporation's three Outputs - Economic, Environmental and Social?

This research has addressed all three outputs for CRDC research. Limited irrigation water and nitrogen fertiliser are just two elements that have been addressed within grower research groups with the use of OZCOT and HydroLOGIC Growers and industry personnel have been provided with risk assessments of different crop management options during the course of the project. Growers have used this information to make educated decisions how to best manage their crops, which ultimately afftects the profitability of their farm. The maintenance of natural resources and profitable cotton growers will lead to sustainable rural communities, an aim which crop simulation can help to acheive.

6. **Provide a summary of the project ensuring the following areas are addressed:**
   a) **technical advances achieved (eg commercially significant developments, patents applied for or granted licenses, etc.)**
   N/A
   b) **other information developed from research (eg discoveries in methodology, equipment design, etc.)**
   N/A
   c) **are changes to the Intellectual Property register required?**
   The primary software packages used in this project, OZCOT, HydroLOGIC and APSIM, remain the property of CSIRO Plant Industry and the Agricultural Production Systems Research Unit (APSRU) respectively. Publications developed through this project will remain the property of CSIRO and other information produced will be distributed with a standard disclaiming statement. Soil characterisation information generated within the project will be available to industry and project collaborators will be required to acknowledge the source of this data.

   - HydroLOGIC – software to assist cotton growers with strategic and tactical irrigation – CSIRO Plant Industry
   - OZCOT and User-friendly OZCOT - CSIRO Plant Industry
   - APSIM - Agricultural Production Systems Research Unit, CSIRO Sustainable Ecosystems

7. **Detail a plan for the activities or other steps that may be taken:**
   (a) to further develop or to exploit the project technology.

To maintain and improve the adoption of the HydroLOGIC, the software must be developed in response to grower and consultant requests. These request can be classified into 2 main areas; improvements in functionality; and improvements in data used as inputs.
A wide range of potential improvements in functionality have been compiled in the last 2 growing seasons, from users and during training workshops. These involve considerable programming time and will need prioritisation, but focus predominantly on generating more specific outputs for the current growing season. Linked to these refinements is the integration with other tools such as soil moisture recorders and weather stations. Developing improved information on soil water holding capacity through soil characterisation is the second important area.

(b) for the future presentation and dissemination of the project outcomes.

These project outcomes will be presented and disseminated where appropriate through the CRDC project CSP164C 'Delivering science to agribusiness: smart approaches to cotton irrigation management'.

(c) for future research.

Future research into improving HydroLOGIC to incorporate seasonal climate forecasts and whole farm water management, and exploration of alternative and new cropping systems, should be seen as important priorities. As stated above, the further development of knowledge on soil water holding capacity for all cotton growing soils is an important need, especially with reduced water availability. A more detailed knowledge of soil moisture will enable modelling tools such as HydroLOGIC to be used with greater accuracy, but also provide basic knowledge to growers on how hard they can push their soil.

The linkages created with industry, research and extension in this project have been very important to achieving the stated objectives. Collaboration with software developers and the proposed decision support systems scientist will be equally important for future tools to assist in cotton management.

Of importance to all these future research areas are the skills and capacity within the industry for software development and water research. CSIRO Plant Industry is committed to developing these attributes within the cotton industry through the appointment of software developers, Mr Stephen Yeates and Mr James Neilsen.

8. List the publications arising from the research project and/or a publication plan. (NB: Where possible, please provide a copy of any publication/s)

Journal Papers

Bange, M.P., Carberry, P.S., Marshall, J. and Milroy, S.P. (2004) *Row configuration as a tool for managing rain-fed cotton systems: Review and simulation analysis.* Australian Journal of Experimental Agriculture 44(9).

Ritchie, J., Abawi, Y., Dutta, S., Harris, T. and Bange, M. (2004). *Risk management strategies using seasonal climate forecasting in irrigated cotton production: a tale of stochastic dominance.* Australian Journal of Agricultural and Resource Economics. 48(1): 65-93.

Submitted conference papers

Richards, D., Bange, M.P., and Tennakoon, S.B. (2002) *Raising the bar – techniques to evaluate increases in water use efficiency in cotton using crop simulation*, Proceedings of the 2002 Irrigation Association of Australia Conference, Sydney May 2002

Richards, D.Q., Bange, M.P., and Roberts, G.N., (2001) *Assessing the risk of cotton 'earliness' management strategies with crop simulation*, Proceedings of the 10th Australian Agronomy Conference, Hobart, January 2001

Richards, D., Bange, M.P., Milroy, S.P., and Rayner, F. (2002) *Development of simple techniques for rapid leaf* area measurement in cotton, Proceedings of the 11th Australian Cotton Conference, Brisbane, August 2002.

Richards, D.Q., Roberts, G.N., Bange, M.P., Felton-Taylor, C., and Gregory, R. (2004) *Managing cotton under limited water conditions using HydroLOGIC.* Proceedings of the 12th Australian Cotton Conference, Brisbane, August 2004

Industry publications

Richards, D., Bange, M.P., and Milroy, S.P. (2001) *The 2000-01 season in review*, The Australian Cottongrower, May-June 2001.

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9. Have you developed any online resources and what is the website address?

Details about the HydroLOGIC software and upgrades have been written and placed on the Cotton CRC website, under the CottonLOGIC support page. The address for this site is www.cottoncrc.org.au/cottonlogic.

10. Provide an assessment of the likely impact of the results and conclusions of the research project for the cotton industry. Where possible include a statement of the costs and potential benefits to the Australian cotton industry or the Australian community.

Project results have indicated that yield and maturity can be optimized using HydroLOGIC, under both full and limited water situations. In particular, HydroLOGIC results demonstrate that in spite of reduced irrigation water, crop water use can be optimized to achieve similar water use efficiency as conventionally irrigated cotton with no impacts on fibre quality. In the future, maximizing yield will require optimum application of irrigation water and use of in-season rainfall.

Uniquely HydroLOGIC allows irrigators to make informed decisions based on the predicted response in plant growth to moisture conditions, and is a quantitative tool to assist in risk management. The benefits to the industry from the project outcomes will be ongoing, as tools such as HydroLOGIC, are developed further. Feedback from users and workshop participants indicate that the industry places a high value on the research conducted over the last 3 years and the tools developed.

Part 4 – Final Report Executive Summary

This research project involved the development and application of crop simulation tools to assist with crop management within the cotton industry. These tools allow risk assessments to be made about crop management decisions, which when combined with on-farm experience aims to maximise crop potential. In addition, by providing extension and research staff and other industry personnel with a simulation capacity through the project, the benefits to industry will be more widespread and gain greater exposure. Irrigated and dryland growers involved during this project have benefited from information generated by simulation technology and refined their crop management strategies. This project had several objectives in the application of crop simulation to the cotton industry.

Exploration of on-farm crop management scenarios using simulation in dryland and irrigated crop production.

One of the keys to developing software tools that generate information that growers and consultants value, and have a true impact on crop management, has been through collaborative research on-farm. Linking soil sampling, soil characterisation for water holding capacity and the output from OZCOT has been shown to maximise yield potential under a range of growing conditions and seasons. Research in 2001-02 demonstrated the general principles required for modelling in-season for decision making, whilst subsquent research facilitated the development of a focussed tool for irrigation scheduling and water related decision making.

Provision of support to extension staff, researchers and industry personnel in the use of the 'user-friendly' OZCOT.

Providing support to industry staff using OZCOT and related tools has been important to the uptake of these tools and promotion of simulation in cotton. This has involved training in 'how to drive' the software and how to interpret the information generated by these tools. This support has been achieved through training workshops held in each cotton growing valley for growers and consultants, and more focssued training for extension staff. Using OZCOT and HydroLOGIC, extension and industry staff have compared topics such as fruiting potential, yield potential under reduced water allocations and strategies to maximize available water.

Maintenance of a simulation capacity and skills within the CRC and cotton industry to enable growers and industry representative to access this technology.

The ability to generate complex crop potential information over a wide number of locations and crop management scenarios has been an important part of this projects success. This capacity has allowed investigation of issues such as sowing date, dryland potential, row spacing, water allocation, and irrigation scheduling. It has involved the application and evaluation of simulation in new areas and novel crop management strategies such as skip-row planted irrigated cotton. Focussed workshops have been conducted on the physiological response of cotton to water stress, the impact of reduced allocations, the implications of timing the first irrigation, and understanding the impact of stretching irrigation deficits during different crop stages.

Training in the FARMSCAPE accreditation scheme to provide a proven framework for adoption.

Research conducted on-farm with growers and consultants allowed the investigation of local crop management issues in greater detail. This objective focussed on providing the appropriate training for this applied research, and methods for extension of information and tools to the cotton industry. Accreditation also aimed to maintain the credibility of the project officer as a trainer for OZCOT and related software. Since enrolling in the accreditation program in July 2001, numerous workshops were attended to assist with the accreditation process. Stage 1 of the scheme was finished in June 2001, and stage 2 was completed in June 2004.

Appendix 1. Collaborative onfarm research involving investigations into applications of cotton modelling and delivery of simulation results.

2001-02 OZCOT trials

Methodology

On-farm OZCOT research in 2001-02, was conducted on properties at Jandowae and Dalby in Queensland, and at Merah North, Bourke and Breeza in New South Wales. On these farms, a single field was soil sampled at sowing for nitrogen and soil moisture, and this information was used in subsequent simulations in the season. Crop measurements were taken during this season to allow comparisons between simulated soil moisture balance, leaf area and fruiting development and actual figures. Following sowing, the OZCOT software was installed on growers' computers, each given an introduction to OZCOT, and how to simulate their own cotton crop for this season and to generate long term simulations for crop decision making. Fortnightly or when required, each grower was provided with climate files for the current season. Comparisons of crop growth to date could then be made for this season specifically.

Results

As the trials covered a wide range of growing conditions and soil types, the accuracy of OZCOT was varied. Initial on-farm OZCOT research in 2001-02, was conducted at Jandowae and Dalby in Queensland, and at Merah North, Narrabri, Bourke and Breeza in New South Wales.

Waverley: comparisons between model predictions for fruit development at Waverley indicated that delays were experienced in-crop which was not apparent within the generated fruiting curves. The pattern of delay was the same for both squares and green bolls, although the peak numbers were close. And although first open boll was correctly predicted, the final boll number was lower than actual. The final yield was close to the field average. Leaf area index was found to follow the same pattern and peak achieved in the field experiment. Comparisons between soil moisture deficits, measured using the neutron probe and a general probe calibration, and simulated deficit indicated a good correlation and gave confidence that OZCOT was accurate.

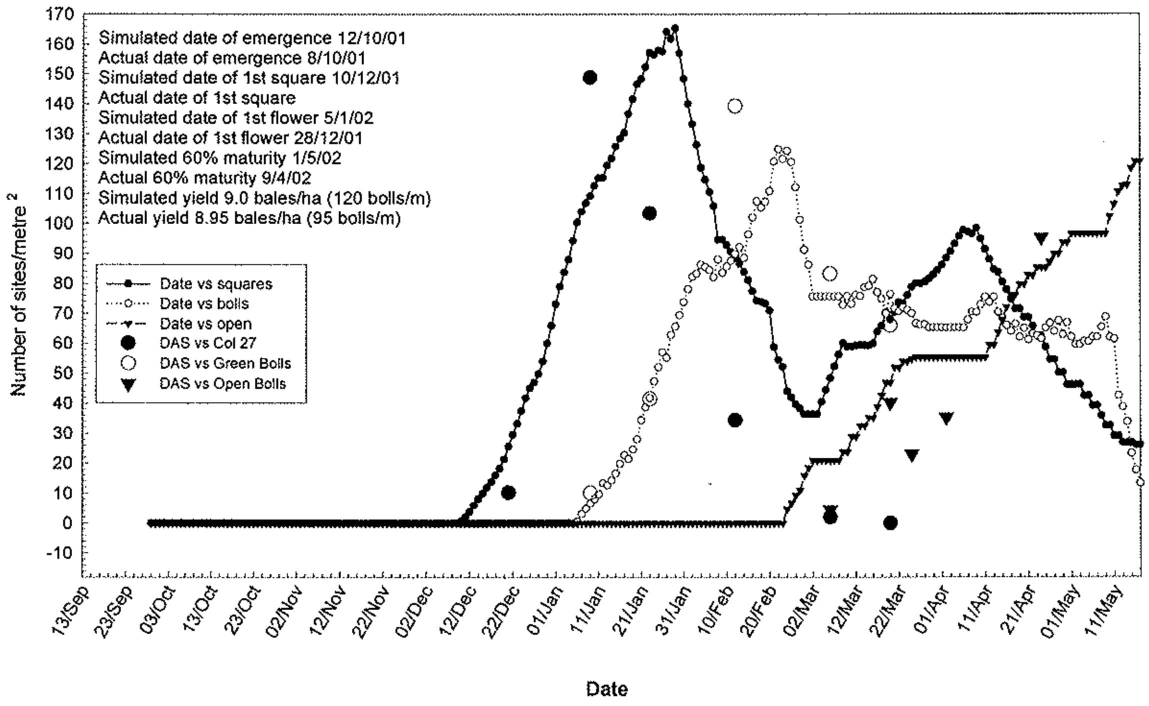
Prattenville: the predictions of square and green boll development were close to actual crop measurements, with peak numbers achieve at approximately the same time. Moisture stress later in the season resulted in 2 weeks delayed maturity which the model did not predict, and final yield was much higher at 7.7 bales/ha than the actual yield of 4.48 bales/ha. Simulated leaf area index did not however reach the peak of 2 measured during mid January, which will have affected predicted crop water use and the soil moisture balance.

Patricia Downs: The site selected for this trial was unsuitable in many ways, from variable soil type from head ditch to tail drain and limitations on the supply of water via bore. Therefore the correlations between predicted and actual values differed significantly, although fruit development was predicted accurately up to the 2nd irrigation during early February. Peak leaf area was achieved in the simulations and final yield was close to actual harvested yield. Discussions regarding the simulated soil moisture balance and consultant probe readings indicated potential break down of the probe calibration in dry conditions.

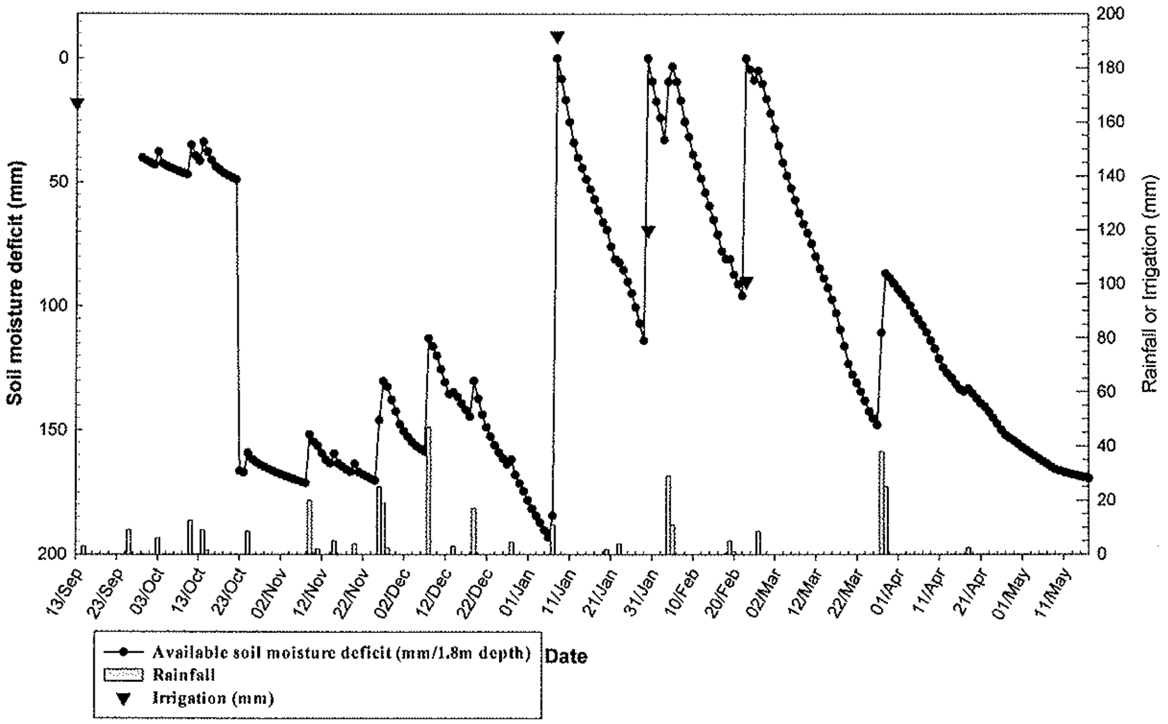
Gebar: Whilst the predicted fruit development was behind by 7 days during the season, including 1st flower and 60% maturity, the final yield of 10.81 bales/ha was close to actual (10.77 bales/ha). The rate of boll opening within OZCOT was slower than crop records, possibly due to boll openers used at defoliation. Leaf area index was measured at close to 3, which OZCOT was unable to reach under the parameters provided. Comparisons with neutron probe and Enviroscan measurements during the season in collaboration with Qld RWUEI staff indicated good correlation with simulated soil moisture deficit.
Battery Hill: Square and green boll peak numbers were achieved with OZCOT although approximately a week later than recorded in the crop, with this delay apparent at maturity. Final yield potential was 9 bales/ha compared with 8.95 bales/ha achieved in the trial. Simulated leaf area followed the measured crop values closely, as was found with soil moisture deficit. Two neutron probes and an Enviroscan were used in this trial, with approximately a 30mm range between the instruments.
Cardale: Appearance of first square, flower and peak boll numbers were simulated accurately at this site, with 60% maturity predicted within 3 days indicated by field sampling. Final yield potential was 10.44 bales/ha, which compared favourably with the harvested yield of 9.9 bales/ha.

Validation graphs are presented here for the Breeza and Bourke trials.

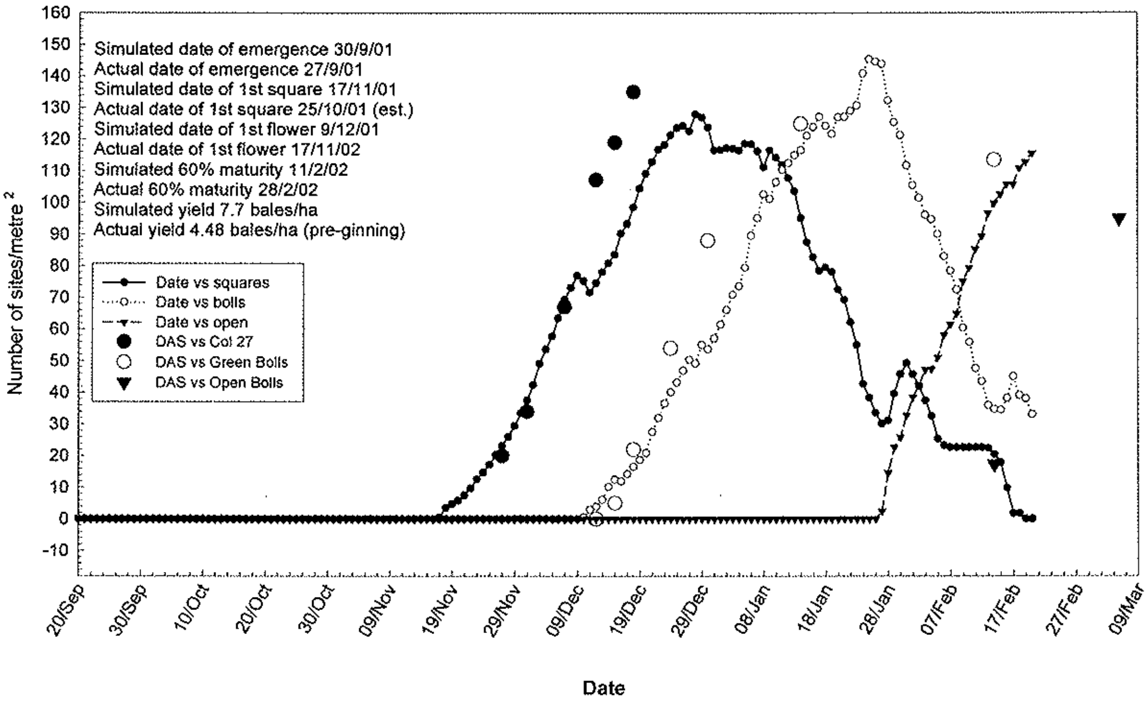
Fruiting curve, Battery Hill Field 7, 2001/02 Validation simulation



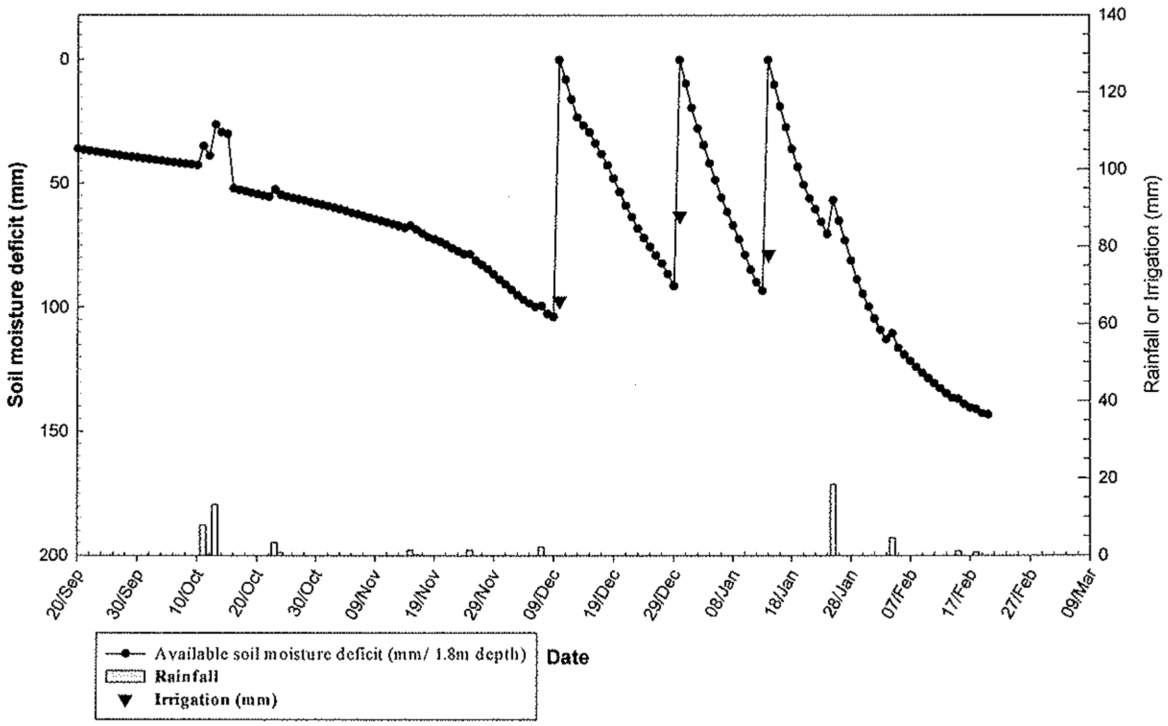
Soil moisture deficit, irrigation and rainfall (mm), Battery Hill, Field 7, 2001/02 Validation



Fruiting curve, Prattenville Field 1a, 2001/02 Validation simulation



Soil moisture deficit, irrigation and rainfall (mm), Prattenville Field 1a, 2001/02 Validation



2002-03 HydroLOGIC Trials

Methodology

Two trials in 2002-03 season compared standard management practice with HydroLOGIC management, with a prototype version of the software being tested.

- In the Lower Namoi valley, a trial at Narrabri consisted of 4 treatments; standard management (14 day cycles), HydroLOGIC management with 8Ml/ha (Full) and 4Ml/ha (Limited), and a skip planted irrigated treatment. This trial was sown on the 9th of October with Sicot 289i, and had approximately 173kg/ha available soil nitrate to 1.8m depth. The standard irrigation strategy was to irrigate on 14 day cycles or when plant stress was apparent. The HydroLOGIC managed treatments were irrigated at the optimum soil moisture deficit as indicated by final yield predictions.
- In the Upper Namoi a trial was established on the Breeza Plain at Battery Hill in collaboration with Phillip Morgan. It consisted of 3 treatments replicated twice; HydroLOGIC scheduling; irrigation at 60mm deficit; and at 75mm deficit. It was sown on the 3/10/02 to Sicala 40RRi, and had soil nitrogen at sowing of 204kg N/ha to 120cm depth. Soil moisture was monitored using neutron probes and a single Enviroscan in the 60mm treatment. Fruit development and biomass were monitored during the season and entered into HydroLOGIC where appropriate. Crop maturity was determined by consecutive hand harvests and yield by machine picking, with all lint from each treatment made into a single module.

Results

Narrabri

As the Limited water treatment received only 2 irrigations, warm temperatures and moisture stress during February rapidly opened bolls, giving 2 weeks earliness over the Full allocation and Standard treatments. Final boll numbers were highest in the HydroLOGIC full treatment (114 bolls/m2), followed by the standard treatment (102 bolls/m2), and the HydroLOGIC limited water treatment (90 bolls/m2). Timely water application ensured optimal plant growth and fruit development within the HydroLOGIC treatments, resulting in a harvest of 8.11 bales/ha under full allocation and 5.81 bales/ha under limited water allocation. These results compare favourably with the standard scheduling treatment which yielded 7.56 bales/ha. Seasonal conditions during the growing season affected fibre quality, micronaire in particular. Warm conditions late in the season and adequate rainfall resulted in all treatments producing lint with higher micronaire, which would attract gin discounts. The lower micronaire achieved by the HydroLOGIC limited treatment, demonstrates this crop was not under excessive stress due to stretched irrigation intervals based on HydroLOGIC predictions. (Refer to Richards, D., and Bange, M. (2004) *HydroLOGIC guides furrow irrigation decisions*, Australian Cottongrower magazine, December 2003-January 2004, p18-21. contained within this Appendix).

Breeza

Early growing conditions were dry although rainfall for the season totalled 350mm. Irrigations occurred in the HydroLOGIC treatment on the 6/1/03, 28/1/03, and 11/2/03. The 60mm treatment was irrigated on the 29/12/02, 21/1/03 and 7/2/03, while the 75mm treatment was irrigated on the 6/1/03 and 28/1/03. The final irrigation on the 7/2/03 (60mm) and 11/2/03 (HydroLOGIC) was pushed through in a hurry due to running short of water. Subsequent probing and Enviroscan data showed that the water never reached the bottom of the root zone and didn't refill the profile fully. Crop maturity was similar across the treatments, although the 75mm deficit did have a slight maturity advantage in early March. On analysis of final trial yields, summarised in Table 1 below, variation in the field was apparent with low yield in the second replicate.

Table 1. Final hand and machine yields from Breeza 2002-03 trial.

Treatment	Bales/ha Rep1	Bales/ha Rep2	Bales/ha (Ave) hand pick	Bales/ha machine pick
HydroLOGIC	9.56	5.74	7.65	7.05
60mm	9.95	9.04	9.50	8.13
75mm	8.67	7.23	7.95	6.63

This trial demonstrated the importance of accurate soil moisture measurement for irrigation scheduling. Discussions with Phillip Morgan highlighted how management constraints such as siphon shifts and filling head-ditches on different occasions need to be balanced with HydroLOGIC predictions and current weather conditions.

2003-04 HydroLOGIC trials

Methodology

Trials conducted in 2003-04 season included a trial located at Narrabri and four comparison trials located at Emerald, St George, Wee Waa and Breeza.

- The Narrabri trial experiment was established at the CSIRO lease at Myall Vale. The trial site was sown with Sicot 189 on the 21st of October and watered-up following sowing. With the exception of irrigation timing and allocation, the crop was grown and managed under normal cultural conditions. Three different water allocation treatments were imposed; 8ML/ha, 4ML/ha, and 2ML/ha, with timing of irrigations determined individually using HydroLOGIC. Each treatment was replicated three times. Soil moisture and nitrogen was determined prior to sowing. Plant sampling and neutron probes were used during the season to determine fruit numbers and soil moisture deficit. On a weekly basis, the most recent crop information and farm weather data was entered into HydroLOGIC software. The decision to irrigate a treatment was made using a range of HydroLOGIC scenarios, which varied the soil moisture deficit used to initiate irrigation from 60mm to 130mm and by the available water allocation. The scenario with the highest potential yield was selected and the corresponding predicted irrigation used. This operation was also done following significant rainfall events. Crop maturity for each plot was determined and the experiment was harvested by twin row pickers and weights for each plot determined using boll buggy fitted with weigh cells.
- The demonstration trials used split fields or paired fields side by side, allowing a direct comparison between the existing grower's irrigation management and field management using HydroLOGIC. Plant development during the irrigation period, soil moisture deficit and fruit numbers were collected in both management areas, which was entered into HydroLOGIC for decision making purposes. A decision log was maintained by each co-operator and recorded dates and crop stages where HydroLOGIC was used and other considerations at the time. These trials were located at:
    - Arcturus Downs, Rolleston in collaboration with Toni Anderson

- Cubby Station, in collaboration with Greg Nichol and Steve Ginns
- Caroale, Moree in collaboration with Julie O'Halloran
- Drayton, Breeza in collaboration with Penny Van Dongen
- Togo, Wee Waa in collaboration with Anne Johnston
- Drayton, Breeza in collaboration with Penny Van Dongen

Results

Narrabri

Unlike other locations within NSW, rainfall in Narrabri was close to average for most of the season, although April was dryer than normal. There were however five rainfall events of above 40mm, that had a significant impact of the response and growth to the irrigation treatments. In particular the 150mm received from 14th to 17th January kept the 2ML/ha treatment growing, whilst waterlogging the 4ML/ha and 8ML/ha treatments which were irrigated on the 5th of January. HydroLOGIC predictions were run on the 29th November to determine the first irrigation date in all scenarios, with only the 8ML/ha treatment to be irrigated on December 17th. Predictions continued to be assessed during the season and following rainfall (for actual irrigations dates refer to appendix 2).

Maturity picks commenced in March and continued on a weekly basis until harvest, which began on the 7th of May 2004. Very little difference was observed in crop maturity, with 60% of bolls being open between the 19th and 25th of April in all treatments (Figure 3a). Final open boll numbers on a square metre basis were 95, 100, and 103 for the 2ML/ha, 4ML/ha and 8ML/ha treatments respectively. As expected, yields increased with the frequency of irrigation and total allocation applied (Figure 3b), although boll size was not greatly different between treatments. The average boll sizes (seed cotton per boll) for the 2ML/ha, 4ML/ha and 8ML/ha treatments were 4.30 gm/boll, 4.45 gm/boll and 4.29 gm/boll respectively.

The results from this experiment demonstrated that HydroLOGIC can be used to effectively schedule in-season irrigations under limited water situations. The complementary nature of the software was also highlighted, with the information from soil moisture probes being value-added by HydroLOGIC to give predictions of the next irrigation date and crop growth. Work is continuing to evaluate the HydroLOGIC system under a range of growing conditions and scenarios. Future refinements to HydroLOGIC in response to requests include; the ability to assess years that have certain characteristics (e.g. hot seasons); seasonal climate effects; and use for overhead irrigation systems. For further details and graphs refer to the attached document, Richards, D.Q., Roberts, G.N., Bange, M.P., Felton-Taylor, C., and Gregory, R. (2004) *Managing cotton under limited water conditions using HydroLOGIC*. Proceedings of the 12th Australian Cotton Conference, Brisbane, August 2004

Demonstration sites

Emerald
The trial field of DP560 was divided into two 4.75 ha blocks with one irrigated according to HydroLOGIC and the other controlled by the farmer. Capacitance probes were used to backup decisions made by both the program and the grower. As a consequence of in-

season rainfall irrigation scheduling for the 2 treatments didn't differ greatly due to rain through out the season. However, throughout the season HydroLOGIC consistently indicated long range irrigation dates that were backed-up by the capacitance probe readings. Unfortunately this trial received herbicide drift damage in early November, which effected plant vigour and fruiting capacity, further challenging irrigation scheduling. The final measured yields were HydroLOGIC 5.26 bales/ha and Grower 4.84 bales/ha, whilst after harvest benchmarking using HydroLOGIC indicated yield potentials of 6.93 bales/ha and 6.85 bales/ha respectively. The trial co-operator and Toni Anderson felt that despite the final yields being poor, they indicate that even in difficult years HydroLOGIC is a useful tool when making irrigation decisions.

St George
This trial was planted into moisture on the 14/10/03 with Sicot 80 and flushed the following day. Both treatments received 8 in-crop irrigations, with the HydroLOGIC treatment generally being 2-4 days later than the standard treatment, which correlated very closely with C-probe measurements in each treatment. Trial yields were 9.73 bales/ha in the standard scheduling treatment and 9.55 bales/ha in the HydroLOGIC treatment. These results indicate the grower already had a good knowledge of soil type, accurate soil moisture measurement, and optimum time to irrigate.

Moree
This trial was established on Caroale and planted to Sicot 289i on the 18/10/03. In addition to the grower and HydroLOGIC treatments, 2 additional treatments were introduced. A dry treatment was 2-6 days later than normal, while the wet was 2 days early. Each treatment received 4 in-crop irrigations and total rain for the season totalling 470mm. Final yields were HydroLOGIC (9.1bales/ha), standard (8.9bales/ha), dry (9bales/ha), and wet (8.1bales/ha). The scheduling predictions made by HydroLOGIC were earlier than the standard dates, however the proximity of rain to irrigations during the season may have influenced the final results.

Wee Waa
This comparison trial was planted in 2 adjacent fields with Sicala V3RRI on 14/10/03 and was watered up. Scenarios were run coming up to first irrigation, indicating a 5 to 7 day delay would be optimal compared to usual practice. Increasing temperatures in the week leading up to first irrigation in the standard field (14/12/03) brought this delay back to 2 days. HydroLOGIC was used later in the season to evaluate irrigation strategies when evaporation and application amounts were greater than expected over the whole farm. The trial fields was harvested on the 17th and 23rd of April and yielded 7.9 bales/ha (standard) and 8.6 bales/ha (HydroLOGIC). Discussions with Mr Ben Stephens following harvest outlined some of the limitations with the current software and highlighted that scheduling operations could be enhanced with output classified by seasonal climate forecast or anticipated rainfall percentages.

Breeza
This trial was planted to DP547 on the 17/10/03 into reasonable moisture. During November the trial was sandblasted, followed by hail in January, and was subsequently abandoned due to plant damage. The trial did indicate potential refinement is required with the response of OZCOT to cool temperatures and that the incorporation of forecast temperatures for the coming week could assist with scheduling decisions.

HydroLOGIC guides furrow irrigation decisions, Australian Cottongrower magazine, December 2003-January 2004, p18-21

HydroLOGIC guides furrow irrigation decisions

By Dirk Richards and Michael Bange, CSIRO Cotton Research Unit and Australian Cotton CRC

HydroLOGIC is an irrigation management system to assist effective and timely application of irrigations for furrow irrigated cotton crops. HydroLOGIC has been developed by CSIRO Plant Industry, as part of the Australian Cotton CRC, incorporating up to date cotton research into a management decision aid to optimise water use and yield.

Using the HydroLOGIC software can help to evaluate the consequences of different irrigation strategies on yield and water use, using a range of simple plant and soil moisture measurements.

Specifically there are four ways in which HydroLOGIC can help irrigated cotton growers make decisions (Figure 1):

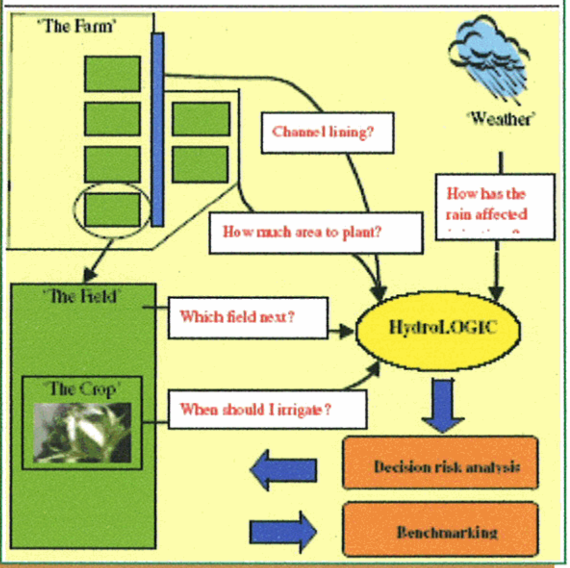
1. Optimise cropping area

Predictions of yield can be made using historical climate information, with a range of water allocations. The optimum irrigated cropping area can then be determined for a given water allocation.

2. Schedule the next irrigation

HydroLOGIC can be used to predict the date when a field will next need irrigating.

FIGURE 1: HydroLOGIC can operate on many levels of farm decisions



> *"Irrigation decisions are compromises between reducing the risk of water stress and increasing the risk of waterlogging"*
>
> **(Hearn and Constable, 1984)**

3. Conduct scenario analyses

HydroLOGIC can be used to assess the consequences of different irrigation management strategies. Two types of irrigation issues can be explored:

- Timing of irrigations — the effect of changing first and last irrigation dates, and the impact of stretching irrigation deficits. For example "what if I delay irrigating this field in an attempt to save water?" or "what if I irrigate at a lower deficit and more frequently?"
- Amount of water — the effect on yield and water use efficiency with different water availability (allocation and irrigation system efficiency). For example, 'what will crop yields be if I receive and apply an extra two megalitres per hectare of allocation flow?'

4. Benchmarking performance of previous crops

Benchmarking is one way to assess crop productivity and track changes over several seasons, and compare with other fields on the farm. It can be used to:

- Calculate crop water use efficiency figures in conjunction with actual field results, to allow comparisons between crops and seasons.
- Help assess the impacts on crop growth if irrigation management from the previous year had been different.

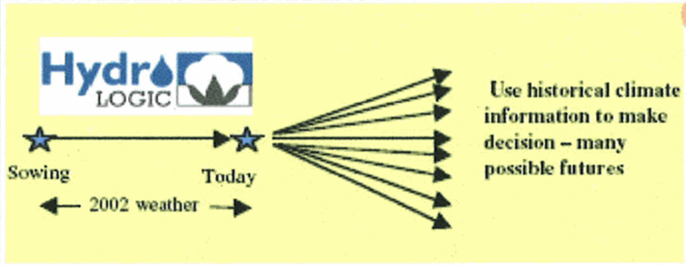
An important component of HydroLOGIC is the use

HydroLOGIC can help schedule irrigations.

of actual crop growth (fruit load and leaf area), soil moisture measurements, current weather information (rainfall and temperature) and irrigation information for a crop to the present date in the season. The prediction of crop growth and water usage for the remainder of the season is based on the modelled soil water balance, historical climate information and different management scenarios (Figure 2).

Importantly, HydroLOGIC is designed to complement, not to replace, continuous soil moisture monitoring systems, as information can be used from any existing soil monitoring equipment that has been properly calibrated.

FIGURE 2: The prediction logic of HydroLOGIC



BACKGROUND

HydroLOGIC uses the OZCOT model developed initially by Dr Brian Hearn and CSIRO. OZCOT simulates the effects of environment (soil, water and temperature) and crop management (such as sowing time, nitrogen and irrigation) on yield development.

Over the past decade OZCOT has shown considerable versatility in simulating commercial irrigated crops with different management regimes. Within HydroLOGIC, each cotton field is treated individually, since irrigation scheduling is conducted on a field basis.

Central to the HydroLOGIC software is the weather information provided through the Bureau of Meteorology SILO project. Most cotton growers will be familiar with another SILO product, the SILO day degree calculator hosted on the Australian Cotton CRC web site. The other major advance in access to climate data has been the development and availability of the Patched Point Dataset for research.

This is a continuos dataset containing daily rainfall, minimum and maximum temperatures, radiation, evaporation and vapour pressure for any weather recording station in Australia. It combines original Bureau measurements for a site, with any missing data filled using estimation from measurements at surrounding stations. Historical climate for any official recording station may be accessed directly from SILO, and then used within HydroLOGIC.

HydroLOGIC performance in the field

In detailed field evaluations of HydroLOGIC conducted during the 2002–03 season, the use of HydroLOGIC for scheduling irrigations was shown to optimise yield, maturity, and water use under both full and limited water situations. A large scale field trial at Narrabri consisted of three treatments:

- Standard management with eight megalitres per hectare;
- HydroLOGIC management with eight megalitres per hectare (Full); and,
- HydroLOGIC management with four megalitres per hectare (Limited).

The trial was sown on October 9, 2002 with Sicot 289RRi, and had approximately 180 kg per hectare of available soil nitrate to 1.8 metres depth at sowing.

The standard irrigation treatment was irrigated on 14 day cycles or when plant stress was apparent. A series of simulations was conducted using HydroLOGIC to determine the optimum soil moisture deficit to irrigated at, and to maximise final yield predictions.

YIELD AND FIBRE QUALITY

Timely water application ensured optimal plant growth and fruit development within the HydroLOGIC treatments. The highest square and boll numbers were achieved under the HydroLOGIC management. This resulted in a harvest of 8.1 bales per hectare under full allocation and 5.3 bales per hectare under limited water allocation. These results compare favourably with the standard scheduling treatment which yielded 7.6 bales per hectare (Figure 3).

Micronaire was not significantly different between the standard and HydroLOGIC managed treatments. These results demonstrate that HydroLOGIC was able to minimise water stress and negative effects on fibre develop-

20 ▷

FIGURE 3: Final machine picked yields from the large scale HydroLOGIC evaluation trial at Narrabri.

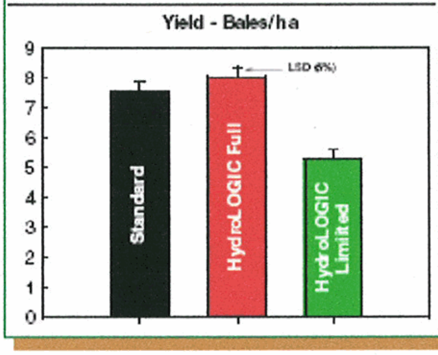


TABLE 1: Water use efficiency indices

Water details	Standard scheduling	HydroLOGIC Full	HydroLOGIC Limited
Total water applied (Ml)	7.2	8.5	4.6
Irrigations	5	6	3
Total seasonal water use (Ml/ha)	9.3	10.8	6.7
Irrigation application efficiency	81	78	88
Gross production water use index (bales/Ml/ha)	0.8	0.8	0.8
Irrigation water use index (bales/Ml)	1.1	1.0	1.2
Crop water use index (kg/mm)	2.6	2.7	2.4

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ment. Other fibre quality properties were not affected by the different irrigation scheduling and water allocation.

WATER USE EFFICIENCY

During the 2002–03 season only 197mm of rain fell on the crop, which provided ideal conditions to evaluate the value of HydroLOGIC. To determine the total irrigation water applied to the treatments, water flow was measured at the siphon and furrow (tail water) in each treatment during all irrigations.

The total seasonal water use was then calculated using the volume of irrigation applied, the change in soil moisture from sowing to defoliation, rainfall and estimates of deep drainage. These figures allow several water use efficiency indices to be calculated (Table 1):

a. **Gross production water use index (GWUI):** Is the yield (bales) produced from all water applied to the crop, which includes soil moisture, rainfall and irrigation water.

b. **Irrigation water use index (IWUI):** Allows irrigators to determine how efficient their irrigation water has been in producing bales of cotton. It is calculated by dividing the yield (bales per hectare) by the water applied as irrigation (Ml).

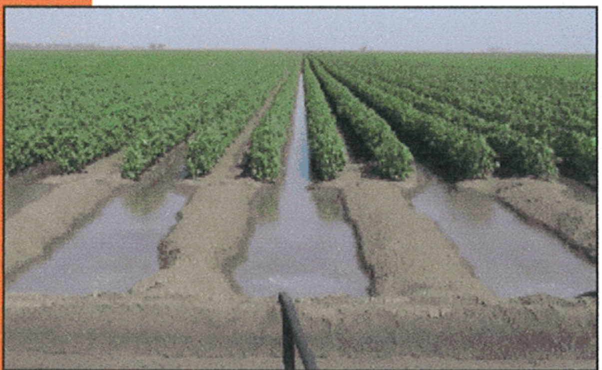
c. **Crop water use index (CWUI):** Calculates how efficiently the water used by the cotton crop in evaporation and transpiration (mm), was converted into lint harvested (kg).

The differences between the total water applied as irrigation and total seasonal water use indicates there should have been considerable differences in crop growth. But comparisons of GWUI showed no differences between treatments.

Comparisons between treatments indicated that IWUI (Table 1) was maximised in the HydroLOGIC reduced allocation treatment, where 1.2 bales were produced for each megalitre of water applied. This compared with 1.1 bales/Ml and 1.0 bales/Ml from the standard scheduling and HydroLOGIC full allocation treatment.

Crop water use index showed little variation between the different management treatments, with comparable results achieved under a limited water scenario using HydroLOGIC. The HydroLOGIC full allocation treatment achieved the highest crop water use index of 2.7 kg of lint/mm of evapotranspiration.

These results demonstrate that HydroLOGIC can be used to maximise yield and achieve optimal WUE, through scheduling irrigation applications to satisfy plant water demand and maintain good crop growth.



HydroLOGIC can be used to maximise yield and achieve optimal WUE.

FUTURE FEATURES OF HYDROLOGIC

New features will be incorporated into the HydroLOGIC software in future versions, following feedback from cotton growers and consultants. Some of the features planned include:

- The ability to select particular seasons for comparisons (such as drought years) and analogous seasons based on the current seasonal climate forecasts.
- The ability to customise soil moisture parameters used for predictions of crop growth and import data from existing soil moisture measuring devices.
- A farm water accounting system.

SOFTWARE

Copies of the HydroLOGIC software are available from the cotton industry development officers, situated in each cotton growing valley, or by contacting the Australian Cotton CRC's Technology Resource Centre at Narrabri. Further details can be found at http://www.cotton.crc.org.au/CottonLOGIC/.

Managing cotton under limited water conditions using HydroLOGIC

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Key Points

- Under limited water scenarios HydroLOGIC was able to optimise yield.
- Irrigation application efficiencies were estimated to be near the industry average of 60%.
- Combining soil moisture probe information with HydroLOGIC predictions gave reliable assessments of crop growth, response to moisture stress and final yield.

Introduction

Increased pressures are being placed on irrigators in Australia to maximise their water use efficiency. This has in turn highlighted the need for more focused research and extension on water management. The HydroLOGIC irrigation management system has been developed to provide information for irrigation decisions. The system provides a range of information to assist with the effective and timely application of irrigations for furrow irrigated cotton crops. Uniquely, the software has the ability to evaluate the consequences of different irrigation strategies on daily crop growth, yield and water use, using a range of simple plant and soil moisture measurements. HydroLOGIC especially offers opportunities for optimising irrigation management in limited water situations, where understanding the consequence of different irrigation strategies become even more important to productivity.

Field experiments conducted during the 2002-03 cotton growing season demonstrated that HydroLOGIC could achieve above average yields and water use efficiency (Richards and Bange, 2003). This paper presents the results of a HydroLOGIC experiment in 2003-04, which aims to further demonstrate the 'value' of HydroLOGIC in improving water use efficiency.

Materials and Methods

The experiment was established at the Australian Cotton Research Institute, Narrabri, NSW in October 2003. The trial site was sown with Sicot 189 on the 21st of October and watered-up following sowing. With the exception of irrigation timing and allocation, the crop was grown and managed under normal cultural conditions. Three different water allocation treatments were imposed; 8ML/ha, 4ML/ha, and 2ML/ha, with timing of irrigations determined individually using HydroLOGIC. Each treatment was replicated three times. Soil moisture and nitrogen was determined prior to sowing, with 130mm soil water and over 400 kg nitrate nitrogen (NO_3) available.

Plant sampling during the season determined the numbers of squares, green and open bolls on a square metre basis, and estimates of leaf area were made using the HydroLOGIC photo guides. Neutron probes were installed in each treatment to estimate the soil moisture deficit prior to irrigation.

On a weekly basis, the most recent crop information and farm weather data was entered into HydroLOGIC software. The decision to irrigate a treatment was made using a range of HydroLOGIC scenarios, which varied the soil moisture deficit used to initiate irrigation from 60mm to 130mm and by the available water allocation. The scenario with the highest potential yield was selected and the corresponding predicted irrigation used. This operation was also done following significant rainfall events.

At each irrigation event, the water levels were monitored using Odyssey capacitance water depth recorders at head ditch and tail drain. Siphon input was then estimated using the Bos head height siphon flow equation (Bos, 1989), and tail water was estimated from recording flumes. The total water applied to the experimental plot was then calculated, taking the soil moisture deficit into consideration. Following irrigations, the total water applied was deducted from the remaining allocation within each treatment, with subsequent HydroLOGIC scheduling scenarios using this revised allocation. The application efficiency was calculated by dividing the irrigation water supplied to the crop by the water applied by siphon.

Crop maturity for each plot was determined by weekly hand harvests over 4 metres of planted row, giving a total of 12 metres of hand harvest per treatment. The 16 hectares of the experiment was harvested by twin row pickers and weights for each plot determined using boll buggy fitted with weigh cells. An assumed turnout of 40% allowed calculation of final lint yields. To determine the irrigation water use index or the productivity of applied irrigation water, final lint yield was divided by the total applied water for the season. To calculate the gross water use index, final lint yield was divided by the total water inputs for the crop, which includes irrigation water applied, rainfall and the difference in soil moisture between sowing and harvest.

Results and Discussion

General

October and November temperatures remained cool, with the incidence of cold shocks considerably higher than average until mid November. The following months of December to February recorded above average number of hot days, and day degree accumulation returned closer to the long term average. Unlike other locations within NSW, rainfall in Narrabri was close to average for most of the season, although April was dryer than normal. There were however five rainfall events of above 40mm, that had a significant impact of the response and growth to the irrigation treatments. In particular the 150mm received from 14th to 17th January kept the 2ML/ha treatment growing, whilst potentially waterlogging the 4ML/ha and 8ML/ha treatments which were irrigated on the 5th of January. In the week 12th to 16th of March, following the final irrigation in the 4ML/h and 8ML/ha treatments, another 75mm was recorded during this boll filling and opening period.

HydroLOGIC predictions were run on the 29th November to determine the first irrigation date in all scenarios, with only the 8ML/ha treatment to be irrigated on December 17th. Predictions continued to be assessed during the season and following rainfall, with actual irrigations on the dates given in Figure 1.

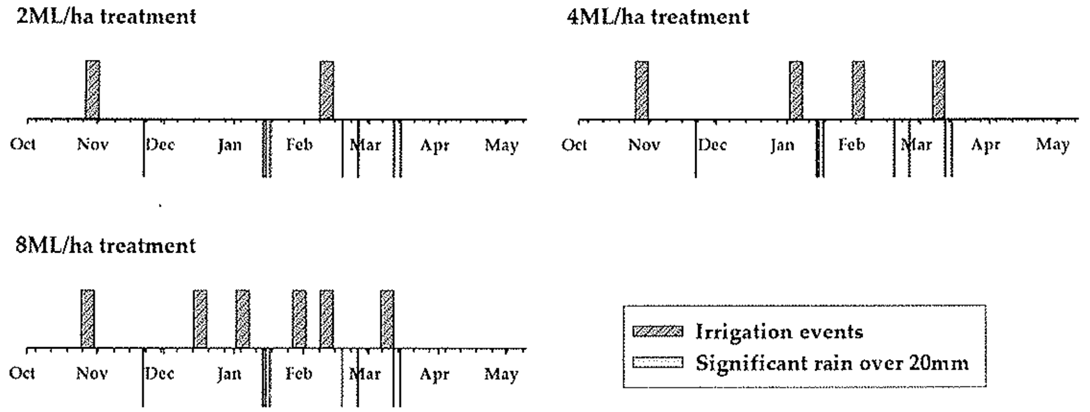

Figure 1. Irrigation and rainfall timeline in HydroLOGIC irrigation experiment, 2003-04 season.

A range of plant sizes was the most apparent impact of the different irrigation dates and allocations. Under a full allocation regime, the 8ML/ha treatment grew to 115 cm and averaged 27 nodes at harvest, as opposed to 108 cm and 29 nodes in the 4ML/ha treatment, and 104 cm and 29 nodes in the 2ML/ha treatment. The reduction in plant size with allocation indicates moisture stress has occurred to some degree in both the 2ML/ha and 4ML/ha treatments. Regrowth was also apparent from the final boll numbers.

Applied irrigation water

Following irrigations, the total water applied to each treatment and the in-field application efficiency was estimated. The soil moisture deficit at sowing was 104mm, however during the water-up event over 2ML/ha was applied to the field. This indicated that a considerable amount of applied water (99mm) percolated below the rooting zone, due in part to the large cracks in the dry soil which did not close immediately. Tail water of 0.9ML/ha was also recorded during this event. As a consequence, the application efficiency for this particular irrigation was only 36%. Total water applied in all irrigation events for the season was calculated at 1.56ML/ha for the 2ML/ha allocation treatment, 3.02ML for the 4ML/ha allocation treatment, and 4.29ML/ha for the 8ML/ha allocation treatment (Figure 2a). The application efficiency for the whole season was found to be 59% (Figure 2b) or close to the industry average of 60% (Tennakoon and Milroy, 2003).

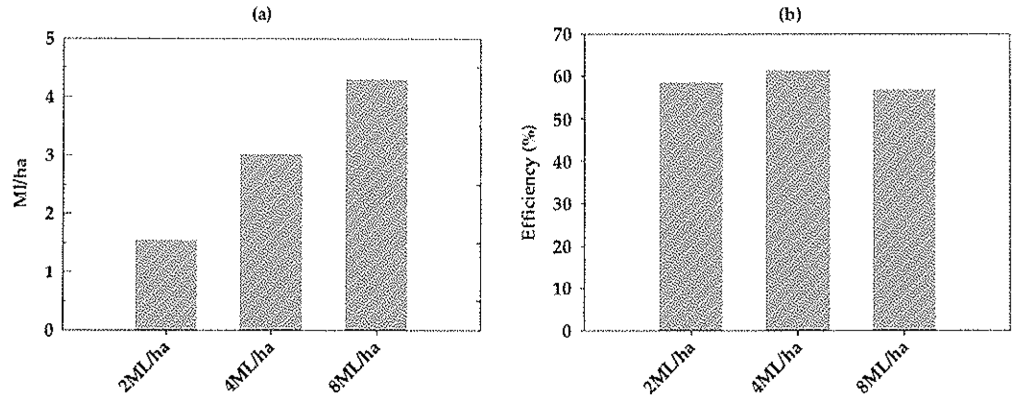

Figure 2. The (a) applied irrigation water and (b) application efficiencies calculated for the whole of the season.

Yield and maturity

Maturity picks commenced in March and continued on a weekly basis until harvest, which began on the 7th of May 2004. Very little difference was observed in crop maturity, with 60% of bolls being open between the 19th and 25th of April in all treatments (Figure 3a). Final open boll numbers on a square metre basis were 95, 100, and 103 for the 2ML/ha, 4ML/ha and 8ML/ha treatments respectively. As expected, yields increased with the frequency of irrigation and total allocation applied (Figure 3b), although boll size was not greatly different between treatments. The average boll sizes (seed cotton per boll) for the 2ML/ha, 4ML/ha and 8ML/ha treatments were 4.30 gm/boll, 4.45 gm/boll and 4.29 gm/boll respectively.

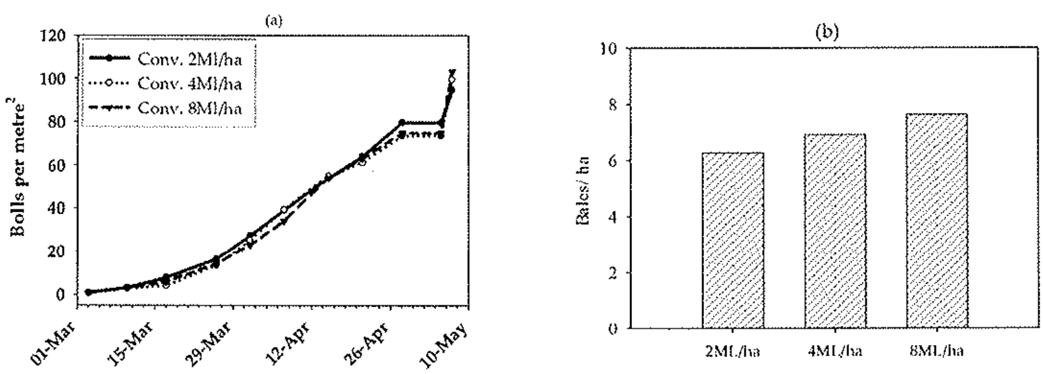

Figure 3. The (a) number of open bolls over time used to identify crop maturity and (b) final machine harvest yield results for 2003-04 HydroLOGIC trial.

Water use indices

The yield benefit of the irrigation water applied (or irrigation water use index) was calculated following harvest. The 2ML/ha treatment achieved the highest index, where 1.8 bales was grown for each megalitre of irrigation water applied. This compared favourably with 1.4 bales/ML and 1.2 bales/ML from the 4ML/ha and 8ML/ha treatments respectively. Comparisons with recent industry surveys show that all treatments were above the Australian average of 1.3 bales/ML (Tennakoon, Milroy and Richards, 2003). The high irrigation water use index in the 2ML/ha can be attributed to the relatively high yield, primarily due to the 150mm rainfall event contributing to favourable crop growth prior to the only irrigation. Increasing the frequency of irrigations may have also increased the waterlogging from subsequent rainfall, and may have reduced yields in the 4ML/ha and 8ML/ha treatments. The gross water use index, which includes the input of rainfall and utilised soil moisture, was also calculated. These values ranged from 0.69 bales/ML in the 2ML/ha treatment to 0.66 bales/ML in the 8ML/ha treatment, with the 4ML/ha in between.

Conclusion

The results from this experiment again demonstrate that HydroLOGIC can be used to effectively schedule in-season irrigations within cotton, especially under limited water situations. The complementary nature of the software was also highlighted, with the information from soil moisture probes being value-added by HydroLOGIC to give predictions of the next irrigation date and crop growth. Work is continuing to evaluate the HydroLOGIC system under a range of growing conditions and scenarios. Future refinements to HydroLOGIC in response to requests include; the ability to assess years that have certain characteristics (e.g. hot seasons); seasonal climate effects; and use for overhead irrigation systems.

Acknowledgements

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