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CSIRO Division of Plant Industry
Cotton Research Unit
Locked Bag 59
Narrabri, NSW, 2390

# Development of the OZCOT Cotton Crop Simulation Model

(Project CSP28C)

## Final Report

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Report compiled for the Cotton Research and Development Corporation

# FINAL REPORT
## COTTON RESEARCH AND DEVELOPMENT CORPORATION

**PROJECT TITLE:** Development of the OZCOT cotton crop simulation model.

**PROJECT CODE:** CSP28C

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| Mr A.T. Wells, | (Experimental Scientist; to March 1993) | 100% |
| Dr A.B. Hearn, | (Senior Principle Research Scientist) | 15% |
| Dr D.C. Godwin, | (Consultant) | 30% |

### Background

The OZCOT cotton crop simulation model was developed from the model of fruiting dynamics used extensively as part of the SIRATAC pest management system. In OZCOT the fruit model was linked to sub-models of soil water, nitrogen uptake and leaf area development to produce a crop level model applicable to a range of management decisions. OZCOT has been extensively calibrated against field data and has been shown to accurately simulate yield under a wide range of Australian growing conditions.

The model is an important research tool and is an integral part of a number of other projects being conducted both within CSIRO and in other institutions to the benefit of the cotton industry. These include the work of Dr V. Sadras on compensation to insect damage (CRDC project: CSP39C), Mr S. Routley on the use of GIS in evaluating the potential for dry land cotton production, Dr M. Porter (USQ) on compaction in irrigated cotton (CRDC project: DDI1C), Dr N. Dudley (UNE) on water allocation policy and Mr L. McKewen on the development of decision support systems.

The simple soil water and nitrogen uptake sub-models in OZCOT limited its capacity to handle detailed nitrogen issues, both at the tactical level and for long term simulations. Of particular interest are sustainability issues such as the effect of crop rotation systems on profitability and soil degradation. For long term issues of this nature, simulation forms a vital adjunct to extend the results of long term experiments to other areas and to account for the full range of weather variability. It was therefore decided to redevelop the model to incorporate more realistic plant and soil nitrogen sub-models and a more detailed soil water sub-model. This will improve its usefulness both for tactical and strategic applications and is important for the model's future use in projects associated with the CRC for Sustainable Cotton Production.

## Aims

To make the OZCOT cotton crop simulation model more robust and versatile; enabling it to be used for decision support in a broader range of applications and situations.

This involved five specific objectives:

1. Improve the water balance component of the model, particularly the parts dealing with water movement in the soil profile, by incorporating the CERES water balance subroutines.

2. Incorporate the soil nitrogen subroutines from CERES to allow simulation of nitrogen and organic matter dynamics in the soil.

3. Develop an explicit carbon balance for the model in which photosynthesis produces dry matter which is then partitioned between organs. In the past, carbon balance has been modelled implicitly by using "carrying capacity" (bolls supported per metre of row) as a surrogate for photosynthetic capacity.

4. Develop subroutines to model the uptake and distribution of nitrogen within the cotton plant. This will allow the model to respond dynamically to nitrogen supply, introducing the capacity for consideration of tactical nitrogen issues. It is also a necessary interface for connection to the soil nitrogen sub-model.

5. Collect data on key developmental parameters which characterise the differences in fruiting dynamics between cotton cultivars. These model parameters allow a degree of cultivar sensitivity in the simulation output. The data will be used to maintain the models relevance to current cultivars and to test the importance of variation in these parameters for simulation output.

## Summary of Results

Redevelopment of the model has progressed well and it has now been re-named CERCOT to reflect the CERES origin of a number of its sub-models. Final calibration and validation of the new model remains to be completed. This work has been included as a component of a subsequent project funded by the CRDC. Outcomes for each of the objectives specified in the original submission are summarised below. This progress has been made despite considerable disruption due to staff changes; the project leader, Dr Hearn, retired in September 1992, the principle researcher, Mr A.T. Wells, resigned in March 1993 to take up a position elsewhere. The new researcher (Mr S.P. Milroy) took up the position in December 1993.

In the following summary, numbers in parantheses relate to publications from the project which are listed later.

1. *Complete the revision of the water balance model, particularly the parts dealing with water movement in the profile, by completing the incorporation of the CERES water balance.*

   The incorporation of the new water balance into the model has been completed. The subroutines dealing with water movement in the soil have been calibrated for the local vertisols. To incorporate the new water balance it was necessary to construct subroutines to simulate the pattern of root distribution under cotton during growth. The root distribution governs the plants capacity to access water (and nutrients) from different levels in the soil. These new subroutines have been developed and incorporated into the model but require further calibration and validation. These new features will allow for the interaction between nitrogen and water extraction by the plant which results from possible differences in their vertical distribution in the soil. Nitrogen is rendered inaccessible to the plant when the soil dries. This is most important in the upper layers of the soil which often contain the most nitrogen and are the most prone to drying. This is particularly relevant in dry land or limited irrigation situations.

2. *Incorporate the soil nitrogen subroutines from CERES.*

   This modification has been completed. The approach used and its applications were outlined in a paper presented to The Sixth Australian Cotton Conference (1). Having the crop model linked to a soil sub-model allows the simulation of long term effects of management practices. The soil is the central unit in these studies as it is the status of this resource which is carried between seasons. The sequence of crops and/or fallows interacts with management and weather to modify nitrogen and organic matter pools in the soil over a number of seasons. Field studies of such long term effects are limited in being restricted to a few locations and by their dependence on the weather conditions they chance to experience. Simulation is therefore a vital adjunct to extend the results of long term experiments to other areas and to account for the full range of weather variability.

   The model was used to study the long term impact on soil organic matter of current crop rotation practices used in cotton production. This work was presented by Dr D.C. Godwin at the 'Cotton 2001' workshop in March 1993. The results indicated that each of the rotations considered (continuous cotton, wheat/cotton/wheat, wheat/wheat/cotton, fallow/cotton/fallow, fallow/fallow/cotton, and wheat/fallow/cotton) resulted in a net decline in soil organic matter. The rate of decline was exacerbated by removal of crop residues.

3. *Develop an explicit carbon balance for the model to replace the modelling of carbon implicit in the use of carrying capacity as a surrogate for photosynthesis and strengthen the feedback links in the model.*

   The carbon balance, describing dry matter production by the plant and its distribution to the different organs, has been developed and incorporated into the model. The inclusion of an explicit carbon balance in the model allows for the incorporation of management and environmental factors which can impact on the crop through modifying photosynthesis or dry matter partitioning. An example is mite damage, which reduces leaf area (and hence light interception) and also the efficiency with which the light is used. The result is a reduction in growth and ultimately yield. Currently the carbon balance gives reasonable simulation of the pattern of total dry matter production under non-stressed conditions (fertilised and fully irrigated), as well as realistic partitioning of dry matter between vegetative organs. Some adjustment is still required in the allocation of dry matter to boll growth in precedence over vegetative growth. The model currently tends to under predict yield due to a tendency to under estimate dry matter allocation to the bolls. Final calibration and validation are required. It is anticipated that portions of the data collected by Drs Sadras and Wilson in their study of the effect of mites on the physiology of cotton will be useful in calibrating these relationships.

4. *Develop subroutines for the uptake and distribution of nitrogen within the cotton plant.*

   A significant development has been the inclusion of CERES-type subroutines for plant nitrogen dynamics into the model code. They form a critical component of and exert a major influence on crop development. They allow the model to respond dynamically to nitrogen supply, introducing the capacity to consider tactical nitrogen issues. They also form the interface for connection to the soil nitrogen sub-model. These subroutines were originally constructed for determinate crops and required significant development to make them applicable to cotton. Progress on this objective was hampered by a lack of suitable data available at ACRI or in the literature, so these subroutines still require calibration and validation. Of particular significance is the lack of information on the change in the upper and lower limits of nitrogen concentration in the various plant parts over time; nitrogen concentration decreases as plants increase in size. The trends in these limits have been obtained from a compilation of previously published data. This has allowed improved estimates of critical nitrogen levels in developing fruit and to some extent in vegetative tissues. However, while this approach has proved satisfactory for other crops, the concurrent vegetative and reproductive growth that occurs in cotton means that the decline in nitrogen concentration in the vegetative parts (important for photosynthesis) due to their own growth is difficult to separate from the effects of competition for nitrogen from the growing bolls. A field experiment was conducted on nitrogen uptake and distribution within the plant. Completion of the calibration and validation of the subroutines, together with a further experiment on nitrogen distribution within the plant has been included as part of a subsequent project.

5. *Collect and incorporate developmental parameters, known to influence fruiting dynamics in cotton, for a range of new cultivars.*

The development of yield varies among cotton cultivars. The inclusion in the cotton crop model of parameters to account for cultivar differences in fruiting dynamics aims to allow a degree of cultivar sensitivity in the simulation output. To maintain the model's relevance to current cultivars and to test the importance of variation in developmental parameters for the accuracy of simulation output, the development and yield of eight cultivars was studied in two field experiments. The experiments were conducted in the 1990/91 and 1991/92 seasons and each incorporated a number of times of sowing (3,5). The developmental traits measured were the time to first square, square period, boll period and the squaring rate up to the time of rapid boll growth (after this, competition from boll growth may start to reduce the rate of square production). No differences were detected between cultivars for any of the traits in the first experiment. However in the second experiment, significant differences between cultivars were detected in square period, boll period, and squaring rate.

An important outcome of this study was that the parameters used to characterise development were not stable between the different times of sowing or between the experiments. This has implications both for the stability of model output for different environmental conditions and for the simulation of differences in performance between cultivars. Additional investigation of this data is currently under way. The initial indication is that an improved method of accounting for the effects of environment on development could be derived.

Alongside the field study, a sensitivity analysis of the model was performed to assess the importance of the observed variation in the developmental parameters for the simulated yield and time to 60% bolls open (5,7). This was done by varying the value for the parameters in the model, one at a time, over the range observed in the trials. The model was then run, using 31 years of historical weather data, for a Siokra-type crop sown at Myall Vale on October 10 with 150 kg ha$^{-1}$ of nitrogen. The model was run for both irrigated and dry land crops.

Simulated yield for irrigated crops was relatively insensitive to the developmental parameters. However, for dry land crops, simulated yields responded strongly to the duration of the phases of fruit development. Increasing the square period reduced the average yield while a longer boll period increased it. Over the range of values observed in the field trials, both square period and boll period caused variations in simulated yield in the order of 30%. The trends agreed with correlations between average yields for the cultivars in the 1991-92 experiment and observed values for these parameters.

Simulated time to 60% boll open also responded to square period and boll period; slower development delayed the crop in both cases. The range of square periods observed in the field trials gave an 11.5 day range in time to 60% boll open. Under irrigated conditions, a response was also seen to variation in the squaring constant, which governs the squaring rate. A higher squaring rate lead to an earlier crop. The range of squaring constants observed in the field trials gave a 10.5 day range in the simulated time to 60% boll open. The direction of the simulated trends are consistent with published experimental data.

The results of the sensitivity analysis show that the response of the model to changes in developmental traits known to influence fruiting dynamics in cotton is qualitatively appropriate. The magnitude of the response in the simulation output to the variation in the traits observed in the field trial emphasise the importance of obtaining stable parameters to characterise these traits. Having achieved this, the degree of variation between cultivars will be reassessed and the implications for precision of simulation output again evaluated.

## Dissemination and Application of Results

The results of the experimental work on varietal performance have been published in the proceedings of The Sixth Australian Cotton Conference (2,3). The simulation study on the decline of soil organic matter under current cotton cropping systems was presented at the 'Cotton 2001' workshop in March 1993. It is also intended to present these results in *The Australian Cottongrower.*

A number of research projects are currently using OZCOT and anticipate moving to CERCOT when it becomes available. The new model will offer more robust simulation of nitrogen/water interactions, the capacity to handle detailed nitrogen issues, both at the tactical level and for long term simulations and growth functions more appropriate for use in considering the physiological response of the crop to damage. In addition, CERCOT will replace OZCOT in extension and management applications through being linked to the entomoLOGIC database and may also replace OZCOT in the APSIM simulation shell developed by the APSRU group (CSIRO / Queensland Dept. of Primary Industry) in Toowoomba. Of particular relevance to these applications is the capacity to consider tactical nitrogen management issues and the more robust simulation of nitrogen/water interactions.

## Recommendations for Future Research

In light of the requirement of other projects to use the model, the calibration and validation of the recent modifications is an urgent priority. As indicated earlier, this has been included as a component of a subsequent project.

The derivation of stable parameters to describe the development and fruiting dynamics of cotton cultivars is required. Additional analysis of the data is under way to explore how this can be achieved. Developmental parameters will need to be obtained for new cultivars as they are released to keep the model current.

Ongoing work will be required to keep the model abreast of current research and to incorporate new findings; for example the incorporation of findings on the effect of mite damage and the physiology of compensation to fruit loss.

The inclusion of a capacity to account for environmental effects on fibre quality would increase the power of the model in both tactical and strategic applications through its capacity to reflect economic returns rather than yield alone.

## Publications from this Project

1. Godwin,D.C., Wells,A.T., Hearn,A.B. (1992). Modelling nitrogen dynamics in cotton cropping systems. The Sixth Australian Cotton Conference, Broadbeach, Qld, Australia, 103-109.

2. Kruizinga,J. and Wells,A.T. (1992). Varietal response to irrigation and nitrogen. The Sixth Australian Cotton Conference, Broadbeach, Qld, Australia, 99-102

3. Wells,A.T. (1992). Cotton variety yield performance over a range of planting dates. The Sixth Australian Cotton Conference, Broadbeach, Qld, Australia, 159-162.

4. Wells,A.T. (1992). What use is a cotton crop simulation model? Conference on Engineering in Agriculture, Albury, NSW, Australia, 249-252.

5. Wells,A.T. (1994). Estimating parameters for the OZCOT cotton crop model for a range of cotton cultivars by field measurement. Master of Engineering Thesis, School of Engineering, University of Southern Queensland.

6. Wells,A.T. and Hearn,A.B. (1992). OZCOT: A cotton crop simulation model for management. *Mathematics and Computers in Agriculture,* **33**: 433-438.

7. Wells,A.T. and Milroy,S.P. (1994). Varietal differences in cotton development: Implications for crop modelling. The Seventh Australian Cotton Conference, Broadbeach, Qld, Australia, 431-437.

## Detailed Report

Most of the results of this project have already been reported in conference proceedings, papers and a thesis. In lieu of a detailed report, the publications arising from the project are attached.

# Modelling Nitrogen Dynamics in Cotton Cropping Systems

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## Introduction

Nitrogen management plays a key role in cotton production. It is the nutrient required in greatest quantity by the crop and it is the nutrient most often deficient. Despite a large investment in fertilizer N in cotton cropping systems, the efficiency with which it is used by the crop can often be very low. This efficiency can vary greatly from season to season, between different forms of management and between cotton cropping systems. Much of this variation can be attributed to variations in the amount of N lost from the cotton cropping system.

The N that is not recovered by the crop may be lost to the atmosphere through volatilization of ammonia or as the gaseous products of denitrification. It may also be lost from the rooting zone via the leaching of nitrates and it can be made unavailable to the plant through immobilization in the soil. In dryland cropping systems it may also become inaccessible to the plant through lack of water. The relative importance of each of these various transformations which affect the use of N is influenced by climatic, soil and crop management practices. The many transformation pathways and the number of factors affecting each makes N one of the most complex plant nutrients to study. The difficulty of quantifying these factors and their interactions makes the task of prescribing fertilizer rates and management practices a difficult task. The N which is lost from the cropping system is of considerable concern. Some of the N lost via denitrification is an atmospheric pollutant and a significant contributor to the greenhouse effect and ozone depletion. Some of the N lost via leaching can pollute groundwater and N lost from the surface of soils, either directly from the fertilizer or with soil loss can be a significant source of stream pollution. In some regions of the world these negative aspects of N fertilizer use have precipitated legislation aimed at restricting levels of fertilizer application.

## Simulation Models

Computer simulation models that predict the effects of weather, soil properties, and crop management on nutrient dynamics and crop growth processes can contribute to our understanding of fertilizer management in cropping systems. Such models, with the capability of readily simulating various crop and fertilizer management strategies, should lead to an improvement in the efficacy of fertilizer decision making. Optimizing fertilization strategies, given the uncertainties of climate, is generally difficult and can become more difficult when issues of soil trafficability and compaction associated with the passage of heavy machinery are considered.

A comprehensive simulation model of the cotton crop incorporating procedures to describe the growth and development aspects of the crop and the balance of water and nitrogen in the soil is needed to address these issues of fertilizer management. The OZCOT model (Hearn 1990; Wells and Hearn 1992) developed at the CSIRO Cotton Research Unit is a model which simulates the daily growth and development of cotton fruit, leaves and stems. The model incorporates a soil water balance procedure enabling the simulation of the effect of water deficits on growth, development and the components of yield. The model is driven by daily weather data and is thus sensitive to prevailing temperatures, rainfall conditions and solar radiation inputs. The simulations produced by this model provide the basic crop data for decision support packages used in pest management and irrigation scheduling.

In cereal cropping systems the CERES (Ritchie 1991) family of simulation models have been widely used to address several issues of fertilizer management. The CERES models simulate water balance, growth and development of the crop as well as the balance and transformations of nitrogen in the soil. The models have been widely tested (Otter-Nacke et al. 1985) and have proved reliable in a diversity of cropping systems. Work is currently in progress at the CSIRO Cotton Research Unit to combine the water and nitrogen simulation routines of CERES to the crop growth, development and yield components of the OZCOT simulation model.

## Description of the CERES nitrogen simulation model

A technical description of the nitrogen component of the model may be found in Godwin and Jones (1991) and thus only an overview is presented here.

The nitrogen component of the CERES model describes the breakdown of crop residues and root material and the associated mineralization or immobilization of nitrogen. The mineralization of the soil organic matter or "humus" is also simulated. The pools and pathways considered in the model are depicted in Figure 1. The model can simulate losses of nitrate through leaching and through the process of denitrification and it also simulates the conversion of ammonium to nitrate (nitrification). Ammonia volatilization is depicted in Figure 1 with a dotted line to indicate that this process is not explicitly described in the model. Under most circumstances in cotton cultivation fertilizer is placed below the soil surface and significant N losses through this process are not likely to occur. Exceptions to this can occur if broadcast or water run applications of urea or anhydrous ammonia are made. Ammonia volatilization is included in a special version of the model for rice cropping systems where ammonia loss from the floodwater can form a substantial portion of the nitrogen lost from the system.

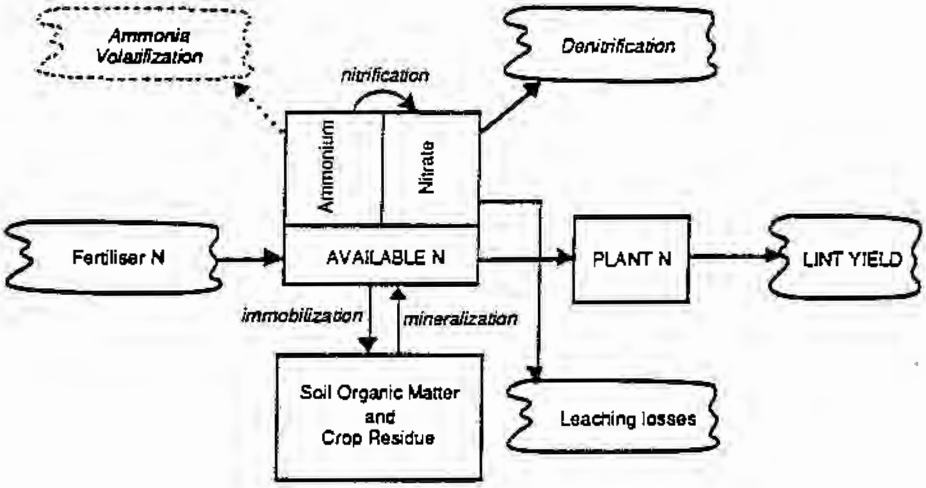

**Figure 1:** Systems diagram of nitrogen in the cotton cropping system.

The model is sensitive to the type of fertilizer used and to the placement of fertilizer. It addition to the inputs required by the crop and water balance parts of the model the N component requires data on the amount of mineral N in the profile at the start of simulation, the concentration of soil organic carbon, soil pH, and an estimate of the amount and type of crop residue present. The fertilizer data required by the model are the date, type of fertilizer, placement depth and amount for each fertilizer application. The model maintains pools of nitrate, ammonium and urea in each soil layer. When fertilizer applications are made, the fertilizer nitrogen is partitioned into these pools according to the type and depth of placement.

## Testing of the Model

Considerable testing of the nitrogen components of the CERES model has been reported elsewhere (Otter-Nacke et al. 1985), and this has shown the model to be quite reliable over a diverse range of data sets. To date only limited testing has been performed under cotton. A priori there is no reason to suspect differences in simulation of soil nitrogen and nitrogen losses between cereal and cotton cropping systems.

As part of the ongoing work on testing and development of the model, it was run against a field experiment at Myall Vale conducted by Freney and Humphries (unpub). In this experiment 60 kg of N per ha as $^{15}$N labelled urea was placed under ridges in each of March June and September 1988. Periodic observations of $^{15}$N were made after placement. The simulated time course of mineral N and the corresponding observations in the top 30 cm of soil in this experiment are depicted in Figure 2. Here the spike following fertilizer application can be seen and the subsequent run-down in mineral N as N is lost from the system and as some movement from the upper part of the profile occurs. The model is simulating these conditions effectively

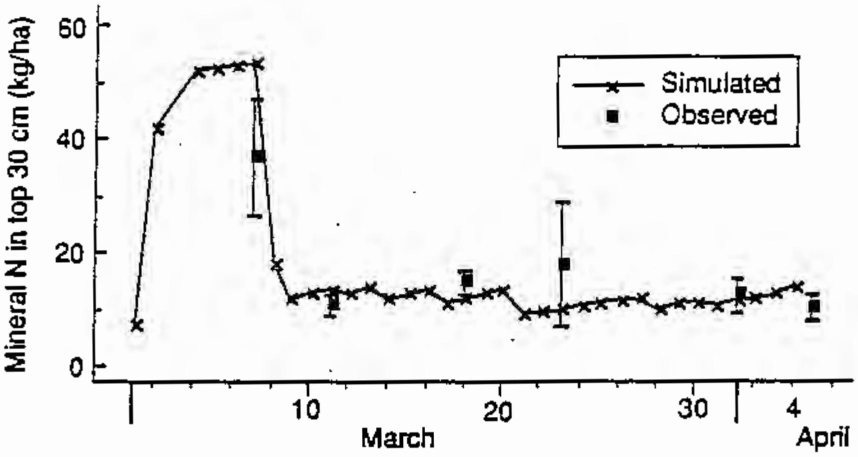

**Figure 2:** Comparison of simulated and observed mineral nitrogen levels in the top 30 cm of soil after a March nitrogen application.

## Applications of the Model in N Management

It is envisaged the model could be used for the following:

- evaluation of the risks of losses attached to early applications of fertilizer;
- examination of the probability of response to split applications;
- determination of the magnitude and frequency of N losses;
- evaluation of fertilizer management options.

When the work on coupling the soil N model to the plant routines of OZCOT is complete the model will be used to examine the consequences of differing fertilizer management strategies on crop growth and performance. Broader applications of the complete model in risk studies on dryland cotton, irrigation management and agronomic and environmental studies are envisaged.

## N Risk Study

The N model at this stage of development is suitable for examination of the fate of N in fallows as shown by the testing described above. A study to examine the risks associated with early applications of N fertilizer has been conducted. The aim of this study was to find out how often large losses of N from early pre-plant applications of fertilizer occur. In this study soil physical and chemical data representative of a typical Namoi cotton soil were used. Simulations were run examining the fate of applications of fertilizer made in each month from January to September. In each case 100 kg of N as urea was applied at a depth of 10 cm. The simulations were run with weather data for each of the 16 years from 1976 to 1990. In each year of simulation the same initial soil conditions were deemed to exist on January 1. Cumulative losses to the end of September were compared. Losses in most years were primarily due to denitrification although some leaching did occur. Losses were in general greatest from the January applications. Losses varied greatly from year to year and from the January application varied from 8 to 70 kg N/ha. The range of these losses and the mean loss is indicated in Figure 3. In this Figure the upper bound indicates that N losses would be less than this amount in 80% of years. Losses in excess of 48 kg N /ha can be expected less frequently than 1 year in five. The lower bound indicates that losses would be less than 14 kg N/ha in 20% of years. In 60% of years losses are between this two bounds.

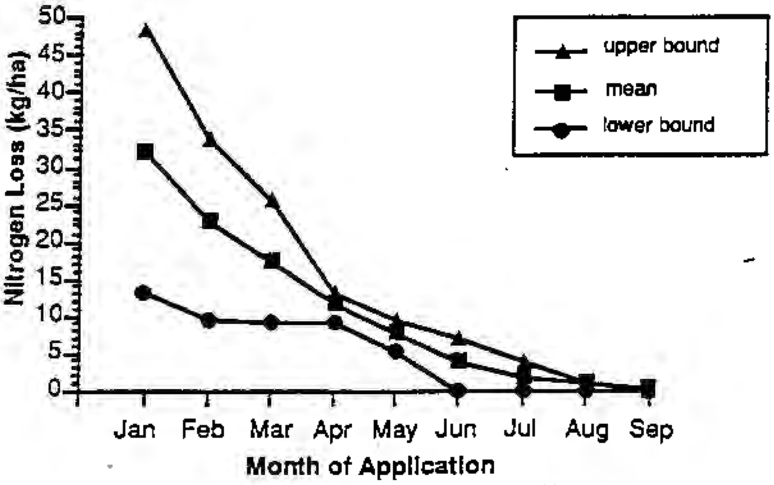

**Figure 3:** Simulated effect of time of nitrogen application on the likelhood of nitrogen loss.

From a practical point of view the Figure indicates there is considerable risk associated with a January pre-plant application of N and the chances of substantial losses of N from applications made after June are small.

## Further Work

Work is continuing on the merger of the CERES and OZCOT models. Additional procedures are required in this model to accommodate such practices as water run fertilizer and to overcome some small anomalies associated with N movement in the ridge and furrow system. Simulation of water movement and the associated movement of N in cracking clay soils has long been a problem with all models. An examination of alternative approaches is underway. The status of N in the tissues of a cotton plant is an important determinant of crop growth and formation of yield. Procedures for simulating the response of plant N to soil N and the corresponding response of the plant to a changing N regime are undergoing development. These procedures will be fundamental to achieving a reliable prediction of cotton crop response to nitrogen.

## Summary

The CERES simulation model described here can reliably describe the fate of nitrogen in cotton fallows. When this model has been successfully merged with the OZCOT cotton model, detailed studies of N dynamics under cotton crops can proceed. Simulation modelling of N dynamics in cotton cropping systems has the potential to become an important adjunct to field experimentation. Because simulation modelling has the ability to rapidly evaluate a range of crop management alternatives it will have an important role in decision support systems of the future.

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## Varietal Response to Irrigation and Nitrogen

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### Introduction

An experiment was conducted at Narrabri Agricultural Research Station during the 1991-92 season to investigate the response of a range of currently available cotton varieties to irrigation and nitrogen treatments. This experiment, along with the date of planting experiments described by Tony Wells elsewhere in the conference proceedings, forms part of a long-term program to study the agronomic requirements of new cotton varieties. These experiments also provide data for development of crop simulation models including the Hydrologic program.

This paper describes the yield and fibre quality results from the experiment and discusses the implications for irrigation and fertiliser management of different varieties. Some recommendations also apply to dry land cotton production.

### Description of Experiment

The following varieties were used:

- CS 7S
- Siokra S324
- Deltapine 90
- Siokra 1-4
- CS 50
- Sicala V1
- 83203-183
- Siokra L23

All varieties are currently, or are soon likely to be, commercially available. Siokra L23 is a potential replacement for Siokra L22 and 83203-183 is a potential replacement for CS 189. Irrigation treatments of 90, 105 and 120 mm deficit and no irrigation were used; irrigation dates, as shown in Figure 1, were determined using the Hydrologic program. Nitrogen rates of 150, 75 and 0 Kg/ha were applied. The area was pre-irrigated on 1 October 1991 and planted on 10 October using a cone seeder. The previous crop was grain sorghum; pest and weed control were standard; and the soil was a grey cracking clay.

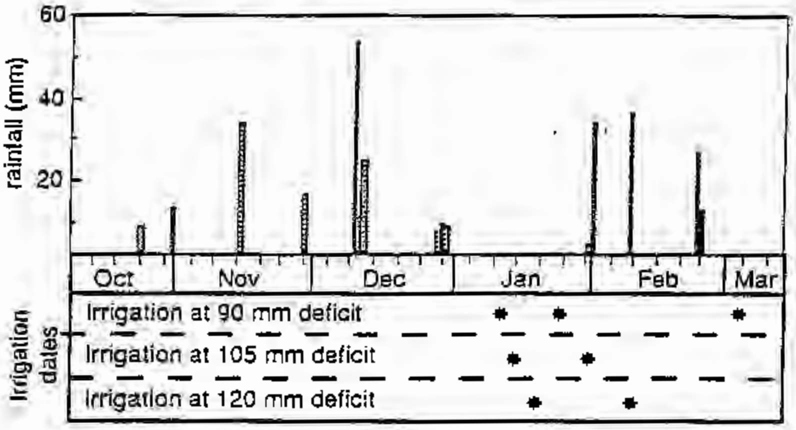

**Figure 1:** Dates of irrigation for different irrigation treatments and rainfall during irrigation period.

Variety responses to irrigation

As Figure 2 shows all varieties responded in a similar way to water stress. That is, there was no interaction between variety and irrigation treatment; so the highest yielding variety (Siokra L23) for fully irrigated production was also the highest yielding for dry land conditions. This finding is in agreement with results from the breeders experiments. The effect of irrigation on yield over all varieties and nitrogen rates was highly significant between rain and 120 mm deficit and between 120 mm and 105 mm deficit but not between 105 mm and 90 mm deficit.

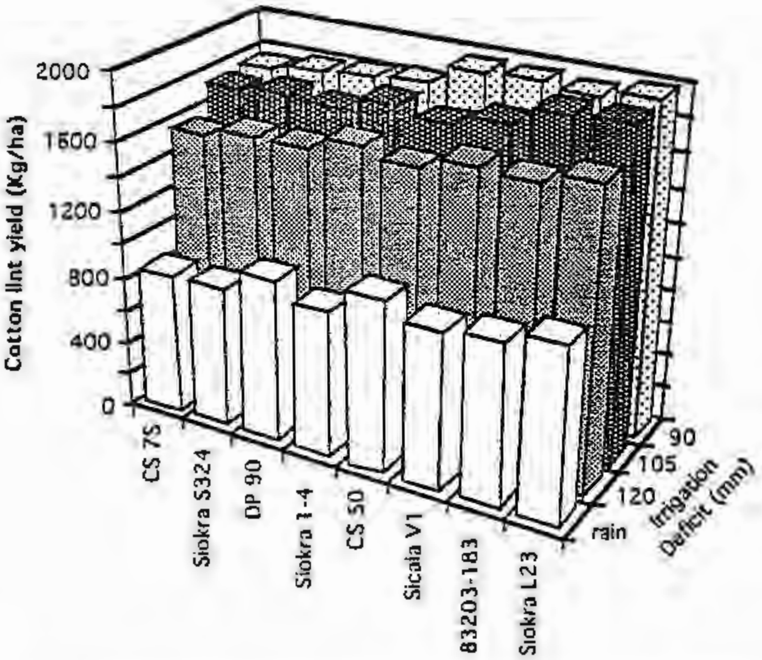

Figure 2: The yield response of eight cotton varieties to four irrigation treatments. The yields are averages of three nitrogen rates.

## Variety responses to nitrogen

It is clear from Figure 3 that yield was highly sensitive to nitrogen supply but the ordering of the varieties from highest to lowest yield does not change for different nitrogen rates.

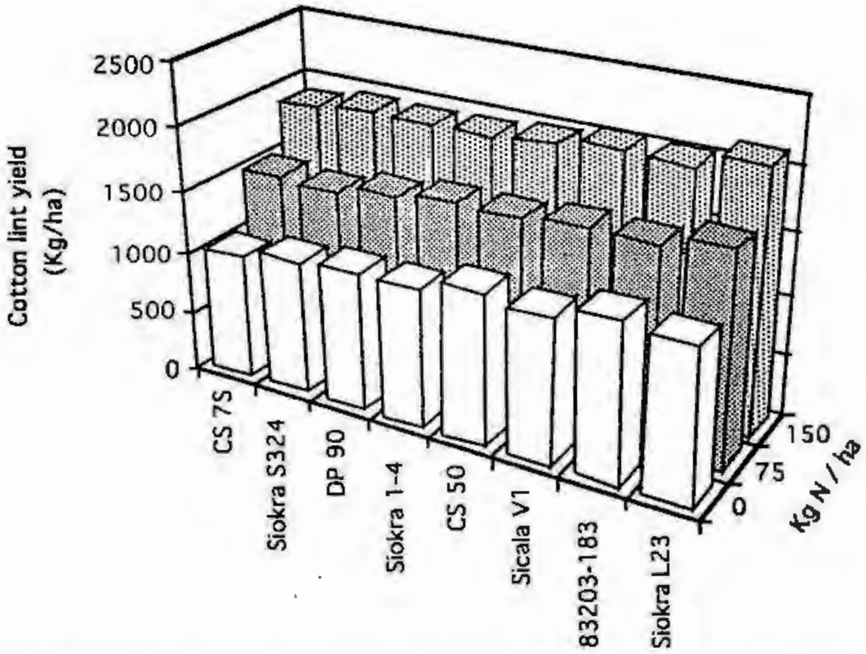

**Figure 3:** The yield response of eight cotton varieties to three nitrogen rates. The yields are averages of four irrigation treatments.

## Combined irrigation and nitrogen effects

Figure 4 shows that for the irrigated treatments higher yields would have been obtained with higher nitrogen applications in this instance following grain sorghum.

The most striking feature of Figure 4 is the lack of yield increase per nitrogen rate under rain grown conditions. The rain grown treatment did not utilise nitrogen above 75 kg/ha. nitrogen applied above this rate was wasted. This result confirms the results of work done on other varieties.

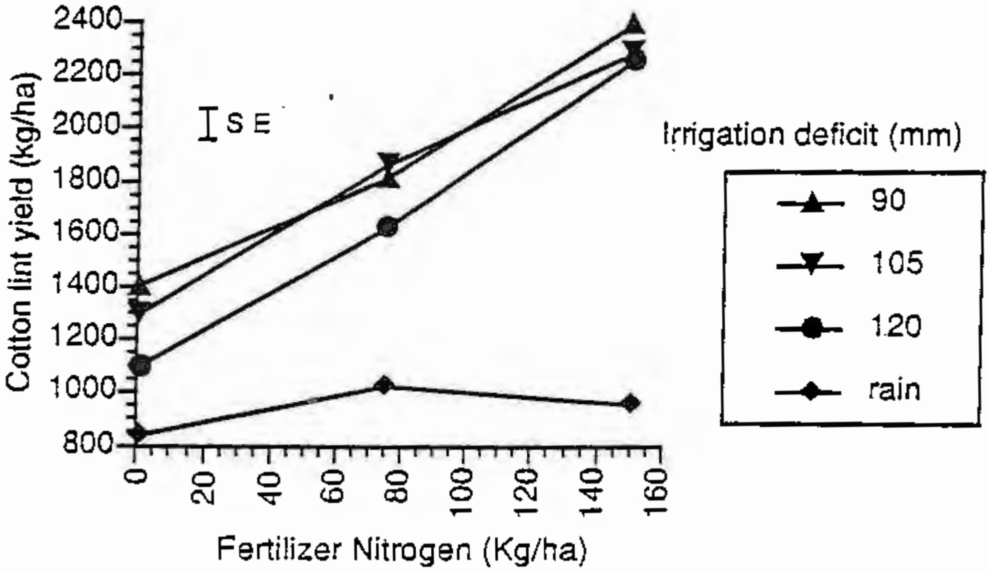

**Figure 4:** The average yield response for all varieties to four irrigation and three nitrogen treatments.

## Fibre quality

Fibre length was slightly reduced by shortage of nitrogen except with Sicala V1 which remained constant. Length was also reduced by water stress particularly in Siokra L23, DP90 and 83203-183. Less affected were varieties CS 7S and CS50. The experiment showed that strength was more influenced by nitrogen treatment than by irrigation. Sicala V1 showed no change in fibre strength under different nitrogen rates. Uniformity went down with nitrogen supply for DP90 and Siokra L23. All other varieties were less affected. Micronaire, in this experiment, showed a decrease with lower nitrogen and increase with less water.

## Conclusions

Although all varieties were influenced by either water or nitrogen stress or by both, there was no variety that was particularly better under stress conditions. The potential replacement for Siokra L22 (L23) confirmed its promise from other experiments by being the highest yielder.

# COTTON VARIETY YIELD PERFORMANCE OVER A RANGE OF PLANTING DATES

Tony Wells, CSIRO Cotton Research Unit, Narrabri

## Introduction

During the 1990-91 and 1991-92 seasons planting date experiments were carried out at Narrabri Agricultural Research Station using a range of cotton varieties. These experiments form part of an on-going program to investigate the agronomic performance of new cotton genotypes and they also provide data for the development of crop simulation models.

This paper presents the yield results from these experiments and draws conclusions about the most appropriate varieties for planting in various parts of the season.

## The Experiments

Eight varieties and five sowing periods were used in both the 1990-91 and 1991-92 seasons as shown in Table 1. The varieties chosen were either industry standards (i.e. Siokra 1-4 and Deltapine 90) or were newly released commercial varieties for the 1990-91 season. The same genotypes were used in both years.

The experiments were fully irrigated and fertilised with 150 kg nitrogen per hectare. Pest and weed control were standard. The previous crops were wheat for the 1990-91 experiment and sorghum for the 1991-92 experiment.

**Table 1:** Cotton varieties and planting periods used in two experiments at the Narrabri Agricultural Research Station.

| Varieties | Planting Dates | |
|---|---|---|
| Siokra 1-4<br>Siokra S324<br>Siokra L22<br>Sicala 33<br>Sicala V1<br>CS 189<br>CS 6S<br>DP 90 | Mid to late Sept. | 24 Sep 1990<br>24 Sep 1991 |
| | Early to mid Oct. | 15 Oct 1990<br>15 Oct 1991 |
| | Late Oct. to early Nov. | 26 Oct 1990<br>6 Nov 1991 |
| | Mid to Late Nov. | 14 Nov 1990<br>28 Nov 1991 |
| | Early to Mid Dec. | 4 Dec 1990<br>20 Dec 1991 |

### Planting Date Effects on Yield

Figure 1 shows the lint yields attained from various planting dates averaged over all varieties for the 1990-91 and 1991-92 seasons. The dramatic decline in yield for December plantings is particularly marked but a small reduction is also evident for the first planting in the 1990-91 season. The generally higher yield levels in 1990-91 are probably due to higher initial soil Nitrogen following wheat and fallow than following sorghum.

There are two major reasons that later plantings yield less than earlier plantings: first, later plantings have a shorter time in which to produce and develop bolls; and second, later plantings can grow rankly so that the plant diverts more energy into vegetative growth and then expends even more energy to maintain this extra mass. Another factor which influenced the results shown in Figure 1, however, was a heavy infestation of mites late in the 1990-91 season which affected the last planting more than the others.

The slightly reduced yield of the first planting in 1990-91 is more difficult to explain. This planting experienced more cold nights and thrip damage than the others and only reached first square a few days before the second planting, but at that point it was still ahead of the later plantings. There must have been a lasting effect from the early unfavourable conditions to cause the yield loss. It seems that the low temperatures caused permanent damage constraining future development. The first planting in the 1991-92 season experienced no low temperatures but was mildly damaged by thrips.

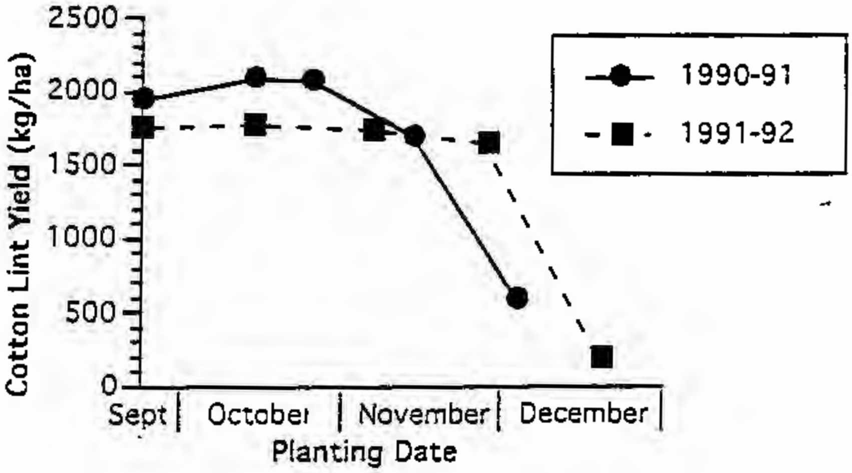

**Figure 1:** Average yields for 8 cotton varieties for a range of planting dates in the 1990-91 and 1991-92 seasons at Narrabri Agricultural Research Station.

## Variety Performance

Figure 2 shows yields averaged over the two experiments for each combination of variety and planting period. Once again the poor yields from December plantings at Narrabri are clearly evident but there is also considerable variation in the performance of the varieties at different planting periods. The following analysis concentrates on the results of the September and mid to late November plantings.

The varieties can be grouped into three categories from their yield responses:

- varieties that maintain high yields from early to late plantings;
  Siokra 1-4 and Siokra S324;
- varieties that do well early but poorly at later plantings;
  Sicala 33, Deltapine 90 and Siokra L22;
- varieties that suffer mild yield declines at either end;
  CS 6S, Sicala V1 and CS 189.

Siokra 1-4 also fits into the third category because it yields lower at either end of the planting window than in the middle, but its overall yield level is so high that the lower end yields are still above those of most other varieties.

Table 2 summarises the late planting response of the varieties. It shows that both Siokra 1-4 and Siokra S324 produced high yields during more typical planting times and were able to maintain them even when planted in mid to late November. In contrast, Deltapine 90 yielded less overall and yield declined more for the mid to late November planting than for any other variety. Sicala V1, CS 6S and CS 189 produced smaller average yields than Deltapine 90 for the first three plantings due mainly to their poor performance at the September planting, but they were able to maintain quite good yields for the mid to late November planting.

**Table 2:** Yield of the fourth planting expressed as a percentage of the average yield of the first three plantings.

| Variety | Av. yield of 1st three plantings (kg/ha) | Yield of 4th planting (%) |
|---|---|---|
| Siokra 1-4 | 2053 | 87 |
| Siokra S324 | 1982 | 96 |
| Siokra L22 | 1987 | 87 |
| Sicala 33 | 1919 | 83 |
| Deltapine 90 | 1826 | 79 |
| CS 6S | 1798 | 90 |
| Sicala V1 | 1782 | 95 |
| CS 189 | 1732 | 90 |

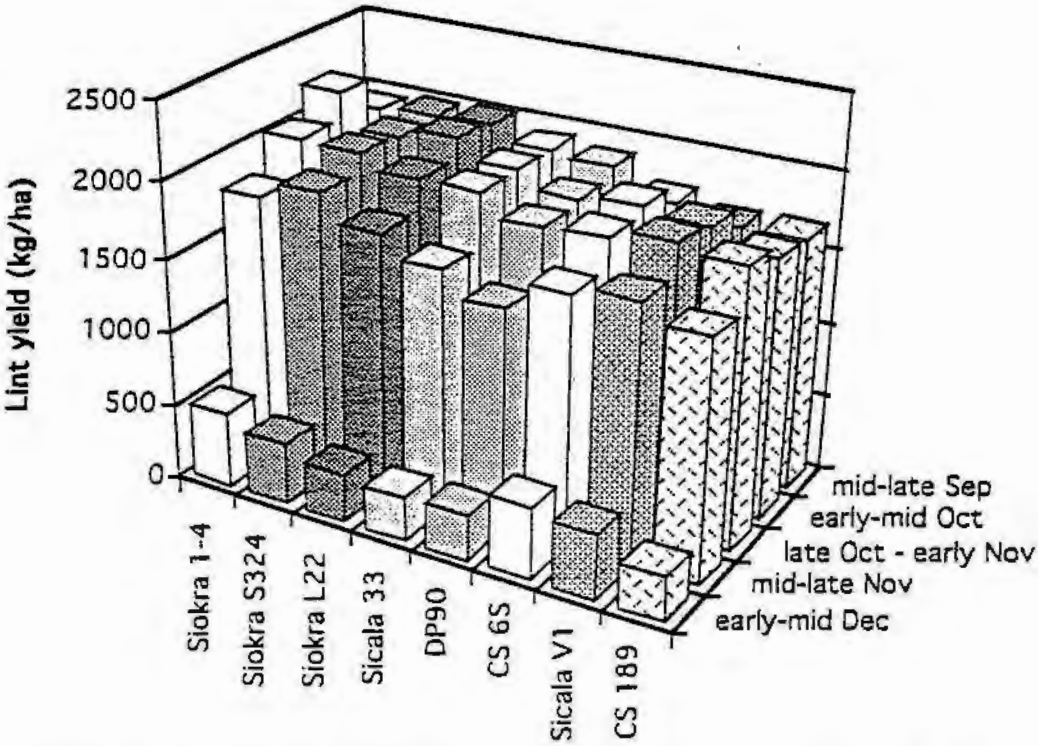

**Figure 2:** Lint yield from eight cotton varieties planted at five periods. The data are pooled from experiments carried out in the 1990-91 and 1991-92 seasons.

## Conclusions

The results of these two date of planting experiments show that December plantings, for irrigated production in the lower Namoi Valley at least, are not usually worthwhile. The experiments have also demonstrated that there are real differences in the ability of cotton varieties to yield well at the extremes of the commercial planting window. While some varieties did poorly at one or both extremes Siokra 1-4 and Siokra S324 yielded well at all plantings from mid September to late November.

It must be remembered that these results are dependent on the weather experienced during the last two seasons in the Namoi Valley, particularly the temperature regime. However, the findings show that Siokra 1-4 or Siokra S324 were the best bet for both early and late plantings.

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(4)

# What Use is a Cotton Crop Simulation Model?

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**SUMMARY:** The relevance of computer simulation of cotton cropping systems for achieving a sustainable Australian cotton industry is examined. The OZCOT and CERCOT cotton crop models are presented. Model structure is briefly described and the types of applications best suited to crop models are discussed. The past, present and potential future applications of the models are considered.

## 1. INTRODUCTION

In light of the theme of this conference: "Quality Soils, Quality Food, Quality Environment", I wish to make a case for the usefulness and relevance of a cotton crop simulation model developed by the CSIRO Cotton Research Unit in Narrabri NSW.

The modelling effort began in the early 1980's when a method was needed to predict the production and survival of cotton fruit so more informed pest management decisions could be made. A simple computer simulation model of cotton fruiting dynamics was developed which became part of the SIRATAC pest management system (1) . The fruit model was later linked to soil water, leaf area growth and nitrogen uptake models in order to broaden its application to other management decisions. This more complete crop model, named OZCOT, has since formed the back-bone of the crop modelling work done at the Unit and has been successfully applied to many problems. More recently a major redevelopment of the model has begun to add simulation of soil and plant nitrogen dynamics at a detailed mechanistic level. The linkage of the new nitrogen modules has demanded more functionality from the soil water and crop models. Soil nitrogen and water models were adapted from the CERES suite of crop models (2) as they simulate crop growth processes at a similar level to OZCOT and have been widely used and validated. This enhanced version of OZCOT has become known as CERCOT, however, references to OZCOT in this paper will apply to both the original and enhanced versions unless otherwise specified.

The case for OZCOT will begin with a brief description of its structure followed by some consideration of its accuracy in simulating real crops and the type of situations were it can be applied effectively; then, the performance of the model to-date will be examined, and; finally, the many opportunities for future applications will be considered.

The final report of the Ecologically Sustainable Development Working Group on Agriculture (3) has recognised that to "... maintain, or preferably enhance, the quality and integrity of the environment ... continuing economic viability is vital". The group point out that "a farmer whose enterprise is profitable is in the best position to introduce improvements", while, "a farm sector which ignores ecological and environmental issues will not be sustainable in the long term" . On this advice I will present the model as a tool for both production and environmental purposes because they are equally important for achieving a good quality environment.

## 2. DESCRIPTION OF MODEL STRUCTURE

OZCOT is a deterministic simulation model developed for crop management. It is driven by daily weather data and is sensitive to various soil properties and farm management practices. The model has become more detailed as it has been applied to a progressively wider range of management problems but is no more complex than it need be to answer those questions. It does not purport to be a complete physiological description of the cotton crop. The fruiting model is very simple but has proved highly versatile in capturing the essential features of the dynamics of cotton fruiting (4), (5). The linking of the most recent nitrogen models has required the incorporation of a carbon partitioning scheme to the crop model so that dry-matter and nitrogen concentrations of the various plant parts can be calculated. The Ritchie soil water alance model (2) currently being used is a layered model which simulates water movement between layers and into the roots of the crop. It calculates infiltration and runoff using the USDA Curve Number method but a newer version using a "time to ponding" approach (6) should be considerably more robust. The soil nitrogen model simulates the dynamics of nitrogen transformations and movement in the soil profile and the plant nitrogen model provides a powerful mechanism for controlling plant growth (2), (7).

## 3. MODEL VALIDATION

A crop model is only useful if it can show acceptable agreement with real systems. OZCOT has undergone considerable validation in irrigated situations. The model was initially calibrated using data in the SIRATAC database (4) which was compiled from cotton farms using the SIRATAC system over a wide geographical range of the cotton industry. More recently the model has undergone two separate validation efforts. One of these tested the model on approximately 20 fields on commercial cotton farms in NSW. The behaviour of the fruiting and soil water modules were both tested and performed well except were significant problems with pests or soil structure were present. The other validation used yield data from agronomic experiments conducted over 17 years at the research station at Narrabri; the model was able to account for more than 70% of the variability in the yields (8). The enhancements incorporated in CERCOT are still to be fully validated. This is more complex than it was with OZCOT because there are many more interacting parts to test.

## 4. HOW SHOULD CROP MODELS BE USED

OZCOT has shown good overall agreement with yield data from the above mentioned 17 years of experiments. The data span a wide range associated with different agronomic treatments and different weather conditions. However, if the yield data is restricted to a small part of the range the correlation between actual and simulated becomes poor. This indicates that the model responds appropriately to the major factors affecting yield but does not take all factors into account or the experimental error associated with the data so that there is some variability it cannot account for. This same effect was noticed when the model was tested against individual commercial crops affected by serious pest or soil problems. Consequently, if a simulation is done of a crop in one location and one season, close agreement with actual data may not be obtained.

These considerations have extremely important implications for the way we use crop simulation models. While there are time and labour advantages in using models to help make tactical decisions for a single crop, models are really no match for direct measurement methods. For strategic applications and for developing policies to apply to whole regions, however, there is no substitute for a well calibrated simulation model.

## 5. HOW OZCOT HAS BEEN USED

### 5.1. SIRATAC

The SIRATAC pest management system incorporates the fruit model from OZCOT with insect development and feeding models and a set of rules for making a spray recommendation. SIRATAC offers cotton growers access to the mainframe computer at the Narrabri Agricultural Research Station via modem so they can interact with the system. The growers input information concerning crop stage and development and pest abundance and receive a spray recommendation based on the results of the simulation models and the rules which apply to the situation. The system only recommends a spray when insect damage is predicted to exceed an economic threshold and if a spray is recommended it suggests the most environmentally friendly chemical for the given situation.

When SIRATAC was first introduced it has been estimated that the number of pesticide applications applied by those using the system fell by 40% or 3-4 sprays per season. However, the whole industry seemed to follow this downward trend and eventually the difference between users and non-users became, on average, 2 sprays per season (1).

### 5.2. Irrigation Management

In some regions the cotton industry experiences chronic irrigation water shortages. As cotton yields are highly sensitive to water stress, optimising the application of limited water to minimise stress has been an important area of research. Many field trials have been conducted to assess various irrigation strategies and the results from these have been generalised and extended by using OZCOT. It is impossible to carry out experiments to test every possible irrigation strategy in every region and on every soil type, but a well validated simulation model that is sensitive to the necessary parameters can be used to extend the application of experimental insights enormously.

OZCOT has also been packaged into a micro-computer decision support program called *hydro*LOGIC which is aimed at individual field irrigation management. It allows an almost unlimited capacity for "what-if" explorations with alternative water management scenarios. Using this package cotton growers can develop their own strategies for dealing with irrigation water shortages.

### 5.3. Climatic Risk

Closely related to the irrigation management issue above is the climatic risk involved in growing cotton. Fully irrigated cotton is largely immune to the effects of short term drought (until the reservoir empties) but when irrigation water is scarce or a dry-land crop is being grown the risks are high. These risks result from cotton being mostly grown in areas of low and highly variable rainfall. OZCOT has been used to quantify these risks in many regions by simulating long periods with actual or synthetic meteorological data (8), (9). OZCOT has also been used to investigate the potential benefit for cotton growers of using the Southern Oscillation Index as a predictor of future rainfall conditions.

Knowing the risks involved is important for any enterprise. If a dry-land cotton grower knows that his crop,on average, will fail due to lack of rainfall in two years out of five, then he may be able to adjust his investment so that the profits from the good years will outway the losses from the dry years.

## 6. HOW OZCOT MIGHT BE USED

There are many exciting prospects for using OZCOT in new applications. Many of the problems that OZCOT has been applied to, such as optimal irrigation management, have been largely solved. More challenging production and sustainability issues remain which will, in many cases, require the more comprehensive simulation of cotton cropping systems that CERCOT provides over the original OZCOT model.

### 6.1. Insect Management

Our cotton model is beginning to retrace its steps. Pest management was the driving force behind the original development of OZCOT and now pest management is again one of the most pressing issues for modelling.

It is uncertain whether higher yielding cotton varieties have a lower tolerance for pest damage. SIRATAC currently says that high yielding crops continue to compensate for pest damage but experimental evidence suggests otherwise (10). CERCOT, with its explicit carbon balance and more complete set of feed-back controls, should be better able to model the behaviour of high yielding crops.

Strong social and political pressures are being exerted to find alternative methods of pest control in the cotton industry and a broad integrated pest management approach is being adopted. A cotton crop simulation model could become a central tool for testing and sifting through the spectrum of pest management alternatives for a particular suite of pests in a particular location.

### 6.2. Nitrogen Management

The simulation of nitrogen and organic matter dynamics in cotton cropping systems is a major component of the CERCOT enhancement. It will allow the investigation of a wide range of nitrogen based issues such as:

(1) loss of applied nitrogen through denitrification;
(2) leaching of nitrogen below the root zone and possibly into ground water;
(3) long term effects of cotton cropping on soil organic matter levels, and;
(4) interaction between nitrogen nutrition and pest damage.

### 6.3. Water Management

Recent blue-green algae blooms in the Darling River have highlighted the impact that modern agriculture can have on the environment. Irrigation water could become more expensive or otherwise restricted to irrigators in an attempt to free water for environmental uses. In this case the need to use water more efficiently will become critical and a whole-farm simulation model which incorporated the cotton crop model would be valuable for assessing alternative irrigation designs.

### 6.4. Soil Degradation

The soil water balance and root growth models incorporated in CERCOT are sufficiently mechanistic to simulate the effects of soil compaction on cotton production. Models are also available describing the effect of tillage and other agricultural operations on soil structure. Combining these models would produce a valuable tool for assessing the long term implications of different soil management strategies for agricultural production.

### 6.5 Crop Rotations

There is a need to incorporate OZCOT into a farming system model containing a suite of crop models so that a sequence of crop rotations can be simulated. Such a model would be useful, not only, for estimating the long term effects of mixed farming enterprises but for including the rotation crops commonly used by dedicated irrigated cotton growers. This amalgamation of models may begin in the near future in collaboration with crop researchers in Queensland.

### 6.6. Regional Modelling

Using OZCOT within a Geographic Information System which contains the necessary soil and climate data could be used to investigate areas suitable for cotton production. Besides the possibly of expanding the area of cotton production, it would also ensure that new areas for development were more likely to have sufficient land capability for the intensive cropping systems.

### 6.7. Cotton Breeding Programs

OZCOT has previously been applied to determining optimal cotton ideotypes for particular climatic regions but it failed to respond appropriately when the genetic parameters with which the model was calibrated were varied. CERCOT, in contrast, is expected to be sufficiently robust and mechanistic to perform this task reliably. Not only should CERCOT be able to calculate the fittest ideotype for a given climate but also for a given climate/soil complex. Such work could be an extremely valuable guide for cotton breeders and genetic engineers in producing cultivars suited to specific agroecosystems.

## 7. CONCLUSIONS

A cotton crop simulation model appears to be a very useful tool for exploring paths to a sustainable cotton industry. Its usefulness, though, depends on its accuracy in modelling real systems and its being used in appropriate situations. The original OZCOT model is still performing valuable tasks for the cotton industry. In the future, as we struggle to find the balance required between development and environment, models like CERCOT, which can model the complex interactions between crops, the environment and management, will become more important. It seems that we are only beginning to appreciate the power and utility of computer simulation models.

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UNIVERSITY OF SOUTHERN QUEENSLAND

SCHOOL OF ENGINEERING

# Estimating parameters for the OZCOT cotton crop model for a range of cotton cultivars by field measurement.

A Thesis submitted by
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For the award of Master of Engineering

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# Abstract

The OZCOT cotton crop model and its predecessor, the cotton fruiting model used in the SIRATAC pest management system, have been of valuable service to the Australian cotton industry since the early 1980's. A stream of new cotton cultivars have recently been released by the CSIRO Division of Plant Industry which have been enthusiastically adopted by the industry and offer benefits of increased yield, improved fibre quality, disease resistance and different maturity times. To remain relevant to the cotton industry OZCOT must be able to simulate the performance of these cultivars. The characteristics of importance to the model are yield and maturity time.

The objective of this project was to estimate parameters used by OZCOT to describe the production and development of cotton fruit for a selection of the most important new cultivars. The parameters were estimated by conducting two field based planting date experiments and measuring fruiting dynamics via non destructive observation and recording with a system known as plant mapping.

A high degree of variability was found in the parameters, especially between experiments. Also, the OZCOT assumption that the development of fruit is driven solely by temperature was not supported by the results. However, the data did not allow for the identification of other factors that were controlling development. Some differences in parameter values were found between cultivars in experiment 2 that helped to explain maturity time characteristics of the cultivars.

Sensitivity analysis was performed on OZCOT to assess the relative importance of the measured parameters to the simulation of cotton lint yield. The parameters describing the development period from flower bud (square) appearance to flowering (square period) and from flowering to maturity (boll period) were found to exert considerable influence on average yields, particularly under dryland conditions. This result might warrant further investigation as a breeding strategy for dryland cotton cultivars.

# 5. Summary and Conclusions

## 5.1. Summary of results

### 5.1.1. Experimental Results

The Siokra cultivars (Siokra 1-4, Siokra L22 and Siokra S324) produced the highest cotton lint yields in both experiments. The yield of Siokra 1-4 planted on 15 October 1990 was exceptionally high at 2,319 kg ha$^{-1}$. The short season cultivars Siokra S324 and CS 6S did well at later plantings but so did Siokra 1-4 and Sicala V1 although they are not known as good later season performers.

Mean DDISQ was essentially equal between the experiments. There was no consistent cultivar effect on DDISQ although cultivars were consistent in node of first fruiting branch (NFB). CS 6S had the lowest average NFB (7.6) and Siokra 1-4 and Siokra S324 the highest (8.4). Siokra S324 does not seem to rely on setting fruit early to effect early maturity. When the influence of NFB was removed from the DDISQ data by using NFB as a co-variate there was still a large effect of planting date. Heat stress was proposed to partly explain the planting date effect.

Square period results were very different between experiments (expt 1: 416 DD12, expt 2: 290 DD12). A hypothesis was proposed that cotton plants respond to minimal water stress by extending square period which delays setting a boll load. It was also proposed that the soil of experiment 1 held water at a higher matric potential for a given water content thus reducing the effective water stress experienced by the plant. Planting date effects dominated the results, cultivar effects were small. No differences were found between cultivars in experiment 1. Siokra L22 had the shortest square period in experiment 2 (279 DD12) and CS 189 and Deltapine 90 the longest (298 DD12).

Boll period was also longer in experiment 1 (913.6 DD12) than experiment 2 (743.1 DD12). Significant differences between cultivars were only found in experiment 2, where the effect of cultivar explained 6 % of the variability in boll period. Siokra S324 was the shortest and Sicala V1 the longest. A short boll period seems to be an important earliness component for Siokra S324 but not for CS 6S.

Mean SQCON was not significantly different between the experiments. Squaring rate declined with later planting which was explained in terms of a decline in the thermal efficiency of plant growth. Significant differences between cultivars were found in experiment 2. Siokra S324 and CS 6S had the highest squaring rate (another earliness mechanism) and Deltapine 90 had the lowest squaring rate which agreed with general observations of this cultivar.

The emerging picture from the two experiments is that environmental factors were stifling the genotypic expression of the fruiting parameters in experiment 1. The possibility that a significant genotype x environment interaction controls the measured parameters is not a desirable outcome for crop modelling as it might mean that the model needs to be calibrated for each new environment.

Temperature was clearly important in describing and defining the parameters but it was equally clear that other factors were also important. The large differences in square period and boll period between experiments could not be explained by temperature differences, and similarly within experiments, temperature effects explained no more than 60 % of the variance of the measurements.

### 5.1.2. Modelling Results

OZCOT performed quite poorly in predicting yields from the planting dates of experiments 1 and 2 ($r^2 = 37.7$ %). However, this is a common result where a model is fitted to only a few data points and the analysis takes no account of errors in the measured yields. OZCOT did simulate the general pattern of the decline in yield with increasingly late planting dates well.

The sensitivity analysis of OZCOT cotton lint yield simulation to the measured parameters revealed the following outcomes:

Average yield and yield variability were insensitive to DDISQ.

Average dryland yield was higher for shorter square periods with the increase being proportional to the decrease. Irrigated yields also increased as the square period declined from 416 to 350 DD12 (the current figure in OZCOT) and then levelled off for square periods below this. Yield variability decreased as the square period decreased under dryland conditions but there was no consistent effect under irrigated conditions.

Boll period affected yield in a similar way to square period. Dryland yields increased as boll period decreased across the full range tested. However, irrigated yields were insensitive. Yield variability decreased as boll period decreased for both irrigated and dryland conditions.

SQCON effects on average yield were subdued, with 30 % changes in the parameter causing 5 to 8 % changes in yield. Yields under irrigated conditions were generally highest near the middle of the range of squaring rate values tested, which is close to the present parameter setting in OZCOT for Sicala and Deltapine 90. A trend for increasing dryland yield as squaring rate decreased was found but it was not completely consistent. The variability of yields was largely unaffected by squaring rate changes.

## 5.2. Summary of experimental techniques

### 5.2.1. Plant Mapping

In general, plant mapping was difficult but very rewarding. It was difficult because it required considerable time and concentration to inspect each fruiting branch of a cotton plant even though only the mainstem fruiting branches were mapped. In addition, for some planting dates, it was difficult to find enough plants that had an intact mainstem growing point. It was rewarding because it afforded enormous insight into the complex behaviour of the cotton plant.

The use of the method of Constable (1991) for judging the time of appearance of a square by the degree of unfolding of the subtending leaf was extremely helpful. It allowed less variable and more reproducible measurements to be made and speeded the plant mapping process a great deal. It would also be a useful technique for general fruit counts.

Plant mapping was more efficient and reliable than flower tagging for measuring boll period. The efficiency depended on whether plant mapping was being used to measure square period so that the mapping of flowers was serving two purposes. The reliability was due to the plant mapping techniques simplicity in comparison to flower tagging. The essence of this simplicity is that plant mapping has less moving parts.

Marking standard nodes on the mapped plants was an important technique for speeding up the mapping process. Not having to count nodes from the, often obscure, base of the plant each time the plant was inspected saved a great deal of time.

### 5.2.2. SQCON measurement

This was the first time the squaring rate constant used in the OZCOT fruit model was measured. It had previously been estimated by model optimisation against yield data. The technique was simple and easy to perform as it only required counting fruiting sites twice. It provided results that were reproducible between the experiments and was able to detect differences between cultivars.

## 5.3. Conclusions

The project has measured the OZCOT fruit model parameters: DDISQ, square period, boll period and SQCON for eight commercial cotton cultivars. The results, as outlined above, will provide parameter estimates for the new CSIRO cultivars that will help OZCOT to simulate the differences in their performance. However, the results have raised more questions than they have answered. The large differences in square period and boll period between the experiments require an explanation that this study cannot supply. Also the differences in the effect of cultivar on the measurements between experiments needs further investigation.

The assumption that the development of fruit is driven by temperature alone has not been supported by the results of this study. It is clear that temperature is important but the use of thermal time and various functions of average temperature do not tell the whole story. Unfortunately a better solution was not found in this study.

The outcome of the sensitivity analyses has provided a focus on the relative importance of each of the parameters by investigating their effect on the most important measure of system performance: cotton lint yield. It has identified that square period and boll period have an unexpectedly large impact on yield, especially under dryland conditions. It has shown that DDISQ has little impact on yield, at least under commercial conditions in the mid Namoi Valley. It has demonstrated that SQCON is more important under irrigated conditions than under dryland conditions. Further investigations of these effects may lead to new breeding programs that can 'design' cultivars suited to different climatic and soil conditions and different management systems.

(6)

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# OZCOT: A Cotton Crop Simulation Model for Management

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## 1. BACKGROUND

The cotton industry in Australia has grown from a planting of 31,600 hectares in 1970-71 to 274,200 hectares in 1990-91. The export earnings from the 1990-91 season were in excess of $1 billion. The present cotton producing areas extend from central NSW to central Queensland. The CSIRO Cotton Research Unit at Narrabri NSW is involved in breeding new cotton varieties, pest management and ecology, agronomic techniques and the development of decision support systems for cotton growers and consultants.

OZCOT is a deterministic simulation model of the cotton crop developed for crop management by the CSIRO Cotton Research Unit over a period of more than 10 years. It is driven by weather data and is sensitive to various soil properties and farm management practices. It began as a very simple model to help make better insect control decisions and has become more detailed as it has been applied to a progressively wider range of management problems. Thus, the development of OZCOT has been driven by management issues; additions to the model have been made only in response to practical needs. As a result, the model is no more complex than it need be to answer management questions. It does not purport to be a complete physiological description of the crop.

Cotton is an indeterminate plant: the mainstem never terminates in an inflorescence but continues to grow vegetatively while conditions remain favourable. After fruiting starts, the plant simultaneously grows vegetative material, initiates flower buds and matures existing fruit. The plant can continue to flower for many months. Reproductive growth eventually competes with vegetative growth for limited resources, which governs further development. This behaviour stands in contrast to that of cereal crops where vegetative growth continues until a sudden switch to reproductive growth occurs. Capturing the dynamics of cotton fruiting provides an interesting challenge for crop modellers.

OZCOT was originally designed for tactical use within a season and was subsequently developed for strategic management applications. For tactical use the model allows actual data, as it becomes available through a season, to update model estimates. Thus model predictions are fine tuned as the season progresses.

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## 2. MODEL DEVELOPMENT

OZCOT began as a simple yet robust cotton fruiting model but has grown to consider other crop growth processes and has been coupled to soil water and nitrogen sub-models.

The early development of the model was driven by a need of the SIRATAC computerised cotton pest management system [1]. SIRATAC needed to know how cotton fruiting would respond to pest attack in order to make sound recommendations. The initial OZCOT fruit model could simulate fruit generation and shedding and introduced the concept of a fruit "carrying capacity", which implicitly represented the photosynthetic potential of the crop [2].

The need to evaluate fruiting behaviour in response to water and nitrogen shortages led to linking the fruit model to the Ritchie soil-water balance model [3] and a simple nitrogen uptake model. These linkages required enhancements to the cotton model: firstly, a leaf area growth model was developed; and secondly, the inclusion of water and nitrogen response functions for various growth processes. In addition, crop carrying capacity was explicitly linked to crop photosynthesis.

OZCOT, at this stage of development, was able to simulate cotton response to water and general nitrogen availability, but the nitrogen uptake model was too simple to be used for any detailed nitrogen related problems. Furthermore, OZCOT was used to define crop ideotypes by evaluation of optimum genetically controlled parameters, such as fruit production rate and fruit size, for particular environments. This use was a very demanding test for a crop model and revealed parts of the model that needed strengthening. It was apparent that the model lacked sufficient feedback mechanisms to respond appropriately.

OZCOT is, therefore, currently being further enhanced. Detailed models of nitrogen dynamics in plant and soil, based on the existing CERES models [4,5], are being added and these require an updated Ritchie soil-water balance [5] and the addition of a carbon partitioning model. We expect carbon partitioning also to strengthen the feedback control of growth processes. The crop model will then be able to investigate a much broader range of problems.

## 3. FRUITING MODEL STRUCTURE

### 3.1 Fruit Production and Shedding

The basic pattern of cotton growth and development is highly systematic [6]. A cotton plant mainstem will begin to form fruiting branches between the 5th and 8th node. Thereafter a fruiting branch will form at every mainstem node. One flower bud is produced at each node (fruiting site) along a fruiting branch. New nodes are produced up the mainstem every 2 or 3 days and each fruiting branch produces a flower bud every 5 to 7 days, depending on temperature. This growth pattern leads to a quadratic rate of increase in the number of flower buds with time. The rate of supply of carbohydrates needed for this development also increases initially as leaf area expands and the crop intercepts more solar radiation. However, once complete leaf cover is reached, the rate of supply of carbohydrates is essentially constant and demand will eventually exceed supply. The plant reacts to the resulting competition by reducing the rate of flower bud production and causing existing buds and young fruit to shed. Fruit site production can be described by

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

where S = number of fruiting sites; T = thermal time (day degrees at base 12°C); r = site rate constant; B = fruit load (fruit / $m^2$); C =carrying capacity (fruit / $m^2$).The fruit load, B, is equal to the number of fruiting sites, S, that still carry an immature fruit. After fruiting starts both S and B will increase with time, resulting in equation (1) behaving in a logistic manner. The production rate will be low at first when S is small but will increase quickly as the first term of the equation provides positive feedback. The rate will begin to decline, as the second term representing the negative feedback effect of fruit load begins to dominate, and will become zero when the fruit load equals the carrying capacity.

The constant r is dependent on variety. A variety with a high r will set fruit quickly and finish early. This is an advantage in areas of high early frost risk. Conversely, a variety with a low r will develop less quickly but can take advantage of areas with a longer growing season. Carrying capacity, and therefore fruit load, is limited largely by crop photosynthesis but is also affected by water and nitrogen supply.

Fruit and flower bud shedding is also a function of fruit load and carrying capacity. Each day of simulation a proportion of the current days production of flower buds and young fruit are marked for shedding. Equation (2) describes the relationship

$$L_t = 1 - a\left(1 - \frac{B}{C}\right) \tag{2}$$

where $L_t$ = proportion of fruit produced on day t to be shed; t = day of simulation; a = shedding constant; B and C are as defined above. However, the fruit and buds are not actually shed until seven days after they have been marked because the abscision process takes time. The second term on the right hand side of the equation defines fruit survival. As the boll load approaches carrying capacity, fruit survival approaches 0 and shedding approaches 1. The shedding constant, a, equals 0.8 so that even with no boll load 20% of new flower buds and young fruit will shed. This represents the background shedding rate attributed to low level physiological stress and pest damage.

If, at some stage in the life of the crop, the fruit load, B, is significantly reduced, by insect attack for example, equation (1) shows that the rate of flower bud production will increase rapidly because B is reduced while S remains unaffected. From equation (2) it can also be seen that a reduction of B will reduce fruit shedding, allowing more of the new flower buds to survive. This behaviour allows cotton to cope with a degree of insect attack and allows it grow in difficult environments. Thus these two simple equations enable the model to capture the essential features the dynamics of cotton fruiting .

### 3.2 Fruit Development

The fruiting model assumes the rate of fruit development is a linear function of the accumulated average daily temperature in excess of 12°C experienced by each days cohort of fruit. The average daily temperature in excess of 12°C is termed day degrees to the base 12 ($DD_{12}$). Development is assumed to be negligible below 12 °C. This linear model works very well over much of the temperature range normally experienced during the cotton growing season. Table 1 shows the $DD_{12}$ requirements for various stages of fruit development used by the OZCOT fruiting model. Fruit development rate is a function of temperature only. It is not affected by carbon, water or nitrogen shortage as are fruit production and shedding.

TABLE 1

Cotton fruiting stages, their thermal development requirements in day degrees to base 12°C ($DD_{12}$) and approximate dates of appearance.

| Stage | Accumulated $DD_{12}$ from sowing | Approximate Dates * |
|---|---|---|
| Sowing to first flower bud | 0-420 | 10 Oct - 25 Nov |
| First flower bud to first flower (1st fruit) | 420-770 | 25 Nov - 22 Dec |
| First flower to first open fruit | 770-1,520 | 22 Dec - 13 Feb |

* assuming an average $DD_{12}$ of 9 in the first period, 12 in the second and 14 in the last period; also assuming minimal shedding and a 10 October planting date.

## 4. APPLICATIONS

The fruiting model from OZCOT has been used for 10 seasons in the SIRATAC system [1]. SIRATAC is used by cotton growers at approximately twice weekly intervals through the cotton season. Fruit and insect counts are regularly made in the crop and entered as input into SIRATAC which then estimates the likely yield loss response of the crop to insect attack and makes a spray recommendation based on this information and rules concerning the use of various chemical groups.

OZCOT has been used to quantify the risk of crop failure associated with dry-land cotton production in various regions in Australia, and with irrigated production when water supply is limited [7,8]. For these applications the model was used to simulate a long sequence of seasons with historical meteorological data. The probability of achieving certain yield levels can then be assessed in the light of climatic variability. Various strategies for improving the probability distribution can be tested.

OZCOT has also been included in a micro-computer decision support package called "Hydrologic" designed for tactical cotton irrigation management within a season [9]. As with the fruit model in SIRATAC, the state of the model can be updated with actual data, such as fruit counts, and leaf area and soil-water measurements, as they become available. The user can evaluate the consequences of future water applications on cotton yield and the timing of maturity. The system is designed to facilitate "what if" explorations so that the user can investigate a range of options.

Future applications marked for OZCOT include: the assessment of areas suitable for cotton production using a geographic information system; the investigation of long term soil nitrogen and organic matter levels in cotton farming systems; and the evaluation of appropriate cotton ideotypes for particular climatic regions.

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# VARIETAL DIFFERENCES IN COTTON DEVELOPMENT: IMPLICATIONS FOR CROP MODELLING

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*Summary:* Simulations were run to test the sensitivity of OZCOT to varietal differences in developmental characteristics known to influence fruiting dynamics in cotton. Thirty one years of historical weather data fom Myall Vale were used. The results indicate that the model is responsive to varietal differences over the actual range measured in two field experiments; both in terms of yield and time to 60% bolls open. Simulated changes in time to 60% bolls open were consistent with experimental evidence. It is therefore necessary to allow for these differences as inputs to the model and to measure the developmental characteristics for new cultivars to keep the model relevant to current production practices.

## Introduction

In the OZCOT (Hearn 1994) and CERCOT cotton crop models developed by CSIRO at the Cotton Research Unit, allowance is made for varietal differences in boll size, lint percentage and some differences relating to the carbon balance of the crop. However it is known that cultivars also differ in developmental characteristics which govern their fruiting patterns. This in turn may alter their response to environmental stresses and insect damage. Of traits of this kind only the rate of square production is changed for the different varieties. In this paper we describe two field experiments designed to determine the natural variation between cultivars in four parameters used in the fruiting dynamics sub-model which is common to both the crop models: the time from sowing to first square, the time from appearance of an individual square to when it flowers (square period), the time from when a flower opens to when the boll opens (boll period), and the rate of square production. We then used the observed range for these parameters in simulations conducted using OZCOT to assess the sensitivity of the model to them (in terms of yield and time to 60% bolls open) as an indication of their usefulness in describing the growth of different cotton varieties.

## The Experiments

The field trials have been previously described (Wells 1992). Briefly, two time of sowing trials were conducted in 1990-91 and 1991-92 at the Narrabri Agricultural Research Station (NARS). Eight cultivars were sown at five times in each year. The cultivars used were Siokra 1-4, Siokra S324, Siokra L22, Sicala 33, Sicala V1, CS 189, CS 6S and Deltapine 90. The sowing dates ranged between 24 September and 4 December in 1990 and 24 September and 20 December in 1991. The experiments were fully irrigated and received 150kg $ha^{-1}$ of N. Standard pest and weed control were used.

The time from sowing to first square and square period were expressed in degree days using a base temperature of $12^oC$ ($DD_{12}$). Boll period is expressed was an exponential function of the average temperature during boll development:

$$\text{Boll period}=\exp(a+m^*T_{av}) \qquad (1)$$

where $T_{av}$ is the average temperature in $^oC$ and $a$ and $m$ are empirically derived parameters (Wanjura and Barker 1985, Constable 1991).

The squaring rate was characterised by the squaring constant: the square root of the rate of site production in thermal time (Hearn and Da Roza 1985). Squaring rate was measured in the period between first square and first open flower to avoid the reduction in squaring rate associated with increasing boll load (Ehlig and LeMert 1973).

## The Simulations

To assess the sensitivity of simulated yield and time to 60% bolls open to changes in the developmental parameters, the model was run for a Siokra-type cultivar sown on October 10 at NARS with 150kg of nitrogen added and either grown dryland or fully irrigated. Simulations were run for each of 31 years of weather data collected at the NARS. The developmental parameters were then changed, one at a time, to reflect the actual range of variation found in the experiments, and the model re-run on the historical weather data.

## Results and Discussion

Tables 1 to 4 present the average simulated yields and maturity times for the 31 years of historical weather data from NARS using the standard OZCOT parameters and using parameter values reflecting the range measured in the field experiments.

**Table 1:** Effect of the observed variation in the thermal time to first square on simulated lint yield (kg/ha) and time to 60% bolls open (days). OZCOT standard: 420 $DD_{12}$.

| | | Degree Days to First Square | | |
|---|---|---|---|---|
| | | 420 | 475 | 530 |
| Irrigated | Av. yield | 1686 | 1688 | 1731 |
| | % change | 0 | 0.12 | 2.7 |
| | Av. maturity | 176.0 | 183.0 | 187.3 |
| | % change | 0 | 4.0 | 6.4 |
| Dryland | Av. yield | 684 | 673 | 629 |
| | % change | 0 | -1.6 | -8.0 |
| | Av. maturity | 160.5 | 166.6 | 167.1 |
| | % change | 0 | 3.8 | 4.1 |

**Table 2:** Effect of the observed variation in the square period on simulated lint yield (kg/ha) and time to 60% bolls open (days). OZCOT standard: 350 $DD_{12}$.

| | | Square Period | | |
|---|---|---|---|---|
| | | 280 | 350 | 420 |
| Irrigated | Av. yield | 1791 | 1686 | 1656 |
| | % change | 6.2 | 0 | -1.8 |
| | Av. maturity | 170.5 | 176.0 | 182.1 |
| | % change | -3.1 | 0 | 3.5 |
| Dryland | Av. yield | 819 | 684 | 603 |
| | % change | 19.7 | 0 | -11.8 |
| | Av. maturity | 157.6 | 160.5 | 165.5 |
| | % change | -1.8 | 0 | 3.1 |

**Table 3:** Effect of the observed variation in the boll period parameters on simulated lint yield (kg/ha) and time to 60% bolls open (days). OZCOT standards: $a$=5.385, $m$=-0.0512. The duration of the boll period in days was calculated using equation 1 and $T_{av}$=25°C.

| | | Boll Period | | |
|---|---|---|---|---|
| | | $a = 5.128$<br>$m = -0.0433$<br>(57 d at 25°C) | $a = 5.385$<br>$m = -0.0512$ | $a = 5.196$<br>$m = -0.0433$<br>(61 d at 25°C) |
| Irrigated | Av. yield | 1714 | 1686 | 1721 |
| | % change | 1.7 | 0 | 2.1 |
| | Av. maturity | 171.1 | 176.0 | 176.6 |
| | % change | -2.8 | 0 | 0.34 |
| Dryland | Av. yield | 511 | 684 | 696 |
| | % change | -25.3 | 0 | 1.8 |
| | Av. maturity | 157.6 | 160.5 | 161.9 |
| | % change | -1.8 | 0 | 0.87 |

**Table 4:** Effect of the observed variation in the squaring constant on simulated lint yield (kg/ha) and time to 60% bolls open (days). OZCOT standard: Siokra=0.0228 $DD_{12}^{-1}$

| | | Squaring Constant | | |
|---|---|---|---|---|
| | | 0.018<br>(slower) | 0.0228 | 0.024<br>(faster) |
| Irrigated | Av. yield | 1627 | 1686 | 1721 |
| | % change | -3.5 | 0 | 2.1 |
| | Av. maturity | 182.4 | 176.0 | 171.9 |
| | % change | 3.6 | 0 | -2.3 |
| Dryland | Av. yield | 717 | 684 | 689 |
| | % change | 4.8 | 0 | 0.73 |
| | Av. maturity | 163.8 | 160.5 | 161.5 |
| | % change | 2.1 | 0 | 0.62 |

*Yield*

Under irrigation the model was relatively insensitive to changes in the developmental characteristics in terms of simulated yield. The largest changes were caused by altering the square period: a range of 8% relative to the yield using the standard square period. The squaring constant gave a 5.5% change in simulated yield. In contrast, under dryland conditions, yield was very sensitive to the duration of the phases of fruit development. Square period again had the largest impact resulting in a 31% variation in yield. However, compared with the irrigated case, boll period also had a big effect resulting in a 27% variation in yield.

*Maturity*

The simulated time to 60% bolls open was most effected by square period under both irrigated and dryland conditions; a shorter square period giving earlier maturity. Under irrigated conditions, the range of square periods as measured in the field generated an 11.5 day difference in time to 60% bolls open and under dryland conditions an 8 day difference. The observed variation in boll period parameters gave differences of 6 and 4 days in time to 60% bolls open for irrigated and dryland simulations respectively. This is consistent with the experimental findings of Gipson and Ray (1970) and Yfoulis and Fasoulas (1973).

Under irrigation, the squaring constant generated a 10.5 day difference in time to 60% bolls open with a higher squaring rate resulting in earlier maturity. It had little effect under dryland conditions. Higher squaring rates result in an earlier development of boll load. Boll load has been shown to be associated with reduced rates of flowering and decreased boll retention (Ehlig and LeMert 1973). Thus the simulated earlier maturity with higher squaring rate is consistent with expectation.

## Conclusions

The results of the simulation study indicate that the model is responsive to varietal differences in characters known to influence fruiting dynamics in cotton; both in terms of yield and maturity time. Simulated changes in time to 60% bolls open were consistent with experimental evidence. It is therefore necessary to allow for these differences as inputs to the model. It is worth noting that while this paper presents the effects of varying one parameter at a time, varieties may differ in a number. This is particularly the case when comparing early and late varieties as traits associated with earliness often vary together (G.A. Constable, pers. comm.). The traits considered in this study will be assessed for a number of new and potential cultivars to maintain the relevance of the models to current production systems.

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