Assessing the feasibility for cotton in tropical Australia: Progress with the development and testing of models for climatic assessment and resource planning

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ABSTRACT

Cotton is not grown commercially in tropical Australia; moreover most of tropical Australia has never been cleared for cropping of any species. In recent years there has been a significant interest in the expansion of irrigated crop production and cotton is being evaluated in some catchments. Most of the region is defined as semi-arid tropics and a review of available land and water resource data found the region has about 60% of Australia's surface water runoff, with significant ground water and arable soils. There are 66 catchments or drainage basins of which at least 24 could grow cotton based on a simplistic criteria of >5000 ha of arable soils and <1400 mm rainfall per year. CSIRO and others have developed simple approaches using modelling tools that can assess the climatic suitability for cotton using historic climatic records and soil data. Hence the main objective of the research described here was to validate these models in tropical Australia. We then used them to make an assessment of the suitability of catchments for cotton production in the dry (winter) season, which was identified as the most appropriate time for sustainable pest management. The OZCOT cotton crop simulation model was validated for yield, time to squaring, flowering and maturity predictions from time of sowing and nitrogen fertilizer rate experiments conducted at Kununurra WA during the 1995 to 1997 dry seasons. Lint yield was accurately predicted $r^2=0.78$, and $r^2=0.59$ (P<0.01) respectively for nitrogen and sowing time experiments respectively, however prediction of the time to first square was on average four days earlier than observed which translated in to similar earlier predictions of flowering and first open boll. Inadequacies in the ability of the OZCOT model to accumulate thermal time with high early season temperatures was identified as the reason for the differences. Time to crop maturity (60% open bolls) was poorly predicted by OZCOT and estimates of time to maturity and harvest were alternatively predicted using a locally derived response for thermal time accumulation. Using historic climatic data from 1957 to 1999, estimated potential yield and lint grade was used to assess the suitability of cotton in ten diverse locations across tropical Australia. This information was also used with a locally derived relationship between cumulative rainfall after maturity and lint colour grade to determine the optimum sowing window in these regions that would accommodate cotton production. Potential operational issues were also identified at some sites, e.g. the need for good traficability at Katherine Northern Territory to permit sowing between March 1 and April 15. However, based on the risk of frost, dry (winter) season production appears feasible in the north and west of the region while summer production is likely in the south and east. The needs for research to further define suitability of cotton production in the dry season are discussed. Two key areas were identified: improving the understanding the effects of high early season temperatures on crop phenology; and the impact of low night temperatures(>0 °C and <11 °C) during flowering which can affect fiber quality and development.

Introduction

There is currently no commercial cotton production in Australia north of 21°S latitude. The region is vast, approximately 30% of the Australian continent, and largely unutilized for cropping of any species. The climate for most of the region is defined as semi-arid tropics and contains about 66 drainage basins or river catchments; these account for around 60% of Australia's surface water runoff, with significant ground water and arable soils (NLWRA, 2001). Improvements in regional infrastructure, opportunities to expand trade in nearby Asia, and reduced access to irrigation water in existing irrigated production regions of Australia has stimulated the interest in exploring the potential of irrigated cropping in tropical Australia. Since 1990 there has been considerable increase in the value and area planted to crops in the region, with the greatest increases (100 to 360%) occurring in the western half (Yeates *et al.,* 2002). A simple criteria where areas with >5000 ha of arable soils and <1400 mm rainfall per year was used to refine those potentially suitable for cotton production (Yeates, 2001). From this assessment 24 of these catchments were identified. The main localities under investigation exist in the states of Queensland, Northern Territory (NT) and Western Australia (WA) (Figure 1). Kunnunurra in WA and Katherine in the NT have been the main areas in which field experimentation is being conducted.

A prerequisite consideration for cotton to be a candidate crop in tropical Australia was sustainable management strategies for *Helicoverpa amerigera*, the insect that devastated the crop when last grown in the region at Kununurra (Ord Valley) during the 1970's (Strickland *et al.,* 2003 these proceedings). Research undertaken since 1995 indicates that effective management of *Helicoverpa amerigera* is possible with minimal use of insecticides (Annells and Strickland, 2003 this volume). Importantly, a key component of this strategy is avoiding peak pest numbers by growing the crop in the dry (winter) season instead of the wet (summer) season, which was the practice in the 1970's (Strickland *et al.,* 1998).

Growing cotton in the dry season is characterized by the crop being exposed to high temperatures early and late in growth and cool temperatures mid-season during flowering and boll filling. This is the reverse of the wet season. Whether cotton can be effectively grown within the dry season in tropical Australia will depend on: (1) the duration of the wet season, which usually occurs between October and April (Figure 2); (2) regional temperature, as there is considerable variation in dry season temperatures between seasons and localities (Cook and Russell, 1983); (3) the effect of highly variable rainfall during the transitions from wet to dry and dry to wet (Mollah, 1986) on planting and picking operations (Figures 2 and 4) access to a reliable supply of irrigation water as flow in the majority of rivers and streams ceases during the dry season (Bauer, 1985).

Locally validated simulation models are powerful tools to evaluate potential growing regions and natural resource management issues. Used in conjunction with long-term climatic data they can be used to evaluate a range of different management scenarios. The OZCOT model, developed by CSIRO, can simulate cotton growth, development, yield and time-to maturity, in response to daily radiation, temperature, water and nitrogen inputs (Hearn, 1994). OZCOT has been used in existing cotton growing regions for decision support (Carberry and Bange, 1998) including optimisation of irrigation allocation (Hearn, 1995). In addition OZCOT has been validated at the Ord Valley for summer grown cotton during the 1960's and 70's (Hearn, 1994). Therefore OZCOT provides an excellent opportunity to generate information to help identify potential dry season production regions and determining likely irrigation water requirements. However, the model requires validation under dry season growing conditions using modern cultivars in tropical Australia.

OZCOT currently does not have the capacity to simulate the fiber quality characteristics specifically the effect of pre-picking weathering on color grade or the effect of night temperature on fiber length. Understanding the impact of these factors on fiber quality will be important in the overall assessment of cotton production in tropical Australia. The previous wet season cotton industry at Kununurra was beset by poor fiber quality (Hearn, 1975), which was associated with exposure to weather pre-picking (Basinski *et al.,* 1973). Quality problems have also been observed in dry season crops; fiber length is often reduced (Strickland *et al.,* 1998) presumably due to cool night temperatures (Gipson *et al.,* 1968), and grade can also be reduced because crops can mature during transition from dry to wet season. Rain or humidity at maturity has frequently caused colour grade discounts in four of the last six seasons of pest management research at Kununurra (A. Annells, Ag WA, Kununurra, unpublished data). A recently developed relationship between rainfall and colour grade (Yeates, unpublished data) can now allow preliminary quantification of the effect of pre-harvest rainfall on likely discounts in fiber quality. This allows further quantification of climate suitability during the dry season for cotton production.

The main objective of this paper is to present ongoing research into validation and application of the OZCOT simulation model along with other simple approaches to make preliminary assessments of climatic suitability of different catchments for cotton production. Assessment of suitability was gauged in terms of optimizing sowing date for yield and minimizing discounts associated with lint color grade for cotton grown in the dry season. This analysis was used to prioritize catchments for inclusion of cotton in future catchment scale impact assessments. Future research to improve simulation capabilities of OZCOT is also discussed.

Experimental procedure

OZCOT validation

The OZCOT model was validated from two types of replicated experiments conducted at Kununurra over three years from 1995 to 1997 (Yeates *et al., 1996*, Yeates unpublished data). The first was three separate sowing time experiments conducted in each year, which compared four sowing dates (late march, late April, mid May and early June), with two varieties (Siokra L23 and Sicot 50). In total 24 treatments were simulated. The second was three nitrogen rate experiments conducted in each year, which compared five rates of nitrogen fertilizer (0, 75, 150, 225, 300 kg N/ha), a total of 15 treatments simulated. For all experiments relevant climatic data was collected within 500 m of the field, established plant population, starting soil NO_3 to 1.3 m, and date and duration of furrow irrigation applications were also recorded. Measurements were lint yield, and lint turnout, and the dates when first square, first flower, first open boll, 60% open bolls and harvest maturity occurred. The experiments were grown on a Cununurra clay (Parberry *et al.,* 1969), which is common to the valley, the plant available soil water for the 0 to 130 cm profile is 205 mm. The average lint turnouts observed in this analysis were 40 and 41% for Siokra L23 and Sicot 50 compared with 43% used in OZCOT. This difference could be due climatic effects on partitioning or due to ginning methods as the observed turnouts were measured from a semi commercial scale gin while the model turnouts were based on averages taken from plant breeding trials in existing cotton crops in southern Australia that were ginned by a large scale laboratory gin. New variety parameter files were created using the observed turnouts for each variety and used in model validation for lint yield.

Quality analysis

Color grade was predicted using a simple relationship between colour grade and cumulative rainfall after maturity developed at Kununurra (Yeates, unpublished). A modification of the standard colour grading system was used to simplify statistical analysis, where the grade was given a numerical value, i.e. 3.1 = 31 and trash was not included as plants were hand picked. Simplified colour grade was linearly correlated with cumulative rainfall up to 60mm, when grade reached about 61 (Strict Good Ordinary), after which there was little change in grade up exposure to a total of 275 mm. For cumulative rainfall = 60 mm, simplified colour grade = 0.5278*cumulative rainfall after maturity +27.602, r^2=0.69, n=66.

Assessment of regional potential

Assessment of catchment suitability was gauged in terms of optimizing sowing date for yield and minimizing discounts associated with lint color grade for cotton grown in the dry season using OZCOT and the quality relationship described previously. In this analysis a suitability assessment was determined for ten sites in tropical Australia, which are shown as large dots in Figure 1. Initially the 10 sites were selected on the basis of: (1) an annual rainfall <1400 mm; (2) known access to water resources and >5000 ha of arable soil (Yeates, 2001); (3) a range of annual rainfalls, altitudes and distances from the coast that is typical for tropical Australia; and (4) sites where field research on cotton was currently being conducted. A Cununurra clay characterised at the Ord River Irrigation Area (Yeates, unpublished data) is used for all locations with a similar clay soil. Locations with sandy textured soils having a high hydraulic conductivity were characterized as Blain Sandy Loam (Williams *et al.,* 1985). Locations with red earth soils are characterized as the Tippera Clay Loam found at Katherine (Carberry *et al.,* 1996; Yeates and Imrie, 1993). At Mareeba, a Kraznozem soil characterized for maize at Kari is used (P. Poulton, CSIRO, Toowoomba, Qld, Australia, unpublished data). Yield and lint grade was simulated for fortnightly sowing dates from mid March to mid May at each location. Climatic data, except for Katherine and Kununurra (research stations), were obtained from the SILO database (Jeffrey *et al.,* 2001).

Sites having a significant risk of frost were identified using the Rainman® program (Clewett *et al*., 1999). Sites with an average of one day <2.2 °C and a lowest recorded monthly minima of <0.5 °C during any month were considered at risk. For these sites sowing dates were adjusted to avoid cotton growth during months were frost could occur. For sites not considered to have a frost risk a winter growing season was assumed, hence the frequency of sub-optimal night temperatures (<11 °C) during cotton growth was determined using the program SAS (SAS Institute 2001).

Results and Discussion

OZCOT validation

The predicted responses of OZCOT to changes in sowing date and nitrogen nutrition on lint yields averaged for each sowing date and nitrogen treatment over three seasons was accurate (Figure 3). When simulations of individual treatments were compared with observed there was highly significant linear regression ($P<0.01$) between observed and predicted values, r^2=0.78 and r^2=0.58 for the nitrogen and time of sowing experiments respectively. The sowing dates covered a two and a half month period and exposed the crops to a wide range of temperatures for each phase of growth (<10 °C to >38 °C). The nitrogen rates also assisted in identifying the optimum nitrogen fertilizer requirement in these soils (150 to 200 kg N ha^{-1}). The feasibility in using OZCOT to simulate production in other tropical regions appears justified. For both cultivars observed time to the temperature dependant stages first square, first flower and first open boll was later than predicted (Table 1). Although, the regression coefficients show that OZCOT accounted for a high proportion of the variation due to season and sowing date. Time to 60% open bolls, which is largely determined by fruiting dynamics and nutrient availability (Hearn, 1994), was predicted more accurately. However the regression coefficients showed that OZCOT was unable to account for the variation across the experiments. The earlier prediction on of time to first square was probably due to a greater heat unit accumulation needed to predict first square in the tropics compared with temperate Australia using the function by Constable and Shaw (1988) with a base temperature of 12 °C (DD_{12}). This function assumes no optimum rate of crop development at high temperatures. OZCOT uses this function and assumes a constant heat unit accumulation (DD_{12}) from sowing to first square (Hearn, 1994) and first square is predicted when 418 and 408 DD_{12} are reached for the varieties Siokra L23 and Sicot 50 respectively. In the time of sowing experiments the time when first square was measured translates into DD_{12} of 541 ± 42 and 535 ± 36 for the varieties Siokra L23 and Sicot 50 respectively. With the use of the DD_{12} function that does not account for high temperatures slowing the rate of development, and the occurrence of high supra-optimal temperatures early in growth are suspected to cause these differences. Work undertaken by Bange and Milroy (2003) also showed that the rate of time to first square slows when plants are grown in high temperatures and postulate that this is one reason for differences in predictions of development using the DD_{12} approach. Relative differences in predictions in time of first square carried over to first flower and first open boll, potentially highlighting that these stages were not poorly predicted. Future analyses with OZCOT will include locally derived variety parameters for heat unit accumulation to squaring and fruiting dynamics.

Fiber color grade

Using the relationship between color grade and cumulative rainfall after maturity the impact of rainfall on cotton grade can be quantified as an increase in 1 grade (10 using the simple grade) for every 15 mm of rainfall. Such an impact has significant implications for selecting growing regions and optimal picking dates in tropical Australia. Figure 2 shows that rainfall averages in Kununurra are >20 mm during October and in Tortilla >50 mm suggesting that color discounts could occur if cotton were maturing at these sites during October. However, analysis of monthly averages is too simplistic because, firstly, the median rainfall is less than the mean and secondly, the analysis of the half monthly rainfall pattern for October has shown that for the first 16 days the median rainfall is <15 mm at both locations, with most of the rain occurring in the last 15 days of the month (Yeates, 2001). A considerable area of cotton can be picked in 15 days.

Growing region comparison for optimal sowing date

The previous analysis found that OZCOT could accurately simulate the effect of sowing date on lint yield for dry season cotton, provided there was optimal nutrition, water and effective pest management. However, OZCOT did not accurately predict time-to-maturity (Table 1), which was needed to determine when the crop finished to establish impacts of rainfall on quality. Alternatively, maturity was estimated using a thermal time sum of 2200, which was the average from the time of sowing experiments. Table 2 shows the optimum sowing date for lint yield based on the median simulated by OZCOT and the latest sowing date where in 50% of seasons lint could be discolored and reduced by 1 or 2 grades due to fortnightly rainfall exceeding 15 or 30 mm. The latest optimal sowing date was defined by the highest simulated yield whist avoiding a median of 15 mm of rain for the fortnight after the crop matured (2200 DDS after sowing). Thus, the optimum sowing window is the period from the earliest to latest optimum sowing date for yield and quality. The comparison of the 10 locations also incorporates the likely rainfall during the optimum sowing window and the frequency of cold night temperatures as a result of sowing in this window (Table 2). Due to the risk of frost risk two sites were considered only suitable for summer production, although, there was not enough data to assess the impact that insect pests may have on summer crops at these locations. On the basis of Table 2, the 10 sites fall into the following broad categories:

- Winter (dry) season with a long optimal sowing window – Nita Downs, Coen, Roper Bar, rain is only likely to interrupt operations during March at the later 2 locations.
- Winter season with intermediate optimal sowing window – Kununurra and Katherine, with traficability during March important at both locations.
- Winter season with a short optimal planting window – Tortilla Flats.
- Summer season with intermediate optimal sowing window – Collinsville.
- Summer season with a short optimal planting window – Mareeba.
- Growing season could not be defined – Daly Waters and Fitzroy Crossing. Both sites expect a large number of minima between >0 °C and <11 °C. The effect of these minima on crop growth and yield is unclear and may not be adequately accounted for by OZCOT because there numbers are well in excess of the greatest number nights (14) observed within this temperature range in the validation experiments.

The above analysis can also be extended to characterize tropical Australia into four regions with respect to growing season length and yield for cotton production (Figure 4). First, regions where annual rainfall is greater than 1400 mm are likely to be too wet for viable cotton production; the analysis for Tortilla confirms this assumption (Table 2). Second, the region that parallels the coast but receives less than 1400 mm rain per annum appears suitable for winter (dry) season production. Third, due to frost risk the region to the south and east is best suited for summer season production, but subject to more data on insect pest species and their population dynamics. Fourth, the transition between the winter and summer growing regions where the growing season cannot be defined due to the unknown effect of >20 mid season minima of >0 °C and <11 °C; understanding the impact of such temperatures is a current research issue (Bange and Milroy, 2003).

Future analysis will evaluate the impact that cool nights could have on fiber length. A capacity to simulate fiber length and other important parameters strength and micronaire is being incorporated into OZCOT (G. A. Constable, CSIRO, Narrabri, Australia, personal communication). A boll cohort specific relationship between fiber length and daily minimum temperature for the first 20 days after flowering developed from the time of sowing experiment described above will be used to simulate fiber length in varieties sensitive to temperature (Yeates, unpublished data).

While the OZCOT model provides information at the paddock scale there is also a need to assess the impact of a new cotton industry in tropical Australia at the farm and catchment scale as most of the region is uncleared and there is little information on the cumulative effect of land clearing and dispersed (or concentrated) developments on sub-catchment health and regional water balances (Yeates *et al.,* 2002). This can best be achieved by the development and testing of models that can predict these catchment scale impacts and cropping systems models such as APSIM that permit simulation of production system scenarios involving a range of rotation crops (McCown *et al.*, 1996; Probert *et al.,* 1998).

Conclusions

The OZCOT model was successfully validated for simulation of lint yields of cotton in response to sowing dates from late March to mid June and nitrogen fertilizer application from 0 to 300 kg /ha when grown in the dry season at Kununurra (15.5 S) in tropical Australia. However, lint turnout required changing in the model code (lowered by 2 to 3 percentage points) for the varieties Siokra L23 and Sicot 50 under these growing conditions.

The following enhancements to OZCOT were identified: (1) improved accuracy of prediction of time to first squaring and crop maturity in this environment. The former appears related to supra optimal temperatures the later to different fruiting dynamics during the tropical dry season; (2) confirm that the model accounts for effects on growth and yield due to prolonged mid season minima between >0 °C and <11 °C.

This analysis identified future analysis using OZCOT, which includes validation and simulation of crop water user at the crop and farm level for later inclusion in catchment scale water balance modeling and validation of fiber length, strength and micronaire simulations as soon as the capacity to simulate these fiber properties is possible.

Combining OZCOT yield simulation with quality grade predictions based on a simple relation between cumulative rainfall between maturity and picking and lint color grade was shown to be a powerful analysis tool in determining optimum sowing window for new locations that have never grown cotton before.

Progress was made in determining the where in tropical Australia dry season cotton production is feasible based on temperature, yield, grade and rainfall pattern. Tropical Australia was classified into 4 broad regions: (1) likely to be suitable, (2) too wet, (3) too cold due to frost and (4) unknown due to a high frequency of sub-optimal night temperatures (>0 °C and <11 °C).

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Table 1. *The observed and predicted times (days) using OZCOT for reproductive growth stages and their respective regression coefficients for the two cultivars compared. Data is for monthly sowing dates March to June in the years 1995 to 1997 (n=48 for each cultivar).*

	Siokra L23			Sicot 50		
Growth stage from sowing	Observed	Predicted	r^2	Observed	Predicted	r^2
1st square	42	38	0.81	41	37	0.91
1st Flower	72	67	0.81	72	66	0.91
1st open boll	140	128	0.79	139	128	0.73
60% open bolls	152	149	0.44	152	149	0.24

Table 2. *Identification of optimal cotton sowing window for 10 sites in tropical Australia using climatic data 1957 to 1999 for each site. Included is median number of nights <11 °C and median rainfall for optimal sowing months.*

Location	Optimum sowing date for lint yield - simulated by OZCOT	Latest sowing date for < 15mm at maturity	Latest sowing date for < 30mm at maturity	Latest optimal sowing date – yield + grade	Median rainfall for latest and (earliest) optimal sowing month (mm)	Median mights < 11°C
Nita Downs	April – mid May	June 15	June 15	May 15	1 (0)	14
Coen	March – May	April 30	May 15	April 30	52	2
Roper Bar	March – early May	May 15	May 15	May 15	0 (121)	10
Kununurra	March – April	April 15	April 30	April 15	10 (105)	8
Katherine	March – April	April 15	April 15	April 15	9 (118)	17
Tortilla Flats	April – May	April 15	April 15	April 15	32	3
Daly Waters	March – April	May 15	May 15	April 30	8 (86)	26
Fitzroy Crossing	Late March – April	May 15	May 15	April 30	4 (56)	34
Collinsville	October – November	November 1	October 16	November 15	35 (13)	Frost
Mareeba	October-December	December 1	November 1	December 15	92	Frost

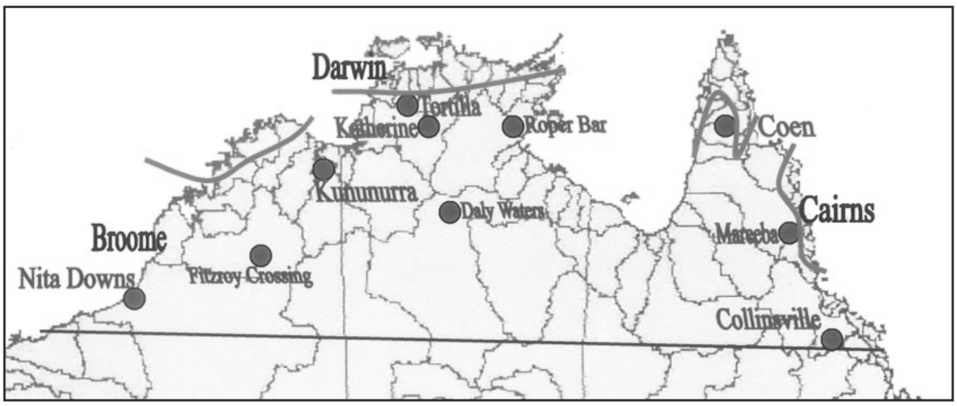

Figure 1. *Area of tropical Australia under investigation showing key localities included in this paper and river catchments. The boundary is 21S latitude to the south and the 1400 mm rainfall isohyet to the north and east. Map of river catchments is adapted from (NLWRA 2001).*

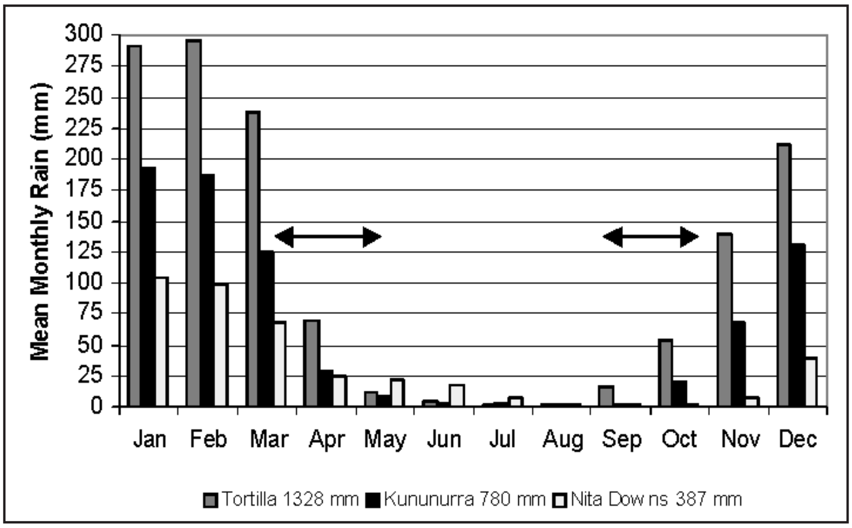

Figure 2.
Mean monthly rainfall pattern for tropical Australia for the range of total annual rainfalls where cotton is being evaluated. Arrows show the wet/dry and dry/wet transitions which are critical for sowing and picking operations.

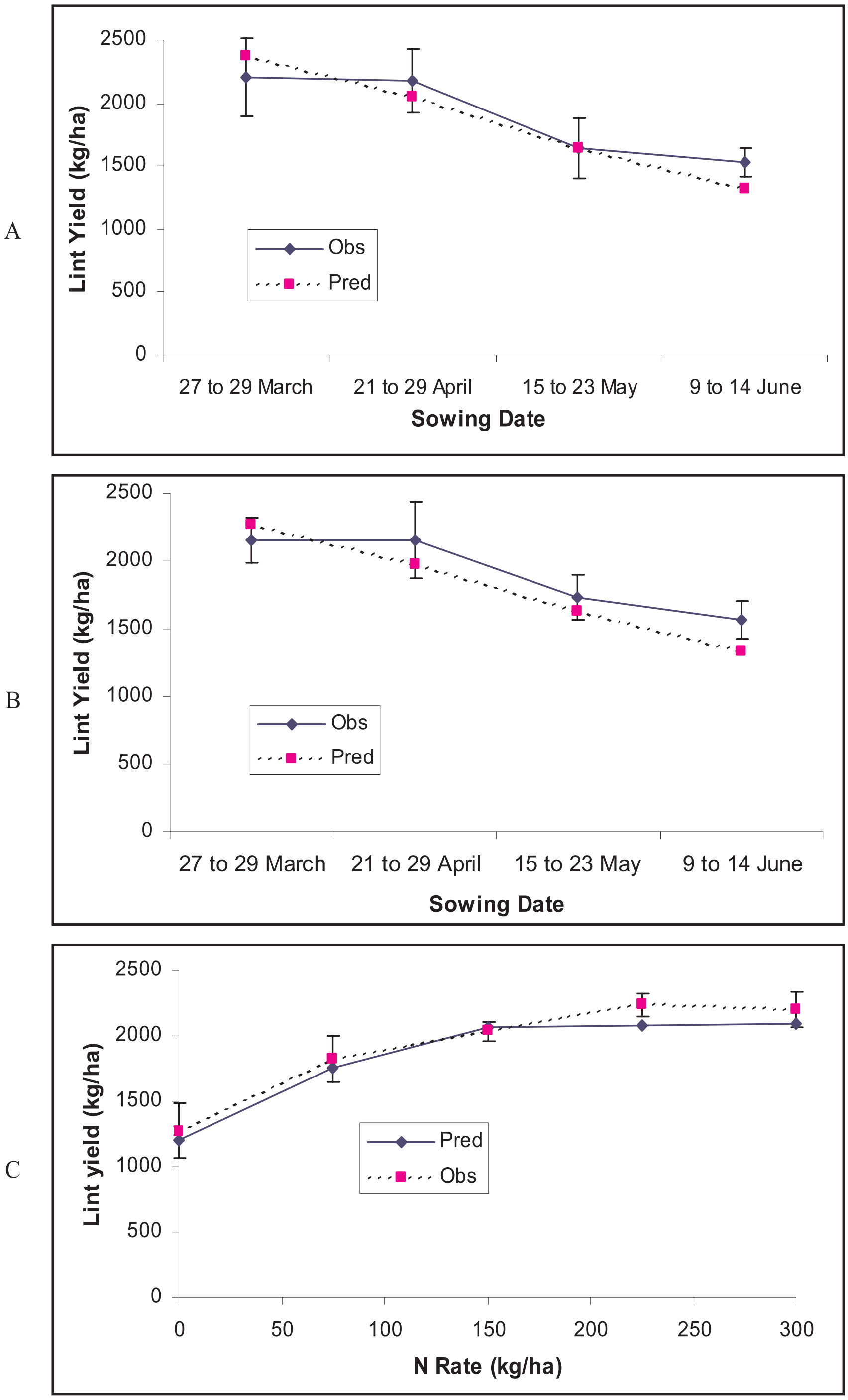

Figure 3.
Mean observed and OZCOT predicted yields for sowing date and nitrogen experiments conducted 1995, 1996 and 1997 at Kununurra WA. (A) Sowing date response for the Variety L23, (B) Sowing date response for the Variety Sicot 50, (C) Response to N fertilizer. Bars = standard errors of raw data (n=12 for each treatment).

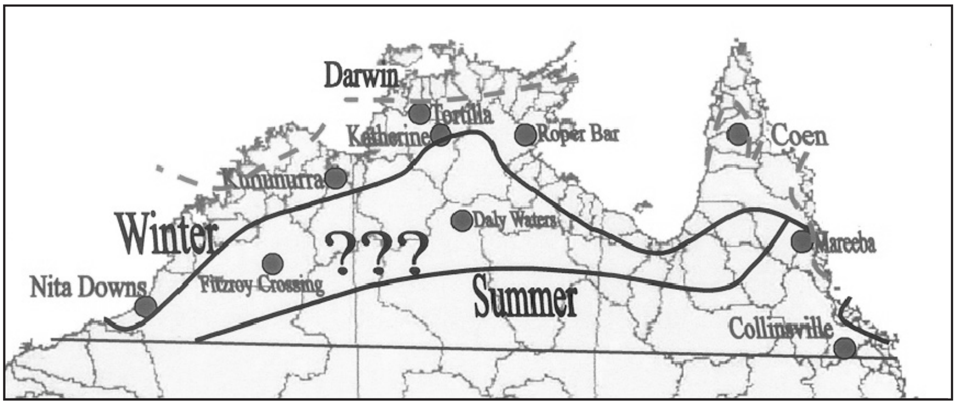

Figure 4. *Approximate boundary of potential summer and winter production areas in tropical Australia based on yield simulation, degree-day accumulation and pre picking weathering risk. Question marks show intermediate region were more knowledge of the impact of night temperatures between 0 and 11°C on cotton growth and yield is required.*