Chapter 4 - The Kimberley Region of Western Australia

4.1. Introduction

Recent reviews of Western Australia's water resources calculate that the Kimberley region has 80% of that State's renewable water resources (KWRDO 1993). This equates to 7,400 GL/yr with only a few percent currently used for human purposes. In addition groundwater in the La Grange sub-basin south of Broome has an estimated sustainable yield of 194 GL/yr.

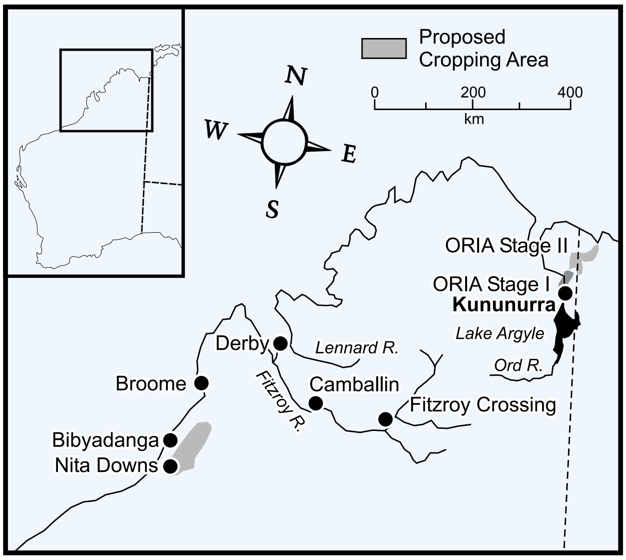
Interest in developing the Kimberley's two major rivers systems (Ord and Fitzroy) for irrigated agriculture has a long history in which cotton has often been a candidate crop. Irrigation dams have been constructed on the Ord, the Dunham River (an Ord tributary) and on the Lower Fitzroy at Camballin. Only the first stage of the Ord River Irrigation Area has seen significant agriculture development to date.

In the early 1990s the WA Government commissioned several studies to evaluate water resource development issues in the region (KWRDAB 1993; Kinhill *et al.* 1993; Hassell and Coffey 1993). With respect to irrigated agriculture the following conclusions were made:

- The second stage of the Ord River Irrigation Area (ORIA) should be developed before the Fitzroy. Because the 'Ord project ranks as one of the best regional development options available in north-western Australia'.
- The projected expansion of the Ord should be based on sugar, horticulture, pasture, seed and tree crops but not cotton. No explanation was given for the exclusion of cotton.
- Cotton was the favoured crop option for 40,000 ha black soils on the Fitzroy at Fossil Downs, Alexander Island and Camballin. Dam sites on the Margaret River and river barrages at Mt Krauss and Gogo was recommended. Production system research was recommended prior to development. Detailed feasibility studies would only be undertaken if experimental work proved successful.
- Irrigation development in other areas were considered longer-term opportunities (e.g., Lennard River).

In 1997 the WA Government called for expressions of interest in conducting feasibility studies into the development of Stage II of the ORIA and large-scale surface and groundwater irrigation development in the west Kimberley. In 1998 Memorandums of Understanding (MOU) were signed with Wesfarmers/Marubeni and the Water Corporation of WA for the Ord Stage II and with Western Agricultural Industries for surface water potential of the Fitzroy catchment and groundwater potential of the La Grange sub-basin. Obviously, the outcomes from these studies will directly impact upon any irrigation developments in the near future.

MAP 4.1: *Kimberly Locations. Note cotton production is being considered within proposed cropping area near Broome not the entire area shown.*



4.2. Cotton research and development in the Kimberley

4.2.1. THE ORD RIVER IRRIGATION AREA (ORIA) SINCE 1993

With respect to the Australian Cotton CRC's activities in northern Australia the ORIA is the most advanced site in terms of cotton production systems R&D. Prior to the Cotton CRC's formal involvement in late 1999 Agriculture Western Australia (AgWA) CSIRO, Cotton Research and Development Corporation (CRDC) Cotton Seed Distributors (CSD) Colly Cotton, Monsanto, the Ord River District Co-operative and local farmers have made a significant contribution to a dry season cotton production system R&D. The process used to conduct this work and the results obtained may serve as a planning guide for other northern regions less developed in their R&D.

The ORIA is also unique to the northwest of Australia because new irrigation land development is happening irrespective of cotton R&D; cotton is simply a candidate crop for the new development. Consequently cotton R&D can focus on issues of production and environmental management and feed outcomes on water requirements and other inputs into the separate land development activities.

Many outcomes of cotton R&D at the ORIA are expected to be transferable to neighbouring catchments, which have potential for irrigation development and have similar climate and soils (e.g. Fitzroy, Bains/Victoria).

4.2.1.1. Background

A feasibility report, prepared by Strickland *et al.* (1993), reviewed the previous attempt to grow cotton in the ORIA during the 1960s and 70s and recommended that the re-establishment of a cotton industry in the Kimberley should be seriously considered. However, due to the severe pest pressure associated with summer cropping, a new industry should be based on a winter cropping strategy and transgenic (INGARD™) varieties. To this end a joint Agriculture WA/CSIRO research project was developed to make preliminary judgements concerning agronomic potential and pest management scenarios. Importantly this feasibility report reviewed the previous attempt to grow cotton at the Ord.

Transgenic cotton varieties (INGARD™) containing specific insecticidal genes (initially the Cry1A(c) delta-endotoxin from *Bacillus thuringiensis* Bt) were seen as greatly improving the prospects of establishing sustainable cotton production systems. In an environment with the potential for high insect densities, such as tropical north-western Australia, it would be essential that the technology incorporate integrated pest management (IPM) methods, be supported by pre-emptive resistance management strategies (Fitt 1996) and merged with cultural and agronomic practices.

It was also recommended that the crop be grown in the dry season to avoid periods of highest insect abundance, particularly for two important species, pink bollworm (*Pectinophora* spp) and *Spodoptera litura*, which beset the previous attempt to grow cotton during the wet season. However, the tropical dry season is the reverse, in terms of temperature and daylength, to the typical summer season in temperate cotton growing areas. Therefore, agronomic studies were required into crop adaptation to the dry season, crop husbandry and operational issues.

Preliminary production systems research aimed at re-establishing a cotton industry in tropical north-western Australia was commenced in 1994 with the following objectives:

- Identify the most appropriate cotton plant types or varieties for dry season production in north-western Australia based on characteristics of yield, quality and maturity.
- Investigate the effects of specific agronomic/physiological factors on cotton growth and performance in the dry season and integrate those factors into a robust agronomic package tailored to the most appropriate varieties.
- Develop and evaluate pest management systems with minimal inputs of pesticide, maximal use of natural mortality factors based on transgenic cottons expressing Bt genes for management of lepidopteran pests.
- Integrate appropriate varieties, agronomy and pest management to provide a technological package for the establishment of an irrigated dry season cotton production system in north-western Australia.

4.2.1.2. Research station experiments 1994 to 1999

The experiments covered an area between 15 and 50 ha. In 1994 and 1995 seed of transgenic varieties was not available and non-transgenic varieties were sown. The area sown was also limited by the absence of ginning facilities; in 1996 it was estimated that $250,000 of lint was destroyed from this research.

In 1996 single gene INGARD™ varieties were grown for the first time although varietal choice was very limited. In the same year (1996-97), INGARD™ cotton was grown commercially for the first time in the established cotton areas of eastern Australia where it accounted for 10% of the total area sown that year (Wilson 1996).

Insect pest management research

The results from this research up to 1998 have been reported in the following publications (Strickland *et al.* 1996, 1998a and 1998b, Strickland and Constable 1995) and in reports to the CSIRO Tropical Initiatives Program, which supported collaborative involvement in the research.

In summary:

- Insect pest pressure was lower during the dry season.
- Parasitoids of *Helicoverpa* spp, the key dry season pest, were abundant particularly the egg parasitoid, *Trichogramma pretiosum.*
- INGARD™ varieties combined with IPM strategies reduced insecticide usage to 1/3 of that applied to conventional varieties.
- IPM systems involving the use of companion crops such as lucerne and niger to maximise beneficial insect numbers required the fewest insecticide treatments without compromising crop yield.

TABLE 4.1. *Key elements of a novel cotton production system for the ORIA contrasted with the previously unsuccessful system of the 1970s (from Strickland et al 1998a).*

1970s INDUSTRY	NEW INDUSTRY
Summer cropping (wet season)	Winter cropping (dry season)
Conventional varieties	Transgenic varieties
Broad spectrum insecticides	IPM systems
No pesticide resistance management	Pre-emptive Bt resistance management

Small plot and other research in progress in 2001 includes:

- Development and validation of heliothis thresholds for *Helicoverpa* spp, and the sucking pests, particularly mirids.
- Evaluation of new IPM compatible insecticides/food sprays including their effectiveness for managing beneficial insects.
- Population dynamics of *Helicoverpa armigera* within the Ord cropping system.
- Resistance testing aphids and *Helicoverpa armigera.*
- Ecology of *Trichogramma* spp, a key egg parasitoid of importance to IPM systems.

Agronomic research

The results of this work up to 1997 are summarised in Strickland and Constable (1995), Yeates *et al.* (1996), Yeates and Constable (1998), Strickland *et al.* (1998a). Research into developing crop husbandry practices (1994-1997) provided an initial technical package for the expanded IPM research and identified some future research priorities. It was expected that additional research questions would emerge from the commercial scale IPM research that commenced in 1997 (next section).

Crop adaptation/sowing date

Where insects were adequately controlled, experimental yields were found to be very comparable with experimental yields from summer grown crops in temperate Australia (Table 4.2). For mid-late and late maturing varieties, sowing from mid March to mid April optimised yield and permitted harvest from mid September to early October, well prior to the likely commencement of wet season rains in November. A very synchronous boll opening, which was due to rising end of season temperatures, reduced the boll periods of later pollinated flowers, ensured a prompt harvest and a degree of compensation from early fruit loss.

Fibre length appeared to be influenced by minimum temperature during the first 20 days after pollination. For late March–April sowing dates and flowering often coincided with cool temperatures; consequently fibre length was reduced compared with the same varieties grown in south-eastern Australia. High, possibly, supra-optimal temperatures during fibre growth appear to reduce fibre length at a June sowing date. As expected, rain on a mature crop could weather lint and reduce colour grade. The severity of weathering appeared related to the volume and frequency of rainfall events.

TABLE 4.2: *Comparison of machine picked small plot lint yields (kg/ha). Summer grown are the mean of 17 trials during 1996-1997 in NSW and Qld, winter grown is the mean of 3 years 1995 to 1997 inclusively at ORIA (from Strickland et al 1998).*

	Summer grown temperate Australia	Winter grown tropical Australia
Average Top 10 Varieties	2069	2043
Best	2529	2483
Range	1650-2529	1829-2483

The timing of crop development could be predicted using heat unit summation (base 12°C), however, the heat units required to reach early development stages were greater than for temperate Australia (e.g., first flower = 777 DD_{12} for a temperate crop, first flower = 884 DD_{12} for a tropical dry season crop). Supra-optimal temperatures are suspected to cause this deviation.

The effect of cold night temperatures on fruit growth and yield was not clarified from these studies for two reasons. Firstly, temperatures were not extreme in the seasons when the bulk of this work was conducted (1995 to 1997). Secondly, temperature effects were confounded by other factors such as insect damage, irrigation scheduling/management and rank growth.

Germplasm evaluation

Varieties and breeding lines have been evaluated since 1994. The previous attempt to grow cotton at the ORIA in the 1960s found varieties bred for mechanised agriculture were favoured over 'tropical adaptation' (Hearn 1996). The number of INGARD™ varieties was limited so emphasis was placed on the evaluation of conventional germplasm that could in future be back-crossed with INGARD™. Most *Gossypium hirsutum* material has come from the CSIRO/CSD breeding program with an additional 10 to 15% contributed by Deltapine Australia and small numbers of other varieties of USA origin. With the potential for sowing in March/April the focus has been on 'full season' or longer duration varieties that performed best in the warmer growing areas of SE Australia (Emerald, Bourke). These also proved to be the best at the Ord. To date, evaluation of genotypes for adaptation to reduced season length, as would be required with later sowing, has been confined to sowing date studies consisting of only three genotypes.

Gossypium barbadense varieties were evaluated during 1995-1997. Most material came from the 'Pima' breeding program in Arizona. Provided sowing was prior to the end of April, yields were good and vegetative growth was not an issue. However, fibre length was always below market acceptability in all genotypes screened. The resultant price discount would make G. *barbadense* less profitable than G. *hirsutum* types.

Crop nutrition

In southern Australia between 100 and 200 kg/ha of N fertiliser are required to grow cotton. Hence, given the low inherent N status of the Cununurra clay, early research focused on N fertiliser requirements. The average total uptake by unfertilised plants was about 80 kg/ha and a rate of 200 kg/ha of fertiliser N banded within a month of sowing was optimal for high lint yield (>2,200 kg/ha). This response was very similar over three years. At the optimal rate split applications did not improve yield. Current research is evaluating the interaction between N, P and irrigation interval/duration.

Growth regulation

During early growth in April and May, warm temperatures combined with management practices designed to minimise stress (e.g., nutritional and water) maximised production of 'Bt' protein, resulting in rapid and often rank growth. Consequently research focused on treatment from pre-squaring to early flowering with the growth regulator mepiquat chloride (Pix™). Mepiquat chloride (MC) reduced plant height and node number in proportion to the total amount of MC intercepted by the crop. Yield was generally unaffected by MC treatment. Further research was required into the interaction between MC and early season insect damage, operational efficiency, varieties and soil moisture.

Irrigation scheduling/water use

Research to determine appropriate irrigation scheduling and crop water usage is ongoing. This research has the following objectives:

- measure the plant available water holding capacity of the Cununurra clay
- to determine optimum irrigation scheduling, which includes frequency and duration of irrigation at different growth stages
- to measure crop irrigation water requirement and water use efficiency
- to measure the effect of irrigation on waterlogging
- to measure whether deep drainage occurs.

Plant density/arrangement

The response to plant density was similar to temperate Australia and the USA, where a density of between 60,000 – 180,000 plants per ha was optimal for yield. A population of 8-10 plants/m of row was recommended on the basis of plant height/lodging and stand evenness considerations. There was no yield difference between wide beds (2 rows separated by 80 cm on a single flat bed with 1 m between rows across the furrow) and narrow beds (single rows per bed separated by 1 m).

In-crop weeds

There are some potentially serious weeds to cotton (Table 4.3). Being an established irrigation area that grows a variety of crops during the dry season, weed management in cotton is integrated with practices adopted for existing crops. Seed bank management during a wet season fallow using knockdown herbicides forms the basis of weed management in annual crops, including cotton. Where possible winter season paddocks are pre-irrigated prior to sowing to germinate weeds, which are killed with a knockdown herbicide (often paraquat-diquat) at sowing. There is some use of selective pre-emergent herbicides in-crop.

The ease of in-crop weed control is influenced by the success of seed bank management during the wet season fallow, which in turn is related to the seasonal rainfall pattern. Rainfall directly influences timeliness and efficacy (rain fastness) of herbicide applications. Rainfall also necessitates the use of aerial application when soil is wet. On clay soils a further impact of rainfall on efficacy is through reduced weed vigour due to waterlogging.

To-date other than a small evaluation of Staple™ (pyrithiobac-sodium) with respect to crop safety and efficacy on *Hibiscus panduriformus*, there has been no research targeted at in-crop weeds or their management. In part this has been because adaptation of the existing practices has been reasonably effective. It is expected that weed problems will evolve if the area

TABLE 4.3: *Some potentially important weeds in cotton in the ORIA*

Weed	Species	Comments
Native Hibiscus Native Rosella	*Hibiscus panduriformus* *Abelomoschus ficulneus*	Both these weeds are important and difficult to manage. Hard seeded – several germinations
Wild Gooseberry	*Physalis minima*	
Pumpkin Vine	*Ipomea spp* *Operculina brownii*	
Black Pigweed	*Trianthema pertulastrum*	Common but controlled with existing herbicides (Stomp™, Treflan™)
Nut Grass	*Cyprus spp*	Only small areas to date
Wild Vigna	*Vigna spp*	Channels mainly
Tridax Daisy	*Tridax procumbens*	Channels mainly – tolerant of glyphosate.

sown to cotton expands. Future weed management research needs to be linked with research into rotations and cover crops.

Compensation

In 1997 the need for research to evaluate the physiological aspects of plant compensation under other types of pest damage, such as tipping of the main-stem terminal and the interaction of damage with growth regulator use, was recognised. Experiments commenced in 1999 are planned to continue for a further 2 to 3 seasons. Higher yields have been obtained from plants with early main-stem damage and early square removal (<9 nodes).

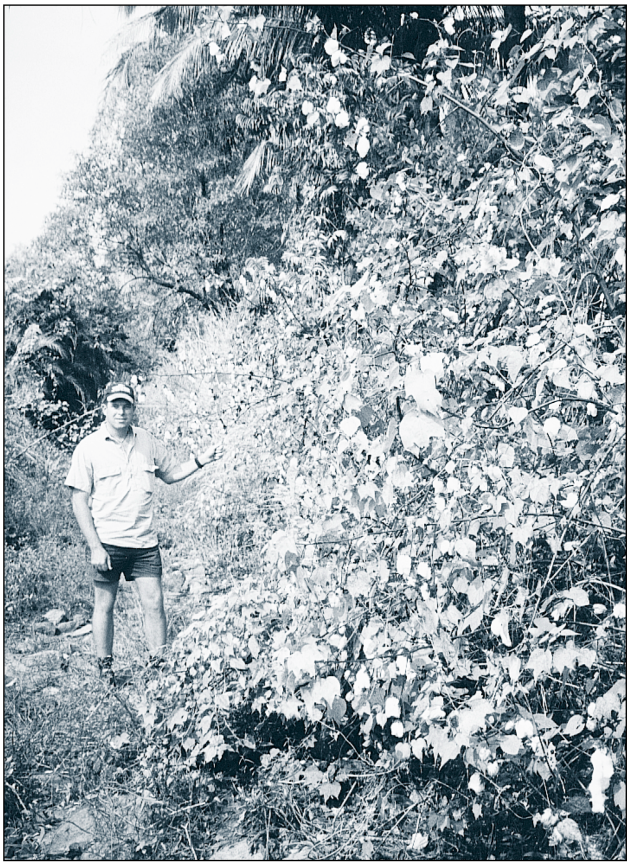
Other Research

Diseases

Disease surveys supported by the Cotton CRC have identified existing disease issues (Nehl *et al.* 2000). Alternaria leaf spot was the main pathogen observed on cultivated cotton. Charcoal rot (*Macrophomina* spp) was also observed where planting problems occur, but this disease was considered to be of minor importance. The presence of Verticillium wilt at Kununurra has not been confirmed. Cotton rust, although not observed during the survey, could be a potential problem. Importation of fuzzy cotton seed from the eastern States for use as stockfeed presents a risk for the introduction of Fusarium, Verticillium and other diseases to the north. Restrictions on movement of fuzzy seed for stockfeed should be given careful consideration.

Ecological risk assessment of transgenic Bt cotton

Prior to any commercial approval of transgenic Bt cotton for northern Australia a comprehensive ecological risk assessment has to be conducted in conjunction with the Genetic Manipulations Advisory Committee (GMAC), now the Office of the Gene Technology Regulator (OTGR), and Environment Australia. A number of aspects (i.e., risk of gene escape, resistance management, impacts on non-target insects) have been addressed. An ongoing component is assessing the potential for the Bt cotton to become a weed in the tropical environment. Experimental studies centre on the ability of the Bt gene to confer additional fitness to cotton in natural habitats outside the areas of cultivation. Potential routes for seed movement into natural environments have been identified and are being quantified. Experimental work is being conducted in four habitats at each of three locations, Kununurra, Katherine, and near Broome where the demography of conventional and transgenic genotypes is being compared. Each site was planted over the wet season to three genotype treatments: conventional, single gene (INGARD™) and two gene Bt cotton (BollgardII™), with each of three seed types: black seed, fuzzy seed, and seed cotton, over two populations.



Andrew Dougall from NTDPIF standing beside naturalised cotton at Bees Creek, NT

Monitoring of small numbers of transgenic plants that have established in areas outside cotton fields (e.g., roadsides) is ongoing. This enables determination of the seasonal growth and development phases of volunteer cotton to better understand factors that may affect the potential to establish and reproduce in non-crop environments.

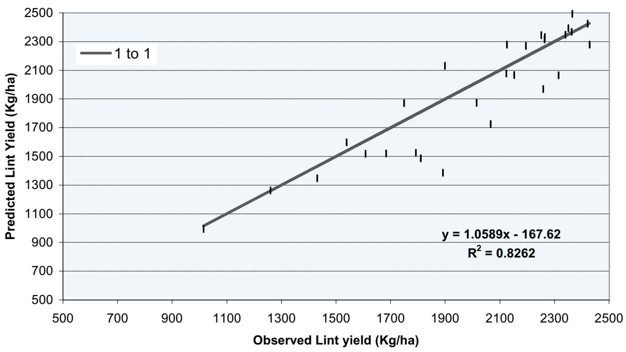
Monitoring of feral populations of conventional cotton is also being conducted. These populations are descended from introductions made many years ago and are small, isolated sites which have not moved from their site of introduction. This aims to address the issue of the potential for the transfer of the Bt gene to these populations, and if this occurred, whether this would provide additional fitness to contribute to increased weediness.

Additional transgenic Bt registration studies are being conducted and funded by Monsanto. These studies are being conducted to meet National Registration Authority requirements to demonstrate field efficacy and effects on non-target insects. Supporting data is being generated from pest management studies conducted by AgWA.

OZCOT-APSIM (1-5) Simulation Model Validation

Validation of the OZCOT-APSIM crop simulation model showed that yields could be adequately simulated provided insect damage was minimal and irrigation did not induce waterlogging (Figure 4.1). However, because of deviation in the thermal time summations described above, OZCOT's predictions of the timing of reproductive development and crop maturity deviated from the observed. The OZCOT model does not simulate the effect of night temperature on fibre length or the effect of weathering rainfall on colour grade. It is not clear whether OZCOT will account for irrigation-induced waterlogging effects in this environment. Validation needs also to extend to include a wider range of seasonal conditions, particularly where sub-optimal night temperatures are more common (e.g., Katherine, NT).

FIGURE 4.1: *Validation of the OZCOT yield simulation model using observed data collected at Kununurra 1995-1997.*



4.2.1.3. Commercial Scale Integrated Pest Management Research 1997–1999

In 1997 Colly Cotton Pty Ltd (now Twynam Cotton) a NSW based integrated cotton business that grows, processes and markets cotton installed a 'research gin' as a joint venture with the Ord River District Cooperative at Kununurra. This permitted research to move onto farms and be expanded to paddock size areas.

The area sown ranged from 300 ha in 1997 to 1,000 ha in 1999. The bulk of this was INGARD™ cotton grown under a research permit granted by GMAC. Three to four IPM treatments were replicated in paddock size areas (>20 ha/plot) with one replicate of all treatments being located on each farm. Each paddock was intensively monitored for pest and beneficial insects. Since 1997 an agronomist from Colly Cotton assisted farmers with agronomic management.

Key results from large Scale IPM research have been:

- INGARD™ / IPM treatments have required an average of four total insecticide sprays, considerably less than the 10–12 needed on conventional cotton, and the 40 sprays of the previous ORIA industry (Table 4.4).
- Lucerne strips in combination with INGARD™ have consistently reduced the number of insecticide sprays by about one compared with INGARD™ only treatments. There has been a trend for higher yields with lucerne strips. Lucerne strips provide a nursery habitat for beneficial species and act as a trap crop for mirids.
- The selection of a nursery/trap crop should also be influenced by agronomic practicalities. Lucerne is often difficult to establish and weeds can infest stands. Niger flowered for a short period and timing of sowing required precision to sustain a flowering stand that would be attractive to insects. Recently lablab has been tried and found to be easy to establish while having a long flowering period. Pigeon Pea is to be evaluated in 2001.
- The levels of *Helicoverpa* spp egg parasitism by *Trichogramma* spp wasps have been variable. Higher in 1996 and 1997 than 1998 and 1999.
- Efficacy of single gene Bt declined after late flowering, with some within season variability as well. Overall efficacy has been higher and more consistent than in south-eastern Australia.
- Food spray (Envirofeast™) had little effect on the requirement for insecticides or beneficial insect numbers.
- Established spray thresholds for major pests heliothis and mirids need validation.
- Endosulfan has not been considered as part of any IPM system and none has been used in on-farm research.

TABLE 4.4: *The mean lint yields, number and purpose of insecticide sprays in the IPM trials, Kununurra, 1996 and 1997 (Strickland et al. 1998)*

TREATMENT[1]	MIRID SPRAYS	APHID SPRAYS	HELICOVERPA SPRAYS	TOTAL SPRAYS	YIELD KG LINT/HA
1. Siokra L23°C alone	2.13	0.25	2.25	4.63	1,584
2. Siokra L23°C + Envirofeast™ + lucerne	1.48	0.15	2.13	3.66	1,610
3. Siokra L23°C + lucerne	1.25	0.13	1.75	3.13	1,756
4.# Siokra L23°C + niger	1.50	0.25	3.00	4.75	1,630
5.* Conventional cotton + Envirofeast™ + lucerne	3.0*	0	7.50	10.50	1,594

[1] all treatments were sprayed when entomoLOGIC thresholds were reached
* includes rough bollworm as a target pest (*grown 1996 only)
# grown 1997 only

Lincoln Heading from Agriculture WA in Kununurra sampling cotton for beneficial and pest insect species

Non-pest management observations from commercial scale IPM research

As expected the large-scale trials identified new problems and research questions:

- Regrowth following defoliation was very rapid due to high temperatures and was influenced by the timing of final irrigation. Significant price discounts resulted from staining of lint by green leaves during picking. Small plot research to investigate the optimum timing of final irrigation was initiated in 1998.
- Why was between paddock yield variability so high?
  - 1997 4.9 to 9.17 b/ha
  - 1998 6.8 to 9.33 b/ha
  - 1999 3.9 to 7.73 b/ha
- Although some of this variability could be attributed to inexperience and non-optimal treatments, it was clear that there was a need for a greater focus on paddock benchmarking (e.g., soil chemical analyses) and increased within season agronomic monitoring (e.g., water use, nutrient uptake).
- Irrigation scheduling required research to account for slope, run length, sowing date, growth stage and variety.
- Were cold temperatures the major cause of lower yields in 1999 or were other factors involved (e.g., long periods of near threshold heliothis larvae numbers or severe alternaria damage)?
- How frequently will fibre quality be down graded by rain at harvest?
- Operational efficiency – are current land preparation and other cultural operations cost effective and timely?
- Optimal defoliation management (e.g., chemicals x timing x irrigation management) has not been determined.

4.2.1.4. Future research direction

Entomology

Entomological research at the Ord is planned to continue until at least two to three seasons of research with two gene Bt cotton is complete (4-5 years hence). This research is supported by substantial funds from Agriculture WA and the CRDC. A research entomologist and technical support is in place. In 4-5 years time an effective appraisal of the potential for sustainable cotton production using BollgardII™, combined with a locally developed IPM and resistance management strategy could be made. Moreover, the specifics of the Stage II development and the potential for cotton to be included will be clear in five years. Concurrent research by Monsanto (with support data from Cotton CRC research) to support registration of BollgardII™ cotton for northern Australia will be completed within five years.

Agronomy

CSIRO will be largely responsible for this aspect by providing a research agronomist with technical and operational support funded by CRDC. Agronomic research will follow the same timeframe as entomological research. The objectives for future work will be to evaluate suitable rotation/wet season cover cropping systems, address problems identified in large-scale trials, continue variety evaluation, complete MC, nutrition and compensation research.

Future links with non-cotton research programs

There are other research programs in the Ord that have objectives or outcomes that are relevant to cotton research and linkages with these programs need to be maintained or initiated:

- Soil water characterisation research for sugar cane.
- The Ord Land and Water Management Plan, which includes crop water use, watertable and chemical best management practice issues.
- The Ord–Bonaparte project, which aims to coordinate a catchment scale environmental study of the impact of agricultural and other development in the east Kimberley.
- Valley wide programs to encourage wet season cover crops for soil and weed management.

4.2.2. Cotton research in the Broome area

For the purposes of the following review the Broome area consists of the La Grange sub-basin, which contains well-drained uniform textured soils (Pindan) of the Yeeda Land System and the clay textured soils of the lower Fitzroy catchment to the north.

4.2.2.1. Prior to 1993

Evaluation of cotton was conducted at Bibyadanga (La Grange) mission during the late 1800s. In 1922 cropping was attempted at Knowsley Agricultural Area near Derby as small lots 160–220 acres for returned soldiers; four blocks were allocated for cotton, which apparently failed due to drought, heat and insects (bollworms). In 1923 it was recommended that the activity be moved to clay textured soils rather than the Pindan soils (Millington 1977).

4.2.2.2. 1993 to 1996

Mr John Logan, a former cotton farmer from NSW, through the company Kimberley Agricultural Industries, initiated a very small-scale evaluation during 1993-96. Sites were established on small horticultural farms near Broome and at Shamrock Station 160 km south of Broome. At least one further site was established inland from Broome at Dampier Downs Station 170 km to the east/southeast. Varieties (mostly conventional) were screened during the wet season. Sowing date varied to evaluate wet season growing (December to early February) supplemented with irrigation. Because the soils were sandy textured, drip irrigation was used. There was some involvement with AgWA who monitored insects at the sites.

4.2.2.3. 1997 to 2000

Background

The research was expanded with the formation of Western Agricultural Industries (WAI) a company comprising Kimberley Agricultural Industries and Queensland Cotton Holdings. WAI employed full time research agronomists and support staff and established a research site at Shamrock Station.

In respect to the Broome area (La Grange sub-basin), WAI signed a memorandum of understanding with the State of Western Australia in August 1997 to conduct feasibility studies into all aspects relevant to the establishment of a large-scale, integrated, irrigated agricultural industry. WAI was given prime responsibility for pursuing all factors associated with the proposal. In summary WAI had to demonstrate to the government's satisfaction that, within the study period, large-scale irrigation activity is environmentally, financially, technically and economically feasible and sustainable using groundwater resources. The study period was till 30 June 2000 with an option to extend for a further three years subject to approval by the State. An extension of the MOU was granted in late 2000.

Cotton production system research

Research conducted to date was located at Shamrock Station in small plot trials with a best-bet test area of 5 ha evaluated in 1999. Cotton production in the west Kimberley contrasts greatly with current cotton production systems in Australia. The cotton is grown on sandy loams and irrigated by sub-surface drip irrigation. The key findings of this research are summarised below:

Crop adaptation

A May sowing date seems optimal in that it avoids temperature extremes (hot and cold) during critical development stages minimises exposure to high insect densities and produces good yields and quality with a low risk of rainfall during the picking period.

Water

Crop water requirements, scheduling, the delivery system (included a range of commercially available drip irrigation systems) and off-site impacts have been the major research issues. Sustainability issues such as water quality and groundwater recharge are also being considered. The developers consider that sufficient progress has been made with the crop water requirements, scheduling and the delivery system to establish a blue print for production on larger areas. Ongoing work is required for issues of environmental impact, particularly groundwater recharge.

Crop nutrition

Nutrient requirements and method/timing of application for most of the major nutrients have been identified, as has the cost of applying different fertiliser forms of each nutrient. Macro nutrient requirements appear similar to the light textured soils in the NT.

Variety assessments

This is ongoing. Better performing varieties have been similar to Kununurra and Katherine. That is, longer season maturity types suited to the hotter areas (Emerald/Bourke) are also best suited to Broome. Obviously selection of adapted BollgardII™ varieties is a critical research task for the future.

Insect pest management

Agriculture WA is a collaborator in pest management research. Little is known of the pest and beneficial insect species present and their abundance in this region. Emphasis has been placed on characterising the insect fauna and seasonal patterns of abundance measurement through trapping and sampling of trial sites and native vegetation. Key pests likely to occur include *Helicoverpa* spp, *Spodoptera litura,* pink bollworm (*Pectinophora gossypiella*) and rough bollworm (*Earias* spp). A study into the population dynamics and movement of *Helicoverpa* spp is proposed. Pesticide efficacy trials are ongoing, as is the quantification of resistance levels in key pests. In the future it is recommended that research move to larger area IPM studies similar to those currently undertaken in the Ord. Research for BollgardII™ registration is essential.

Environmental and social studies

As a requirement of the MOU these studies include:
i) sustainable groundwater yield assessment
ii) impacts on terrestrial flora, fauna and soils
iii) management of aboriginal and native title issues
iv) social and cultural impact assessments.

WAI employ an environmental consultant to advise and coordinate these activities.

Due to the very poor community perception of cotton production, there has been a requirement for extensive community consultation in the above. Moreover the effectiveness of the research development and extension process aimed at these issues is seen by WAI as a critical factor in the success of the project.

4.2.2.4. Future research direction

BolgardII™ registration process
Cotton production systems in this region will need to incorporate BollgardII™ cottons. A clear process for timely registration is essential.

Continue insect pest management research
IPM research must move to a larger scale incorporating BollgardII™ varieties and supported by ecological studies of the pest complex. The Australian Cotton CRC has already agreed to fund an entomologist (employed by AgWA) to support the research.

Modelling of environmental impact
This includes, groundwater recharge, movement and breakdown of pesticides and fertilisers and changes in soil chemistry and structure. This work would also involve a stochastic assessment. WAI are currently investigating models to conduct these tasks; the model developed by the University of Western Australia is an example.

As listed above, impacts on terrestrial flora and fauna must be assessed and compliance with federal biodiversity and similar legislation must be integrated into development plans.

Wet season cover crops/rotation crops
The production system proposed has the potential to leave a highly erodable sandy textured soil exposed to intense rainfall and wind during the wet season and early dry season prior to sowing. Soil cover in the form of a cover crop is required during the wet season between cotton crops. In the monsoon climates of the NT, a system of sowing wet season cover crops is used where annual horticulture crops are grown during the dry season on sandy textured soils. This system utilises forage grass crops such as millet (*Pennisetum uniloidies*), which are deep rooted and can capture residual fertiliser before it is leached below the rootzone (M. Smith NTDPIF, Katherine NT, unpublished data). In the Broome area a range of wet season cover crops need to be evaluated for their value in erosion prevention, soil structural maintenance and capture of residual fertiliser. A cotton monoculture is not desirable so rotation crops need to be evaluated in addition to cover crops. Rotation crops may substitute for wet season cover crops or substitute for cotton in the dry season.

General crop protection
This includes being proactive and reactive to problems (weeds, pests, and diseases). The light textured soil has the potential to harbour nematodes.

4.2.3. OTHER POTENTIAL GROWING AREAS

Currently the Fitzroy Catchment is the only other area to be seriously considered for irrigated cotton development. The Lennard River is relatively isolated and is unlikely to develop sufficient basic soil and water resource data within the next ten years.

Kinhill *et al.* (1993) in their report 'Fitzroy Valley Irrigation: A Conceptual Study' commissioned by the Western Australian Government concluded that irrigated cotton was the favoured crop on black soils. In 1994 the Buster Farming Partnership, which grows cotton near Bourke NSW, evaluated small areas of cotton at Camballin. No conclusive results were produced; cattle entering the site severely disturbed the trials and no further research was conducted. Uncertainty regarding land title was sited as the reason for terminating research.

WAI, as a component of its MOU with the WA Government, is studying the irrigation potential of the Fitzroy River Catchment. Initially centred on the construction of a dam, the surface water component of the project is now focussed on aquifer recharge of the bore-fields from the Fitzroy River, combined with off-river storage at strategic locations. WAI is presently focussing its efforts on the groundwater resource south of Broome. Crop production system research and much of the associated environmental impact research can be extrapolated to an expanded cropping area supplied by surface water.

4.3. Resource review

4.3.1. CLIMATIC POTENTIAL

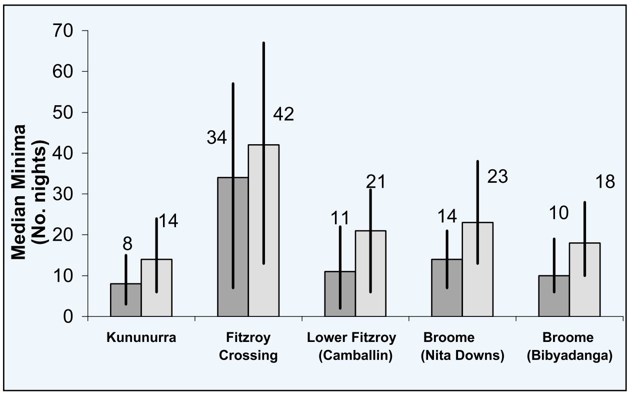
The Kimberley climate is semi-arid tropical. Most rainfall is in the summer months (November to March) and winters are dry and mild. Rainfall is highest in the north and east. Winter season temperatures are coldest to the south and inland from the ocean or where topography is favourable. Consequently the key issues for dry season cotton production are having sufficient heat to sow and pick the crop within the confines of the dry season.

4.3.1.1. Temperature

Figure 4.2 shows the risks of minima below the optimum for cotton growth and development (11°C or 12°C).

Kununurra in the north-east has the lowest frequency of cold shock temperatures. The modulating effect of the Indian Ocean is evident at the southern-most locations of Bibyadanga and Nita Downs. Fitzroy Crossing has significantly greater frequency of cold shock temperatures.

FIGURE 4.2: *Potential Kimberley winter growing areas, risk of cold night temperatures. Median minimum temperatures below; ■ 11°C and □ 12°C (1957 to 1999). Bars show the range for 20% to 80% of seasons. Note that the Lower Fitzroy data is constructed from the Silo database for Camballin, which was derived from observed data collected at Derby.*



Research at Kununurra and Katherine has found an average of 2,200 degree day sums with a base temperature of 12°C (DDS_{12}), (see Constable and Shaw 1998 for method of calculation) are required from sowing to picking during the dry season. Figure 4.3A shows that 2,200 DDS_{12} will be accumulated by mid-October in 80% of seasons at Kununurra and Lower Fitzroy provided the crop is sown by April 15. At Fitzroy Crossing sowing prior to April 15 is required for picking by October 15. To be consistent with research outcomes, a mid May sowing date was considered for the Broome coast (Figure 4.3B). In this case a mid November harvest date is most likely.

4.3.1.2. Rainfall

Due to superior trafficability, rainfall during the wet/dry transition is less likely to affect operations on lighter textured soils that dominate the Broome coast. Sowing operations are more sensitive to rain on clay-textured soils. At Kununurra, rain has delayed sowing of the majority of the crop until after mid April in four of the last six seasons. Obviously the date of picking is influenced by the date of sowing and growing season temperatures (Figure 4.3).

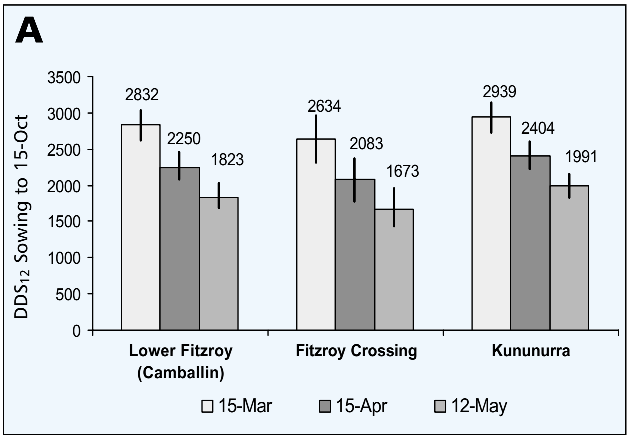
Picking prior to mid October has a low probability of rainfall at all sites (Figure 4.4). As expected rainfall variability is high. Median fortnightly rainfall only exceeds 20 mm after mid November at Kununurra. At Fitzroy Crossing the later onset of rainfall may compensate for cool temperatures extending the growing season. The Lower Fitzroy appears to have a good balance combining mild temperatures and a late onset of rain. Harvest rain is of minor consequence on the Broome coast as median rainfall is less than 5 mm / fortnight until mid December (Figure 4.4B).

4.3.1.3. Potential yield

The good correlation with observed data at Kununurra (Figure 4.2) suggests that the OZCOT-APSIM model will give accurate yield data for similar climatic conditions and management assumptions.

Yield potential was high at black soil sites where sowing occurred prior to May. Maximum yield required a mid-late April sowing date (Figure 4.5A). Simulated yields were very high on sandy soils at the Broome coast (Figure 4.5B). A notable feature of Figure 4.5 is the low variability of yields at the optimal sowing dates. Super optimal temperatures (>38°C) combined with a greater chance of waterlogging during boll growth may explain the lower and more variable yields at May 12 (Figure 4.4A) and May 31 (Figure 4.5B) sowing dates at the Kimberley and Broome coast locations respectively.

FIGURE 4.3: *Potential Kimberley winter growing areas. Variation in degree day sums base = 12°C (DDS_{12}) 1957 to 1999. (A) Sites other than Broome coast at 15 March, 15 April and 12 May sowing dates, and picked on October 15, (B) Broome coast. Bars show range for 20% to 80% of seasons.*



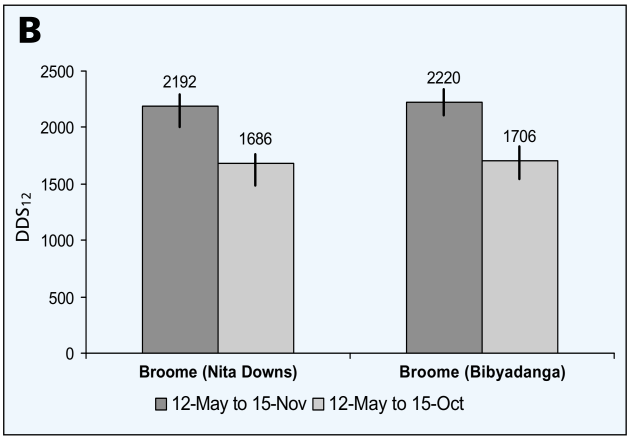


FIGURE 4.4: *Median fortnightly rainfall (1957–1999) over the maturity and picking period for (A) Kimberley and (B) Broome coast. Bars show range for 20% to 80% of seasons.*

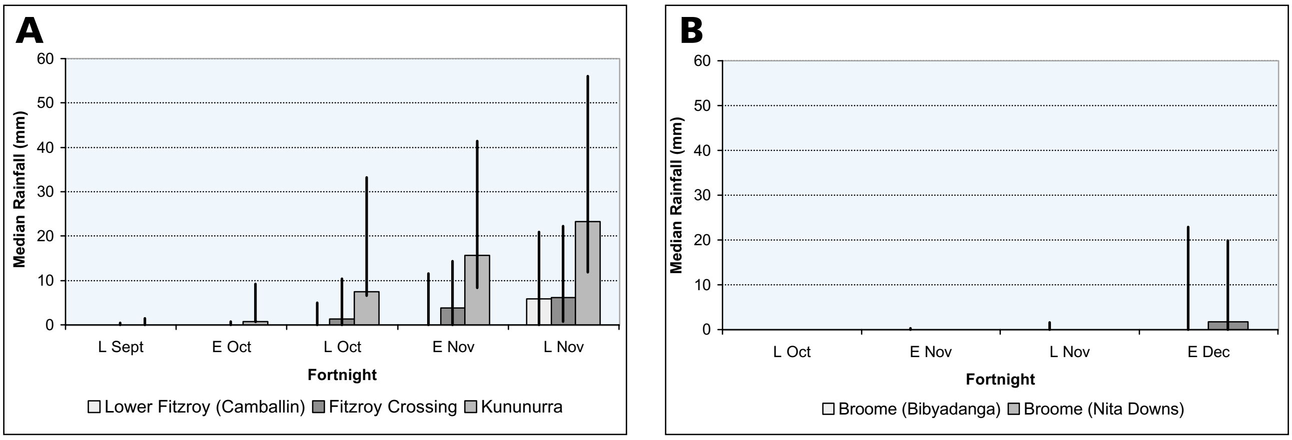
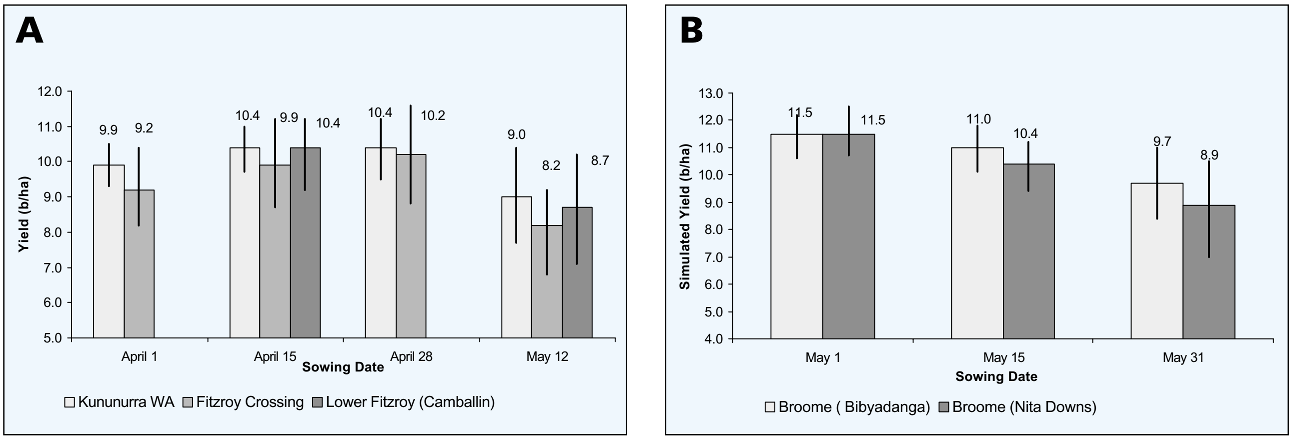


FIGURE 4.5: *The effect of sowing date on median potential yields simulated by OZCOT-APSIM (1957-1999). (A) Kimberley and (B) Broome coast. Bars show range for 10% to 90% of seasons. NB simulated yields assume 100% water allocation, no damage from insects, diseases and weeds, excellent crop management and prompt picking following defoliation.*



4.3.2. SOILS AND LAND RESOURCE ASSESSMENT

Outside the ORIA, soil surveying and land system characterisation has been on a broad scale (see Speck *et al.* 1964, Speck *et al.* 1960 and Stewart *et al.* 1970). The most recent details of the soil surveying and hydrological assessment conducted in the area covered by the M2 development of the ORIA were presented as part of a draft EIS and environmental review and management program submitted for public comment in March 2000 (Kinhill Pty Ltd 2000).

The early surveys identified areas in Ord, Fitzroy, Lennard and small areas of the Robinson catchments as potentially suitable for furrow irrigation (Speck *et al.* 1964, Speck *et al.* 1960 and Stewart *et al.* 1970). These river systems were considered the most likely to have sufficient annual water flow for irrigation combined with Cununurra clay or similar soils in the areas with potential for flood irrigation.

The Ord River is an example of the enormous research effort required to predict the irrigation potential of areas where clay textured soils are dominant. History shows that initial surveys claiming the 'largest area of uniform soils in the world' (Stewart 1944 cited by Chapman 1994) have been continually proved wrong, as the intensity of sampling has increased (see Parberry *et al.* 1968, Gunn 1969, Aldrick and Moody 1977, Aldrick *et al.* 1990, Kinhill Pty Ltd 2000). The Cununurra clay is now described as having five different phases: normal, leached, eroded, brown and darker (Kinhill Pty Ltd 2000).

The La Grange sub-basin south of Broome can irrigate soils that are predominantly deep sandy-loams of the Yeeda Land System (Cotching 1990, Cotching *et al.* 1990). These uniform textured soils are well drained and rapidly permeable (Cotching 1990). Roads formed on these soils are firm and stable. They have few or no weathered minerals and are deficient in phosphorus. They have low capacity to store water for plant growth. WAI consider favourable economies of scale would result by growing cotton on the large areas of apparently uniform soils in this area. Flood irrigation is not feasible on these soils; therefore alternative delivery systems such as subsurface drip are required.

For reviews of soil nutrient status and fertiliser responses for the cracking clay and other soils found in the region see Williams *et al.* 1985, Jones *et al.* 1985 and Chapman 1994. Virtually all soils are inherently low in organic carbon, N, P, S, Zn and possibly Mo, Cu, Fe, B and Mn. On cracking clay soils responses to N, P, S and Zn fertiliser have been reported for a number of crops. Nutrient stratification (natural and induced by fertiliser placement) in the surface layers, particularly P, has been observed and commented upon. There has been little research into the effects of and the amelioration of nutrient stratification. Leaching of nitrate and denitrification has been reported in clay and red earth soils. Nitrogen losses are affected by irrigation management and crop species. Sorption of P has been observed to vary between sites.

4.3.3. WATER RESOURCES

Specific details of proposed water allocations for the Ord M2 development are given in Kinhill Pty Ltd (2000). Briefly it is proposed (subject to public review and comment) to irrigate an additional 33,000 ha. Water allocation is to be sufficient to grow sugar cane, a crop with high water requirement compared to cotton (Dorrinbos and Depruit 1983).

The Dunham River Dam (60 km west of Kununurra) with a potential irrigation allocation of 12 GL/yr could irrigate about 1500 ha of cotton. The dam currently irrigates pasture and hay crops (Ag WA, unpublished data).

The Fitzroy River has a mean annual discharge into King Sound of around 8000 GL. Currently, there is no use of this resource other than by cattle stations and by small communities like Fitzroy Crossing. WAI is expected to complete full Environmental Impact Study (EIS) as part of the feasibility investigations. The groundwater study is to be completed in 2001, with surface water studies to be completed at a later date.

- WAI consider that the combined water resource (including the La Grange-sub basin) could support a total irrigable "green" area of approximately 175,000 ha.
- WAI anticipate that commercial development from bores will begin in 2001, and increase rapidly to the extent of water availability identified in the groundwater studies.
- Subject to the successful introduction of groundwater commercialisation, and a satisfactory EIS, production from the surface water resource would commence.

4.4. Infrastructure issues

4.4.1. ORD RIVER IRRIGATION AREA

- Stage I of the ORIA is fully developed and grows a range of crops on about 10,000 ha. The area is serviced by pesticide spraying contractors, rural merchandisers, transport companies and consultants. The port of Wyndham is 100 km to the north-west. Darwin is 820 km north-east by an excellent all weather highway. There are daily flights to Darwin, Broome and Perth.
- AgWA has a well-maintained research facility near Kununurra. A cotton research team of 10 staff from AgWA, CSIRO and a student from the University of Queensland are located at Kununurra, and are all part of the Australian Cotton CRC. The Cotton Research and Development Corporation provide support funding for three projects. Outside the Cotton CRC, the Ord River District Cooperative provides support through part ownership of the research gin and Monsanto will continue to fund research supporting BollgardII™ cotton registration.
- In December 2000, Twynam Cotton withdrew from the Cotton CRC and direct involvement in northern Australia, due to changing priorities in the company. A replacement for Twynam Cotton as a commercial R&D partner is essential. In 2001 Twynam's involvement will be confined to part owner and operator of the research gin and marketing of the lint produced.
- Increased farmer participation in large-scale trials is needed. Small scale ginning and picking infrastructure requires at least 400 ha to maintain viability. Currently demand from other crops for existing land in Stage I combined with the unfavourable economies of growing cotton at this small-scale are a disincentive for farming cotton. The perception that there is additional economic risk due to these being research trials, and hence unproven management practices, is also a disincentive.

4.4.2. BROOME/WEST KIMBERLEY

- The MOU granted to WAI also requires that Aboriginal and Native Title issues be resolved as a requirement of the MOU. These issues have short-term implications for field research near Broome because the availability of land to conduct research is currently restricted. Land to expand research to large-scale trials to 200 ha in 2002 is urgently needed. WAI have made an application to obtain a clearing permit to develop land for this purpose.
- WAI provide the majority of funding for cotton R&D in the west Kimberley, while research is coordinated through the Cotton CRC. A project manager (Perth), research agronomist (to be employed at Broome) and support staff (on-site) are employed by WAI. AgWA collaborates with WAI by providing entomological research with two staff currently based at Broome. WAI and AgWA staff are committed to the Cotton CRC, which will fund an entomologist commencing in 2001. The Cotton CRC funded research coordinator / liaison officer has a 20% time commitment to Broome issues. The main research site is at Shamrock Station 160 km south of Broome. A research site

for smaller scale work located closer to Broome is currently under investigation. Funding for a new building and laboratory to house AgWA staff at Broome has been approved.

- Broome has a port facility, international airport and road linkage to Perth and Darwin by the Great Northern Highway. Derby also has a port facility, a domestic airport and is also connected by the Great Northern Highway.

4.5. Environmental issues

- As discussed previously, the relevant work is being conducted in both regions to meet the requirements of the respective MOUs with the WA Government. It is important that production systems R&D collect data critical for environmental impact assessment.
- There is organised opposition to cotton in the west Kimberley (e.g., Environs Kimberley). Community consultation is a requirement of the MOU. WAI emphasised the need for a mechanism that can achieve more effective involvement of interest groups (particularly environmental groups). WAI suggested sustainability issues symposium(s) as proposed by the Cotton CRC Director at a Cotton CRC Northern Committee meeting. WAI felt that these symposia should focus on informing groups on critical issues and achieving a better community understanding of the research and development process.

4.6. Conclusions and recommendations

There is a significant commitment by many organisations to cotton R&D in the Kimberley region of WA. Both the west Kimberley and Ord River appear to have considerable potential as cotton growing regions. Future commercial development at the Ord River will depend greatly on the outcomes of the current feasibility assessment for Stage II (33,000 ha) conducted under the MOU between Wesfarmers/Marubeni and the WA Government. It is important to note that the cropping mix in the initial proposal (mainly sugar) is not final (P. McCosker, KDC, pers.comm. 2000). A final decision is expected to be made in late 2001. While in the west Kimberley more than 20,000 ha could be grown using groundwater reserves south of Broome without any additional water from the Fitzroy River. Future commercial development in the west Kimberley will also depend on the outcomes of feasibility assessments under the MOU with the WA Government and land tenure resolution.

The pest management research at Broome, which is to be supported with Cotton CRC funds, is critical. However, given the significant in-kind contribution to the Cotton CRC by collaborating member and non-member organisations and the coordinated approach to irrigation development via the MOUs, a greater contribution by the Cotton CRC in WA is well justified.

Recommendations for Cotton CRC future involvement in WA cotton R&D are listed:

- There is a critical short-term need to continue the role of production agronomist previously supplied by Twynam Cotton in the large-scale trials at Kununurra. This person acts as a development officer, on-farm researcher and data collector. The value of large-scale trials at this critical time in the development and testing of sustainable pest and agronomic management practices would be significantly diminished without this position. The Cotton CRC should assist in developing a means of funding this position either by full / part funding or assisting to secure funding from elsewhere.
- The Cotton CRC should contribute to research into sustainable wet season cover crops and crop rotations at Broome. The need for this research is discussed in section 4.2.2.4. Expansion of research areas will enable this work to occur. However, it is clear that the involvement of Cotton CRC members with relevant expertise and experience on similar systems in the NT would greatly benefit this work and is strongly supported by WAI.
- There is a statewide need for active Cotton CRC involvement in community consultation and general communication issues. The suggestion of a sustainable issues symposium (or something similar) and follow up activities that also include an emphasis on community understanding of the research and development process should be pursued. The Northern Committee of the Cotton CRC has a key role in facilitating this process.