Cotton Research & Development

Annual, Progress and Final Reports

Part 1 - Summary Details

REPORT

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CRDC Project Number: **UNE32C**

Annual Report: ☐ Due 30-Sep-03

Progress Report: ☐ Due 29-Jan-03

Final Report: ☒ Due 30-Sep-03
(or within 3 months of completion of project)

Project Title: **Ecology and management of bladder ketmia (Hibiscus trionum) and other emerging problem Malvaceae weeds and Technical support for the development of WEEDpak.**

Project Commencement Date: 10/01/2000 **Project Completion Date:** 30/06/2003

Research Program: Diseases and Weeds

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Australian Government

Cotton Research and Development Corporation

FINAL REPORT

Ecology and management of bladder ketmia (*Hibiscus trionum*) and other emerging problem Malvaceae weeds, and Technical support for the development of WEEDpak.

UNE32C

January 2000 to June 2003

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Figure 1. *Hibiscus trionum* var. *vesicarius* crimson/red centre flower type.
Wide leaf bladder ketmia.

Executive Summary

Hibiscus trionum L. (bladder ketmia) is one of the most common weeds throughout the Australian cotton industry. There are two varieties of the weed, the narrow leaf introduced variety *Hibiscus trionum* var. *trionum* and the wide leaf native variety *Hibiscus trionum* var. *vesicarius* (Hochr.). There are two types of the wide leaf variety, commonly differentiated by their yellow and red centre flowers. Both *Anoda cristata* (L.) Schltr. (anoda weed) and *Abutilon theophrasti* Medik. (velvetleaf or swamp Chinese lantern) are less common but increasingly problematic weeds from the same plant family, Malvaceae.

Narrow leaf bladder ketmia is common in many 'cooler' and eastern areas and appears to be spreading outside these areas. Wide leaf bladder ketmia is more common in the 'warmer' western areas and is spreading within these areas. Anoda weed is a large problem in many areas in Queensland (Qld) and is spreading into areas in New South Wales (NSW). Velvetleaf is very uncommon in Qld and only found in small areas in NSW. Each of these species reproduces by seed and are spread by poor on-farm hygiene, by dirty machinery moving between clean and dirty areas (especially for anoda weed) and in water (especially the case for velvetleaf). Immediate action is required to manage these weeds and restrict their movement into areas where they presently do not occur.

These weeds are common throughout spring, summer and autumn, although narrow leaf bladder ketmia grows and produces seeds all year round. Wide leaf bladder ketmia and velvetleaf produce mature seeds from December onwards and anoda weed from February. To prevent seed set and cotton yield losses, management of these weeds needs to address three lifecycle aspects, these being firstly, successive seedling flushes after rainfall and irrigation, secondly, preventing adult plants from setting seed and thirdly, ensuring that good farm hygiene is practised so that spread is prevented. There are a number of registered herbicide options to control both seedling and adult plants of bladder ketmia, but limited or no options for the treatment of anoda weed and velvetleaf respectively. Cultivation and chipping are useful management tools in-crop while good farm hygiene should centre on cleaning down machinery and removing weeds from irrigation system infrastructure. These tools should all be used in combination in an integrated weed management (IWM) regime to ensure that successful control is achieved. Further herbicide options may need to be pursued for the control of anoda weed and velvetleaf in Australian cotton farming systems.

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Figure 2. *Hibiscus trionum* var. *vesicarius* yellow centre flower type.
Wide leaf bladder ketmia.

Full Report

Background

The cost of weed control to the Australian cotton industry is estimated to be in excess of $50 million annually (G. Charles pers. comm.). The total cost of weeds to the industry is likely to be much larger given the reduction in cotton yield and contamination of lint caused by weeds. In 1989, approximately 1.2 million kilograms of herbicide active ingredient were applied to Australian cotton fields at a cost of nearly $20 million (Charles *et al*. 1995). With the trend towards reduced-tillage systems in recent years, greater reliance has been placed on herbicides for weed control. Two of the major problems caused by modern weed management strategies are the development of herbicide-resistant weeds and the accumulation of herbicide residues in soil and water. In order to reduce herbicide use, other non-chemical control methods need to be incorporated into sustainable and integrated weed management strategies. Such strategies need to be based on an understanding of the ecology of the weeds that are present since failure to manage problem weeds is often due to a lack of detailed information about their ecology.

One group of weeds which is emerging as a major problem to the industry are those that are closely related taxonomically to cotton (*Gossypium* species) in the plant family Malvaceae. Among these weeds are the newer anoda weed (*Anoda cristata*) and velvetleaf (*Abutilon theophrasti*), as well as the more established and recalcitrant bladder ketmia (*Hibiscus trionum*). Because of their close physiological and phenological relationship to cotton, it can be difficult to find sufficiently selective herbicides for their control in the crop. Although bromoxynil controls bladder ketmia, the herbicide is expensive and other post-emergent herbicide options are limited. Bladder ketmia has been consistently ranked by growers and consultants as one of the six major weeds of cotton (Charles 1991, Johnson *et al*. 1998), but virtually nothing is known about the ecology of this plant, its population dynamics, or why it is proving to be so recalcitrant when several herbicides are supposed to control it. This information is particularly important for low-input farming systems or where key herbicides cease to be a viable control option. Likewise, it is not known whether the newer anoda weed and velvetleaf are likely to continue to spread throughout the industry as they have in the USA, the factors that promote their growth, or how best to manage them. Management methods based on an understanding of the ecology of Malvaceae weeds are therefore needed.

In accord with the CRDC and Cotton CRC research objectives, this project endeavoured to elucidate aspects of the ecology and competitive impact of Malvaceae weeds (focusing on bladder ketmia as the type weed) as the basis for developing integrated weed management strategies for them.

Figure 3. *Hibiscus trionum* var. *trionum.*
Narrow leaf bladder ketmia.

Project aims/objectives and the extent to which they have been achieved

Project aims

All the project aims were achieved.

The project investigated the ecology and competitive impact of bladder ketmia (*Hibiscus trionum*) as the basis for developing management strategies. The project involved literature reviews, field and mail surveys, and glasshouse and field experiments both at ACRI, Narrabri, and on collaborator's properties. The results from the work and information on two other emerging problem Malvaceae weeds i.e. velvetleaf (*Abutilon theophrasti*) and anoda weed (*Anoda cristata*), will be extended to growers to help them identify the species, prevent their spread and manage them where they occur. In broad outline, the research aims were achieved by:

1. literature searches and distilling the available overseas scientific information on the ecology and management of the three weeds;
2. surveying the distribution and spread through the Australian cotton industry and in northern Australia of velvetleaf and anoda weed by herbarium records, mail and field surveys;
3. assessing their potential to spread further through bioclimatic analysis (using comparative computer programs such as CLIMATE or BIOCLIM);
4. collecting seeds of the three weeds from geographically diverse populations and growing them up to determine seed production, dormancy and germination characteristics, and the existence of biotypic variation or variation in susceptibility to key herbicides;
5. regular monitoring of wild and sown populations of bladder ketmia to determine its method of seed dispersal, and when germination and other phenological stages (e.g. seed maturity) in the lifecycle of the weed occurs;
6. comparing germination and growth responses to temperature of the three weeds under controlled-environment conditions;
7. quantifying the competitive impact of bladder ketmia on cotton yield (and the relative competitiveness of the three weeds), and where possible, establishing economic threshold values, through field experiments over at least two seasons;

8. elucidating the principles for managing these problem weeds based on an understanding of the weaknesses of the weeds and other aspects of their ecology;
9. developing CRC Research Review publications on all aspects of the work for distribution to growers;
10. coordinating the production of WEEDpak and author various sections; and
11. providing technical support for the development of WEEDpak (both 10 and 11 were additions to the UNE32C during 2002).

Objectives achieved

All the project objectives were achieved.

The research was undertaken by Dr Stephen Johnson (post-doctoral fellow) as part of a coordinated Australian cotton CRC weeds research team based at ACRI, Narrabri. Dr Johnson's work on weed *ecology* supported the concurrent projects by Mr Graham Charles and Dr Ian Taylor (New South Wales (NSW) Agriculture/Cotton CRC) on weed *management systems*. Joint supervision was provided by Mr Graham Charles (on-site) and Associate Professor Brian Sindel (at UNE). The project was timed so as to fit in three seasons of experimentation. The objectives of the research over the three years were to:

Year 1

1. survey the distribution and spread of bladder ketmia, anoda weed and velvetleaf through the Australian cotton industry and monitor their occurrence in different farming systems, soil types and seasonal conditions;
2. produce a CRC Research Review publication on the weed Polymeria take-all (Dr Johnson's PhD topic), in WEEDpak and various industry publications;

Years 1 - 3

1. examine germination and growth responses, and other key aspects of the biology and ecology of bladder ketmia, and compare selected attributes with those of anoda weed and velvetleaf in Australian cotton-growing systems;
2. quantify the competitive impact of bladder ketmia on cotton yield and, where possible establish economic threshold values;
3. coordinate the production of WEEDpak and author various sections; and

4. provide technical support for the development of WEEDpak (both additions to the original application for UNE32C).

Year 3

1. elucidate the principles for managing these three problem weeds based on an understanding of the weaknesses of the weeds and other aspects of their ecology; and
2. develop material for an extension and awareness program for the three weeds.

Figure 4. *Anoda cristata.* Anoda weed.

How the research addressed the CRDC's outputs

This research has helped address all three of the CRDC's outputs.

1. Economic - more cost effective management of weeds,
2. Environmental - the development of sustainable control measures for weeds, and
3. Social - improve return on investment by ensuring technology is transferred to industry.

Research into the biology and lifecycle of the Malvaceae weeds has highlighted the critical periods at which control should be aimed to reduce weed populations within the existing season, and in future seasons, by reducing seed set. This has resulted in timely and cost effective control. In addition, the communication of this research about velvetleaf and anoda weed has not only resulted in large on-farm reductions of both species on some of the major cotton farms, but also highlighted the need to control small infestations, while they are still small, on other farms. It should be remembered that timely control would result in a reduction in the problems these weeds cause in future years both on- and off-farm. Consequently, the growth and competitiveness of cotton crops in fields with fewer weeds will be enhanced and indirectly there will be a reduction in herbicide use with associated environmental benefits. These measures are increasing the sustainability of control measures for these weeds.

The provision and use of WEEDpak by the cotton industry will help improve the return on current investments in weed management. Farmers, agronomists and consultants will be empowered in their weed management decisions because they have access to a 'one-stop' information resource that is both comprehensive and 'state-of-the-art'. Continued extension of the information contained in WEEDpak by both researchers and extension personnel will ensure that this information is used in the best possible way.

Methodology and justification

Survey of distribution and spread

The distribution and spread of bladder ketmia (*Hibiscus trionum*), anoda weed (*Anoda cristata*) and velvetleaf (*Abutilon theophrasti*), and to some degree other Malvaceae family weeds, was assessed through a variety of methods. These included:

1. herbaria visits including the New South Wales State herbarium (Sydney), Queensland State Herbarium (Brisbane), National Herbarium (Canberra) and the UNE herbarium (Armidale);
2. numerous on-farm visits to all major Australian cotton growing areas from Emerald in central Qld, Hillston in southern NSW, to Tandou in western NSW (with the exception of Bourke);
3. extensive consultations with consultants, farm agronomists and growers throughout the industry; and
4. helping conduct and process information from the Best Bet management surveys of growers, consultants and farm agronomists for WEEDpak.

Herbaria visits were essential to ascertain the traditional and probable current distribution of the species. Other useful lifecycle, biology and ecology information was also obtained by accessing herbaria records. All information from herbaria records was then checked extensively throughout the cotton industry by on-farm visits and consultation with cotton industry personnel. Numerous additional records were obtained, and collections made and submitted to several herbaria so that their material and records could be updated.

Information on the probable spread of each species was noted from the herbaria records and from observations by cotton industry personnel. This dual approach to collecting distribution and spread information from historic (herbaria) and current (cotton industry personnel) sources was essential for at least three reasons.

1. It allowed the determination of the different bladder ketmia varieties and types, particularly when some herbaria records were unclear and cotton industry experience was limited.
2. It helped gauge the increasing distribution and spread of anoda weed throughout Queensland (Qld) and now into NSW, where on-farm experience is somewhat

limited.

3. It was essential in ascertaining the traditional distribution of velvetleaf and helping understand why such a rapid spread had been observed in some areas recently in NSW.

Biotypic variation and susceptibility to key herbicides

Populations or biotypes of weeds of the same species can vary in a number of different physical characteristics. Initially these trials aimed to clearly ascertain the physical and herbicide susceptibility differences between the varieties and types of bladder ketmia (previously thought to be one uniform species). This work was extended to include the physical differences between biotypes of the different species (varieties and types) after herbaria consultations, on-farm observations and discussions with various researchers and cotton industry staff revealed large differences between different populations within each species (variety or type). As such, a number of geographically distinct populations of narrow leaf bladder ketmia, wide leaf bladder ketmia (yellow centre flower form) and wide leaf bladder ketmia (crimson/red centre flower form) were examined in two separate studies. A smaller trial examined differences in geographically distinct populations of anoda weed and velvetleaf after literature reviews indicated that some differences could be expected in those species too (Warwick and Black 1986).

Differences in biotypic variation are usually the result of the interactions between the genetic composition of the population and the environment in which the plants grow. By growing all populations under controlled glasshouse conditions, the 'true' or genetic expression of the biotypic variation under one set of environmental conditions was assessed. A wide variety of physical growth parameters were measured including times to flowering and seed set, plant growth, leaf area, dry weight and reproductive allocations.

Differences in the susceptibility of bladder ketmia to key herbicides were known prior to the projects commencement (R. Daniel pers. comm.). In particular, limited trial work had revealed that narrow leaf bladder ketmia appeared to be more susceptible to bromoxynil, and that there were differences in susceptibility between narrow and wide leaf bladder ketmia to glyphosate. These differences had strong commercial implications since both Roundup

Ready® and BXN (bromoxynil-resistant) cotton were under development at the time. Because of the broad nature of the project, and the limited technical support originally requested, it was decided that Mr Scott Wallace should investigate these differences on a limited number of narrow and wide leaf bladder ketmia populations for his B. Rur. Sc. Honours thesis at UNE under the supervision of Mr Guy Roth, Assoc Prof Brian Sindel and Dr Stephen Johnson.

Lifecycle and seed viability studies

Populations of bladder ketmia, anoda weed and velvetleaf were evaluated in both off- and in-field locations during three seasons. The off-field sites yielded important information about the general lifecycle of the species in the absence of weed management practices. The data obtained represented minimum figures for most lifecycle parameters, for example, emergence, plant recruitment and seed production, and may be similar to fallow populations. The in-field studies showed marked similarity in terms of the lifecycle to the plants examined in off-field locations, and allowed more realistic estimates of certain parameters, for example seed production. Because of the varied nature of many of these trials a basic summary of the lifecycle information will be presented. Because of the prolific emergence of all species only wild populations were assessed rather than sown populations as originally specified in the objective.

One of the largest, and most often neglected areas of a weed's lifecycle is the soil seed bank. Understanding the seed bank dynamics of a weedy species is crucial to ensuring good long-term control once seed set has occurred. Determining the effect that seed burial has on seed viability is one critical aspect of soil seed bank dynamics. For example, if weed seeds survive in the soil for only short periods (several years), efforts to eliminate seed set and prevent reintroduction of seeds back into fields are likely to be rewarded with reduced weed populations. While there is good seed viability data for both narrow leaf bladder ketmia and velvetleaf from overseas indicating extensive seed viability over many years, there is little data on the three other Malvaceae species examined (wide leaf bladder ketmia, anoda weed and marshmallow). This seed viability trial will yield important information on the seed longevity of each species under Australian cotton farming systems.

Germination and growth responses

Basic research into how to reliably break the dormancy of various species is essential so that plants can be grown for experimental purposes. This information has not generally been reported in the literature. Small experiments were conducted for each species applying various dormancy-breaking treatments and assessing germination under growth cabinet conditions. It was planned to examine temperature effects on germination. However, due to the lack of temperature controlled growth cabinets at ACRI, this was not possible.

Competitive impact

There are many ways to assess the competitive impact that a weed has on the growth of a crop. In general field based trials give the best estimates of what will occur under commercial conditions. Due to a number of technical, climatic and resource problems, the competitive impact of narrow leaf bladder ketmia, wide leaf bladder ketmia (both types), anoda weed and velvetleaf had to be assessed under glasshouse conditions. The information obtained indicated the relative competitive impact of each species on normal and okra leaf cotton, as well as providing growth reduction data during the first nine weeks of growth, a critical time for the growth of cotton and competition between cotton, and Malvaceae weeds.

Figure 5. *Abutilon theophrasti*. Velvetleaf.

Results and discussion

Objective 1

Literature searches and distilling the available overseas scientific information on the ecology and management of the three weeds.

This process is still continuing and relevant information will be integrated into journal papers where appropriate.

Objective 2

Surveying the **distribution and spread** of velvetleaf and anoda weed by herbarium records, mail and field surveys through the Australian cotton industry and in northern Australia.

The distribution and spread of bladder ketmia (*Hibiscus trionum*, Figures 1-3), anoda weed (*Anoda cristata*, Figure 4) and velvetleaf (*Abutilon theophrasti*, Figure 5), and to some degree other Malvaceae species such as native rosella (*Abelmoschus ficulneus*, Figure 9), spiked malvastrum (*Malvastrum americanum*, Figure 10) and marshmallow (*Malva parviflora*, Figure 11) was ascertained. This information is currently being readied for publication for both the cotton industry and for the wider scientific community in a journal paper.

Bladder ketmia

There are two varieties of bladder ketmia in Australia, *Hibiscus trionum* var. *trionum* (narrow leaf bladder ketmia, Figure 3) and *H. trionum* var. *vesicarius* (wide leaf bladder ketmia). In addition, there are two phenotypes of wide leaf bladder ketmia, best distinguished by the colour present in the centre of the flower, these being the yellow (Figure 2) and red (Figure 1) centre flower types. These differences have been traditionally recognised in a qualitative sense by various botanists, and are increasingly by cotton industry personnel. The quantitative differences between these varieties and types have been outlined in objective 4.

In a general sense, the distribution of the two varieties follows the division between the north and central west slopes, and north and central west plains in NSW, and the division between the slopes and plains in the Darling Downs and Burnett districts in Qld (Figure 6).

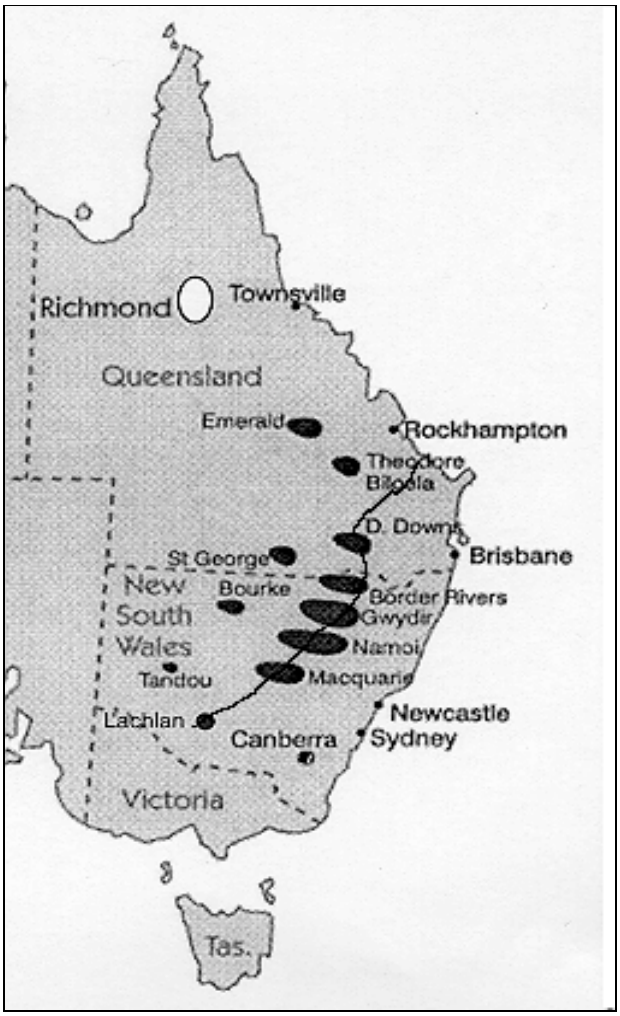

Figure 6. Cotton growing areas in eastern Australia. The line on the map represents the integrade of narrow leaf bladder ketmia from the east and wide leaf bladder ketmia from the west. The line roughly passes along the Newell highway (Dubbo, Coonabarabran, Narrabri, and then east of Moree), through to Macalister or Jimbour on the Darling Downs, and through the South Burnett to the coast. Both varieties coexist around and within 50 km of this line.

The distribution of narrow leaf bladder ketmia, probably introduced, is mainly eastern NSW and coastal Qld, although not as far north as Rockhampton. Narrow leaf bladder ketmia is the only variety of bladder ketmia found around Gunnedah, on the eastern Darling Downs and onto the Tablelands around Armidale and Inverell. Narrow leaf bladder ketmia commonly grows with the yellow centre flower type of wide leaf bladder ketmia in the Namoi, Macquarie and Lachlan valleys, and with both wide leaf bladder ketmia types around Jimbour on the Darling Downs areas. In what could be an unintentional introduction in forage crop seed, narrow leaf bladder ketmia has also been observed at Tandou.

The distribution of wide leaf bladder ketmia, widely thought to be an Australian native (Mitchell and Norris 1990), is western NSW and Qld. The wide leaf type with the yellow/cream centre flower is commonly found throughout western NSW and into southern

Qld, in particular the Macintyre valley. Here the yellow flower centre type intergrades with the red/crimson centre flower type. Both types have been observed growing together in the St. George irrigation area and on the Darling Downs west of Dalby around Jimbour. In addition to the Darling Downs and St. George area, the red flower centre type of wide leaf bladder ketmia can be found throughout central Queensland, particularly near Theodore, Emerald and Rockhampton. Herbarium records indicate that the red centre type is common throughout western Qld, NSW and the Northern Territory.

The apparent clear demarcation between narrow and the yellow centre flower type of wide leaf bladder ketmia, particularly in eastern NSW, is unusual and not clearly understood. Neither is the demarcation between the yellow and red flower centre types of bladder ketmia in southern and northern areas respectively. While there are areas where both varieties and types coexist, there are also distinct areas where either one of the varieties or types can be found. Varieties and types are probably spreading into areas where another variety or type dominates as the occurrence of narrow leaf bladder ketmia at Tandou illustrates. However, in general, there is not wide scale colonisation of either variety or type into areas where they have traditionally not been found. It is likely that conditions required for seed germination, seedling establishment and growth conditions are specific for each variety and type. This suggestion requires further investigation.

Anoda weed

Anoda weed (*Anoda cristata*) appears to have originated in the American continental tropics where it is a minor but troublesome weed of crops. Anoda weed appears to have been introduced into Australia in the late 1800's as a stock feed contaminant (in chaff). After its introduction near Ipswich, the weed rapidly spread across the Darling Downs, the South Burnett, into the Macintyre (Goondiwindi and Mungindi) valley, and eventually into the St. George irrigation area, all areas where the weed is a considerable problem today. For example, anoda weed was identified as a significant problem in the Macintyre Valley, the Darling Downs/South Burnett and St. George regions in a Polymeria take-all survey conducted during 1996 (Johnson *et al.* 2003). The weed is a minor problem in the Dawson/Callide valley where it was recorded as a weed of cotton crops in Thangool in early 1961, a very minor weed in the Emerald irrigation area (V. Osten pers. comm.) and other areas of Queensland.

Although anoda weed was recorded on the north coast of NSW in 1957 and near Parkes in 1959, NSW cotton cropping areas appeared to remain free of anoda weed until the 1980s. Unfortunately, the weed then spread quickly into NSW, probably as a result of poor harvest machinery hygiene. The weed was recorded as a problematic weed of cotton crops around Wee Waa in 1983, Moree in 1992 and Narromine in 1994. Currently there are small but increasing infestations of the weed around Moree and east of Collarenebri (Gwydir), west and north of Wee Waa (lower Namoi), north of Trangie and Warren (Macquarie), and at Bourke. There is strong evidence to suggest that anoda weed is spreading from these isolated sites, both across already infested farms and onto previously clean farms. Anoda weed will need to continue to be managed to contain its spread throughout the NSW cotton cropping areas.

Today anoda weed is a particularly troublesome weed in summer crops including irrigated and dryland cotton, peanuts, maize, sorghum and in pasture situations. Once the weed became entrenched farmers have found it difficult to eradicate, despite the selective action of Staple® (pyrithiobac-sodium) on the seedlings of the weed in cotton crops.

Velvetleaf

Velvetleaf (*Abutilon theophrasti*), also known as swamp Chinese lantern, is an introduced weed, varieties of which are still used in China for making hemp fibre. The path of introduction of the weed into Australia is still unclear, but one plausible theory involves its introduction first to the United States of America (USA) from China during the time of the War of Independence with England, and then to Australia, both times as a potential new hemp fibre source (H. Wood pers. comm.). It appears that initial introductions into the USA involved weedy and not hemp biotypes (Spencer 1984, Wood 1992), and it is suggested the same occurred in Australia, whether independently from China, or via the USA (R. Barker pers. comm.).

Velvetleaf was recorded in isolated areas by Mitchell in 1836 and Mueller in 1855 when the initial botanical surveys were carried out along the Murray and Darling rivers. It has been suggested that early riverboat and overland settlers brought potential new fibre and food crops with them when they settled and that they introduced the plant (R. Barker pers. comm.). In addition, velvetleaf has been recorded in herbaria records in various places in the Murray

and Murrumbidgee rivers systems over the last 100 years.

Despite velvetleaf being one of the most common and difficult-to-control weeds of summer crops on the North American continent, it is surprisingly uncommon in Australia, despite the climatic and cropping similarities of parts of north America to eastern Australia. There are four herbarium records of the weed in Qld, one from the Diamantina river, another from Kingaroy (south Burnett) and two from the Condamine river, south east of Millmerran and Pittsworth, with a further anecdotal record of the weed from the Darling Downs. This indicates that if populations of the weed are indeed still present in Qld then they are isolated in distribution and causing very few problems.

The situation is somewhat different in NSW where the weed has been recorded in herbarium records in a number of locations along the Darling, Macquarie, Lachlan, Peel and Mooki rivers, and on the Liverpool plains. Presently there are severe infestations on at least three cotton farms west of Moree on the Mehi river and in the Gwydir wetlands, one farm in the lower Namoi and one farm in the lower Macquarie. Lighter infestations have been recorded on at least eleven other farms in the upper and lower Namoi, two farms north west of Narromine in the Macquarie and at Tandou. Given that this species appears to grow naturally in low depressions that are easily flooded beside many of the western rivers, it is highly likely that other light infestations exist in the Gwydir wetlands, in the lower Namoi and along the Macquarie river, both above and below the Macquarie marshes where herbarium records indicate populations of the species. Since the seed heads and seed of this species are spread easily in water, it is highly likely that this weed will continue to spread downstream from such infestation sites, particularly if floodwater harvesting continues.

Native rosella

Native rosella (*Abelmoschus ficulneus*, Figure 9) is a native summer growing weed that appears to be restricted to Queensland cotton cropping areas, most particularly in the Dawson and Callide valleys, and in the Emerald irrigation area. It is a common weed in northern Australian cropping areas, in northern Queensland, the Northern Territory and Western Australia (Wilson *et al.* 1995, R. Eastick pers. comm.). The weed has the potential to continue to be troublesome in the more tropical areas where cotton is grown. Although it is not known why this weed does not occur south of central Qld, it may be that this species has

specific temperature requirements for growth and this has not allowed the spread of the species.

Spiked malvastrum

Spiked malvastrum (*Malvastrum americanum*, Figure 10) is an introduced weed of central and southern Qld, particularly the Macintyre valley, and in northern NSW (Wilson *et al.* 1995). Although the weed may be a moderate to major problem in some areas, it is uncommon and often occurs at low density. If the weed is allowed to spread unchecked it can grow at large densities reducing cotton yield. Another malvastrum species, prickly malvastrum (*M. coromandelianum*), again introduced, is a minor weed in central Qld (Wilson *et al.* 1995), and has been recorded in the upper Namoi (T. Smith pers. comm.).

Marshmallow

Marshmallow, or small leaved mallow (*Malva parviflora*, Figure 11) is the only Malvaceae weed that is more troublesome in winter cropping systems than in cotton itself. The species grows throughout winter and well into spring and early summer, usually in fallows and along road and field edges. This weed appears to be increasing in incidence under reduced tillage conditions, particularly those found in the southern and western grain areas of Australia. The biotypic variation and management of marshmallow is the subject of PhD research in Western Australia (Michael *et al.* 2002). The weed is a common problem in cotton growing systems in NSW and southern Qld.

Other species

Other Malvaceae species have been recorded as weeds of cotton, the most prominent of which is *Hibiscus panduriformis* (native hibiscus) throughout the cropping areas of the Northern Territory and Western Australia. Recent research highlighted that there are various forms of this species (L. Juswara and L. Craven, unpublished data). In addition, *Sida acuta* (spiny-head sida), *Sida spinosa* (spiny sida) and *Sida cordifolia* (flannel weed) are common weeds in these cropping areas (Wilson *et al.* 1995), particularly on the red cropping soils (R. Eastick pers. comm.). The incidence of these and other *Sida* species such as *S. rhombifolia* and *S. fibulifera* in the more established cotton growing areas was not investigated in this

study.

Two *Abutilon* species occur in isolated situations, these being *Abutilon malvifolium* (bastard marshmallow) in the Macintyre valley and *Abutilon tubulosum* around Emerald. In addition, one species of hollyhock, *Lavatera plebeia*, (Figure 16), has been found growing in the lower Namoi, around the Murrumbidgee river and at Tandou.

Figure 7. *Hibiscus trionum* var. *trionum.*
Narrow leaf bladder ketmia seedling.

Objective 3

Assessing the weeds potential to spread further through **bioclimatic analysis** (using comparative computer programs such as CLIMATE or BIOCLIM).

The potential for bladder ketmia, anoda weed and velvetleaf to spread further was ascertained using a combination of current distribution information and the likely dispersal mechanisms of the species. The information derived made the use of the comparative computer programs CLIMATE and BIOCLIM unnecessary. This was outlined in earlier progress reports on this project.

Bladder ketmia

The various varieties of bladder ketmia are already widely distributed throughout the cotton industry. The seeds of this species are likely to be spread in mud, crop trash, in irrigation and flood water, harvested lint, in crop seed and on machinery and farm personnel. Good farm hygiene will prevent this species being spread further.

While narrow leaf bladder ketmia appears to be restricted to the more eastern growing areas, its incidence at Tandou shows that the species has the potential to spread and grow in the more western growing areas. The widespread occurrence of this variety in eastern Australia in a range of coastal and tableland areas, and indeed throughout many areas of the world, lends further evidence to the capacity of narrow leaf bladder ketmia to spread further throughout the industry. It is less likely that the wide leaf bladder ketmia varieties will spread any further east of their existing range because this variety appears to require more specific conditions for growth than the narrow leaf variety. More specific research is required to elucidate the differential capacity of the different varieties and types to tolerate low temperatures as this factor probably limits the spread of each variety and type.

Anoda weed

Anoda weed appears to be easily spread on dirty harvest machinery and many new outbreaks can be traced to this source. The weed can also be spread in mud on cultivation machinery, in harvested cotton lint, in forage (hay) and perhaps in water. Since anoda weed is already a problem in all cotton growing areas in Queensland, steps need to be taken to ensure it does not continue to spread from infested to clean areas. Because anoda weed only occurs in

isolated areas in NSW as yet, more proactive measures are needed to prevent the weed spreading from these small outbreaks to otherwise clean areas. These measures need to focus on the Gwydir, Namoi and Macquarie valleys and Bourke area where the weed currently occurs to prevent its spread within these areas and the Lachlan/Murrumbidgee and Tandou area where the weed is yet to be recorded. There is some evidence to suggest that the opportunity to limit the spread of anoda weed in NSW growing areas is almost beyond the capacity of the cotton industry given the recent spread of the weed from isolated farms around Wee Waa and Trangie onto previously clean farms in both of these areas.

Velvetleaf

Water, and particularly flood water, is the predominant means of spread for velvetleaf, particularly to new areas. The weed is commonly moved around farms in irrigation water, especially where poor storage and irrigation channel hygiene is practised. Other mechanisms of spread are strongly suspected including the spread of seeds carried in mud on machinery, on machinery itself, and via bird ingestion with later release. These and other mechanisms are likely to continue to spread this weed, particularly on farms that already have infestations, but also onto farms without the weed. Cotton growing properties that pump river water downstream of known infestations, and those that border farms with existing infestations through which overland flows occur, must be considered as high risk areas for spread. The areas of greatest risk include the Gwydir wetlands and areas west of Moree, the lower Namoi and the lower Macquarie. With good farm hygiene, this weed should be largely restricted to NSW cotton growing areas.

The spread of velvetleaf has been well documented since the winter floods of 1998, but its movement earlier than this is unclear. For example, the spread of the weed from supposed historical plantings has not been assessed but was not apparently great, unlike the historical spread of the weed in the USA. Again, small numbers of velvetleaf plants have been recorded for up to 40 years around Wee Waa, but until recently the weed has never spread rapidly (T. Davis pers. comm.). There are at least two reasons why this may be the case. Firstly, the environmental conditions for the spread of the weed may not have been met, unlikely in the 150+ years the weed has been in Australia, but not entirely unheard of in the case of other weed species (Groves 1999). Rather, it is more likely that the types of the weed may not have been entirely suited to the Australian environment initially and now, after

successive generations, new types have emerged, concurrent with conditions for successful spread. This theoretical 'lag phase' is well known in other weeds and in apparently benign pasture species that are now emerging as weeds. If this theory is correct, the potential for velvetleaf to spread throughout the western rivers of NSW, in particular the cotton growing areas, is enormous and every effort should be made to identify, contain and control outbreaks of this weed.

Figure 8. *Hibiscus trionum* var. *vesicarius.*
Wide leaf bladder ketmia seedling.

Objective 4

Collecting seeds of the three weeds from **geographically diverse populations** and growing them up to determine seed production, dormancy and germination characteristics, and the existence of biotypic variation, or variation in susceptibility to key herbicides.

There were two aspects to the completion of this aim.

1. The existence of **biotypic variation** within bladder ketmia, anoda weed and velvetleaf, including relative assessments of seed production.
2. Variation in **susceptibility to key herbicides**. This involved investigations into the susceptibility of bladder ketmia to two herbicides only and was performed by UNE Honours student Scott Wallace (co-supervised by Guy Roth, Brian Sindel and Stephen Johnson).

1. The existence of biotypic variation within bladder ketmia, anoda weed and velvetleaf populations.

To facilitate research on the biotypic variation and other basic seed biology parameters of these species, various seed collections were made throughout this study (Table 1). Biotypic variation was assessed by growing plants of each of the populations outlined under glasshouse conditions at the Australian Cotton Research Institute (ACRI) at Narrabri. Four trials were conducted, two assessing various bladder ketmia types, a third assessing various anoda weed and velvetleaf types and a fourth assessing only one population of each weed with the weeds grown concurrently in the glasshouse. The first three trials were conducted to assess the biotypic variation between a wide range of populations within a species, while the fourth trial was conducted to compare the lifecycles of the different species.

A wide variety of vegetative and reproductive parameters were measured, most in four sequential destructive harvests approximately three weeks apart. These parameters included seed numbers and weights (planting and harvest), seedling emergence, times to flowering and mature seed set, plant heights, leaf numbers, leaf areas, selected leaf dimensions, shoot dry weight components (stems, leaves, buds, flowers and seed heads), numbers of buds, flowers

and seed heads and root dry weights.

Table 1. A summary of seed collections made to study the biotypic variation and lifecycle of bladder ketmia, anoda weed and velvetleaf.

Species	Populations collected	Populations used in biotypic variation trials	Population locations
Narrow leaf bladder ketmia	29	16	Darling Downs, Namoi, Macquarie, Tandou, Premer, Armidale, Inverell and commercial types*.
Wide leaf bladder ketmia (yellow flower)	30	13	St. George, Darling Downs, Macintyre, Gwydir, Namoi, and Macquarie.
Wide leaf bladder ketmia (red flower)	6	5	Emerald, Theodore, St. George, Darling Downs and Rockhampton.
Anoda weed	11	6	Kingaroy, St. George, Macintyre, Gwydir, Namoi and Macquarie.
Velvetleaf	11	6	Gwydir, Namoi and Macquarie.

*'Commercial types' of bladder ketmia were those sold as ornamental cultivars by large horticultural companies.

Although a wide variety of parameters were measured, only those most relevant to the management of each species will be discussed. Further details can be found by investigating Tables A1-A3 for the three trials assessing biotypic variation and Table A4 for the comparative lifecycle trial in the appendices.

The following differences between wide and narrow leaf bladder ketmia, and two wide bladder ketmia types were observed (see also Tables A1 and A3, and a summary in Table 2).

1. The smaller seeded narrow leaf bladder ketmia was quicker to emerge than the yellow and red centre flower types of wide leaf bladder ketmia, which were similar to each other.
2. Narrow leaf bladder ketmia was quicker to flower and produce mature seed heads than wide leaf bladder ketmia. In general, the yellow flower type was quicker than the red flower type of wide leaf bladder ketmia in these respects.
3. Wide leaf bladder ketmia seedlings were larger than narrow leaf bladder ketmia types in all parameters measured, for example, leaf size and area, and shoot dry weight.
4. Narrow leaf bladder ketmia had more leaves than both the wide leaf types, which were similar after 3-8 weeks. The leaf area of wide leaf bladder ketmia tended to be larger.
5. Although the plant heights were similar after three weeks, wide leaf bladder ketmia became larger after 6-8 weeks. The red centre type of wide leaf bladder ketmia was taller

than the yellow centre type, while leaf areas were similar. Wide leaf bladder ketmia tended to be larger than narrow leaf bladder ketmia in many vegetative parameters.

Table 2. A summary of some of the basic differences in the varieties and types of narrow and wide leaf bladder ketmia. The information has been drawn from Table A1, A3a and personal observations.

Character	Wide leaf bladder ketmia	Narrow leaf bladder ketmia
Plant photographs	Figures 1, 2, 8, 13.	Figures 3, 7, 12.
Introduced/native	Native.	Probably introduced.
Approx. distribution	Warmer, western and northern growing areas.	Cooler, eastern cotton growing areas.
Plant height and habit	Always erect and up to 1.5 m high.	Semi-prostrate to erect, to 1.3 m.
Leaf appearance	Waxy and mid to dark green.	Leaves less waxy often with purple tinged edges.
	Leaves with 3 lobes, not deeply divided.	Leaves have 3, sometimes 5 lobes, deeply divided.
	Margins not toothed (entire).	Margins are toothed.
Leaf size (length x width)	95 x 89 mm (yellow).* 101 x 70 mm (red).	68 x 90 mm.
Flower appearance	Cream with yellow (+/- distinct) or crimson/red centres.	Yellow/cream petals with deep purple centres.
Time to flowering (average)	32 days (range 28-39 days) yellow.* 38 days (range 35-41 days) red.	30 days (range 26-32 days).
Time to mature seed heads **(average)**	51 days (range 49-54 days) yellow.* 61 days (range 59-64 days) red.	45 days (range 42-48 days).
Reproductive plants	Seed heads are conspicuous on the main and larger plant stems.	Seed heads are less conspicuous among the leaves and are scattered all over the plant.
Seed head appearance	Straw coloured and rough in texture with raised ribs. Not see-through upon maturity.	Light grey and papery with soft, raised ridges that are purple. Nearly see-through upon maturity.
Seed head attachment	Firmly attached to plant.	Easily broken or detached from plant.
Seed head number per plant	**67.0** (range 0-199) yellow only.	**163.5** (range 0-395).
Seed size (20 seed wt.)	0.17 g	0.09 g
and colour	Black.	Mid grey.
Seed number per seed head	**37.4** (range 33.7-39.1) yellow.* **34.4** (range 25.9-38.8) red.	**34.0** (range 30.8-40.1).
Total seed number per plant	**2506**	**5559**
Seed production in field/m^2		
2 plants/m^2 (light)	**5000**	**11 100**
10 plants/m^2 (heavy)	**25 000**	**55 600**

*Data from Table A1 only.

6. After 6-8 weeks, narrow leaf bladder ketmia tended to be more reproductively advanced than both types of wide leaf bladder ketmia.
7. At harvest, both narrow and wide leaf bladder ketmia were similar in terms of vegetative and reproductive dry weight.
8. The number of seed heads of narrow leaf bladder ketmia greatly exceeded those of the yellow centre type of wide leaf bladder ketmia, which in turn exceeded the number of seed heads of the red centre type of wide leaf bladder ketmia. Accordingly, seed production in narrow leaf bladder ketmia was twice that in wide leaf bladder ketmia per plant.
9. The number of seeds/seed head appeared varied between the varieties and types. Often, there was more variability within different populations of the one variety or type than between the different varieties and types. In general there was between 34 and 37 seeds produced per seed head.
10. In general, narrow leaf bladder ketmia had a shorter vegetative period and produced flowers and mature seeds faster than the yellow centre type of wide leaf bladder ketmia, which in turn was faster than the red centre flower type of wide leaf bladder ketmia.
11. Narrow leaf bladder ketmia quickly produced mature seed and then produced a larger number of seed heads each day during its reproductive phase. In contrast, wide leaf bladder ketmia took longer to produce mature seed and then produced a smaller number of seed heads.
12. In addition to the difference in the parameters outlined above, that is those between varieties and types, there was considerable variation in the parameters within the different populations assessed of a variety or type. Hence while the lifecycle of these species can be determined by glasshouse studies, variation does occur. For this reason, the lifecycle of individual populations may need to be monitored by on-farm managers to achieve good management.

The following differences between anoda weed and velvetleaf were observed (see also Table A2, and summarised in Table 3),
1. The smaller seeded velvetleaf emerged quicker than anoda weed.
2. Anoda weed plants were far larger and more robust than velvetleaf. This trend was clear in all vegetative parameters measured from plant heights, to leaf sizes and areas, to the various components of plant dry weight.

3. Velvetleaf developed to reproductive maturity faster than anoda weed producing earlier flowers and mature seed heads.

Table 3. A summary of the basic differences between anoda weed and velvetleaf. The information has been drawn from Table A2 and personal observations.

Character	**Anoda weed**	***Velvetleaf***
Plant photographs	Figures 4 and 14.	Figures 5 and 15.
Introduced/native	Introduced.	Introduced.
Approx. distribution	Widespread throughout Qld. Limited but increasing areas in NSW.	Presence very minor in Qld. Small but increasing areas in NSW.
Plant height and habit	Erect and up to 2 m high.	Erect and up to 1.4 m high.
Leaf appearance	Triangular to triangular/oval shaped. Dull green, older leaves with scarlet spots on surface near petiole. Leaves with 3, sometimes 5 lobes, with few irregular teeth.	Heart to circular shaped. Mid green and covered in soft velvety hairs. Leaves sometimes damp with exudates. Leaves with small irregular notches.
Leaf size (length x width)	94 x 70 mm.	36 x 41 mm (up to 100 x 300 mm in wet areas).
Flower appearance	Purple/lavender and around 1 cm wide.	Yellow and 1-2 cm wide.
Time to flowering (average)	56 days (range 55-57 days).	43 days (range 40-46 days).
Time to mature seed heads **(average)**	73 days (range 72-74 days).	62 days (range 58-68 days).
Reproductive plants	Seed heads inconspicuous, initially in main stem leaf axils and later on branches.	Seed heads conspicuous, often above cotton canopy late-season.
Seed head appearance	Brown, star-shaped, flattened and spurred. Seeds contained in wedge-shaped segments in a central 'pie' head and 1-2 cm wide.	Black, cup shaped with a flattened awned surface and 1-2 cm wide. One to three seeds contained in vertical slits.
Seed head number per plant	**87.6** (range 0-261).	**192.4** (range 40-465).*
Seed appearance	Large, dark brown to black	Smaller, light to mid grey/brown.
Seed number per seed head	**13.7** (range 11.7-14.5).	**25.7** (range 24.0-28.5).
Total seed number per plant	**1200**	**4945**
Seed production in field/m^2		
2 plants/m^2 (light)	**2400**	**9900**
10 plants/m^2 (heavy)	**12 200**	**49 400**

*The seed head number per plant data presented here for both velvetleaf and anoda weed have been derived from field trials. Glasshouse trials using potting mix instead of soil appeared to favour the reproductive capacity of anoda weed over velvetleaf in contrast to field trials.

4. Once floral initiation of anoda weed had commenced, the reproductive capacity of this weed quickly exceeded velvetleaf in the glasshouse only (Table A2 c.f. Table 3).
5. Although velvetleaf produced twice as many seeds/seed head, anoda weed produced five times the number of seed heads as velvetleaf and had the largest reproductive capacity of the two species in the glasshouse trial (Table A2 c.f. Table 3).
6. There was a large amount of variation for each parameter measured within each species. This means that different populations of the one weed are naturally very variable once grown under the same set of glasshouse conditions. This means that there is no 'hard and fast rule' and that each population of a weed needs to be monitored closely by on-farm staff to characterise lifecycles accurately and hence adjust control procedures.

The comparative lifecycle trial between all species revealed the following (see also Table A4),
1. Anoda weed and velvetleaf were quickest to emerge while the red flower type of wide leaf bladder ketmia was slowest.
2. Anoda weed and velvetleaf had quicker leaf production rates than any bladder ketmia type resulting in higher leaf numbers earlier.
3. Considering only leaf expansion in the bladder ketmia types, narrow leaf was quicker than or similar to the yellow flower centre type of wide leaf bladder ketmia and both were quicker than the red flower type.
4. After six weeks, velvetleaf was taller than all bladder ketmia types, which was in turn taller than anoda weed.
5. Narrow leaf bladder ketmia developed faster and produced more flowers and seed heads, followed by the yellow flower type of wide leaf bladder ketmia, and velvetleaf. The red flower type of wide leaf bladder ketmia was the slowest to develop and this may have been a result of the temperature conditions in the glasshouse (cooler than normal for this type in early summer), or may have in fact been a real genetic difference.
6. The conditions for floral initiation of anoda weed were not met in this trial, which was conducted under increasing daylength conditions.

Implications

1. The need to understand the lifecycle for all weed species

In the most general sense it is important to recognise the basic species differences to tailor management specifically. This information, combined with the lifecycle information from objective 5, has been discussed in objective 8.

2. The need to understand differences within a species

These studies have shown wide variation in particular species in a number of basic lifecycle and growth parameters. Two varieties have been recognised, the narrow and wide leaf variety (var. *trionum* and var. *vesicarius* respectively). In the wide leaf variety, two types were recognised, a yellow and a red centre flower type. Variation between different populations of each of these varieties and types was also apparent as was the case with different populations of anoda weed and velvetleaf. This once again highlights that while recommendations can be made about the management of each of these varieties or types in a general sense, it is important that growers and agronomists monitor weed populations on farm and manage them accordingly.

3. Taxonomic confusion in Hibiscus trionum

This study has highlighted the differences between the various varieties and types of bladder ketmia, aiding in their identification and management in the cotton industry. The existing literature before this study on identification and botanical classification of narrow and wide leaf bladder ketmia could be described as inconsistent and somewhat confused. There appears to be widespread variation in what is known as bladder ketmia or Venice mallow (*Hibiscus trionum* var. *trionum*) from different populations around the world, whether as naturalised populations or as commercially available (ornamental) cultivars of the plant (Table A3b). There is also some evidence to suggest that wide leaf bladder ketmia may also have been previously described as an entirely different species in the botanical literature. Dr Lyn Craven, an Australian Malvaceae expert from the National Herbarium at CSIRO Plant Industry in Canberra, is seeking to revise the species *H. trionum* and publish a journal paper on this. Information from this study, and herbarium collections made over the last three years will contribute significant data to this proposed future revision.

There are three primary publications that are currently being drafted from this work dealing with

a. A general paper covering the gross differences in bladder ketmia (*Hibiscus trionum*).
b. A more in-depth paper examining the phenotypic variation in *Hibiscus trionum*.
c. The phenotypic variation in *Anoda cristata* and *Abutilon theophrasti*.

These publications will be prepared for both the cotton industry and for the wider scientific community in journal papers. In addition, it is likely that involvement in the botanical revision will result in a further publication from this work.

2. Variation in susceptibility to key herbicides, a study performed by UNE Honours student Scott Wallace, and co-supervised by Guy Roth, Brian Sindel and Stephen Johnson.

Mr Scott Wallace, a former University of New England Rural Science Honours student conducted a study to determine the relative susceptibility of two populations of wide and narrow leaf bladder ketmia to glyphosate and bromoxynil. These two herbicides were chosen because of their potential use in herbicide-tolerant cotton, in particular Roundup Ready® and bromoxynil resistant cotton, and their apparent differential action on the different bladder ketmia varieties. Bayer CropScience has since stopped work on the development of bromoxynil resistant cotton. It was found that while glyphosate (510 g/L) applied at label rates (1.35 L/ha) to adult plants that were in the early stages of flowering and producing green seed heads achieved good control of both varieties, these applications were more effective on the wide leaf variety. This result fits well with growers' experiences of controlling both varieties of bladder ketmia in Roundup Ready® crops.

This contrasted to the situation in bromoxynil, not registered for use on cotton crops. When applied at 1.4 L/ha it was significantly more effective on the narrow rather than the wide leaf variety, causing moderate damage to reproductive narrow leaf bladder ketmia plants at the same growth stages as outlined above. Anecdotal evidence also suggests that trifloxysulfuron sodium, Envoke®, has differential action on the two varieties of bladder ketmia (D. Harvey, Syngenta, pers. comm.). Both bromoxynil and trifloxysulfuron sodium are currently not

registered for the control of bladder ketmia in any situation.

Assoc. Prof. Sindel and Dr Johnson hope to present the most relevant conclusions to the cotton industry at a future cotton conference.

Objective 5

Regular monitoring of wild and sown populations of bladder ketmia to determine its method of seed dispersal, and when germination and other phenological stages (e.g. seed maturity) in the **lifecycle** of the weed occurs.

There are two aspects to the studies conducted under this aim:

1. **lifecycle** studies on bladder ketmia, anoda weed and velvetleaf; and
2. a continuing study into the effect that seed burial has on **seed viability** for narrow and wide leaf bladder ketmia, anoda weed, velvetleaf and marshmallow. This study will be combined into a larger study in the new project *Reducing weed control costs by better understanding the biology and ecology of problem weeds* (DAN175C).

1. Lifecycle studies on bladder ketmia, anoda weed and velvetleaf.

Populations of bladder ketmia, anoda weed and velvetleaf were evaluated in both off- and in-field locations during three seasons (Table 4). The off-field sites yielded important information about the general lifecycle of the species in the absence of weed management practices. The in-field studies revealed striking lifecycle similarities to the off-field sites and because of the varied nature of many of these trials only a basic summary of the lifecycle information has been presented (Tables 5 and 6).

Narrow leaf bladder ketmia

Narrow leaf bladder ketmia grows all year round. Emergence was recorded for all months except June and August, but it is likely to occur in these months as well with emergence events strongly linked to rainfall and irrigation. The bulk of plant recruitment occurs during spring and summer and although seedling numbers in excess of 200 seedlings/m^2 have been observed, seedling mortality is high. Both vegetative and reproductive plants are found year

round resulting in continual seed production and dispersal. Narrow leaf bladder ketmia plants are somewhat sensitive to frost and hence relatively uncommon over the winter months (June-August). This weed will grow over winter in weedy fallows or disturbed grassland

Table 4. A summary of the trials used to determine the lifecycle of bladder ketmia, anoda weed and velvetleaf. Only approximate locations are recorded with a site identification number.

Species	Year	Location and site
Narrow leaf bladder ketmia	2000/01	Lower Namoi A
		Macquarie A
	2001/02	Lower Namoi A
		Macquarie A
	2002/03	Lower Namoi B
	Total	5 trials
Wide leaf bladder ketmia (yellow flower centre only)	2000/01	Lower Namoi C
		Macquarie A
	2001/02	Lower Namoi C
	2002/03	Lower Namoi D
	Total	4 trials
Anoda weed	2000/01	Macquarie B
	2001/02	Macquarie B
	2002/03	Lower Namoi E
	Total	3 trials
Velvetleaf	2000/01	Lower Namoi F
	2001/02	Lower Namoi F
	2002/03	Lower Namoi G
	Total	3 trials

Table 5. A summary of the emergence of bladder ketmia, anoda weed and velvetleaf. A question mark has been used where emergence was suspected but not otherwise recorded.

Species	Emergence recorded or suspected											
	Sept.	**Oct.**	**Nov.**	**Dec.**	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May**	**June**	**July**	**Aug.**
Narrow leaf bladder ketmia	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes?	Yes	Yes?
Wide leaf bladder ketmia (yellow)	Yes?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes			
Anoda weed	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes			
Velvetleaf	Yes?	Yes	Yes	Yes	Yes	Yes	Yes	Yes				

situations, particularly where surrounding crop and weed stubble, or plants, afford protection from temperature extremes. Plant growth, flowering and seed set is reduced, but not eliminated over winter.

Glasshouse studies have shown that narrow leaf bladder ketmia can produce flowers within an average of 30 days (some populations within 26 days) and mature seed within 45 days (Table 2). Similar data have been observed in field trials with the peak of seed production occurring from 6-10 weeks after weed emergence, generally during the summer and early autumn (January-March). If a large weed seedling flush occurs and seedling mortality is not high, the smaller individual plants will produce a similar number of seed heads to a few larger plants. Plants as small as 5 cm high have been observed producing 1-3 seed heads.

Table 6. A summary of the lifecycle of bladder ketmia, anoda weed and velvetleaf. Vegetative plants are defined as those that no longer have cotyledons (6 - 8 true leaf stage), reproductive plants as those producing flowers and or green seed heads, while the seed dispersal stage as plants with open mature seed heads ready to/or having already dispersed seed.

Month	Growth stage	Narrow leaf bladder ketmia	Wide leaf bladder ketmia (yellow)	Anoda weed	Velvetleaf
September	Vegetative	Yes			
	Reproductive	Yes			
	Seed dispersal	**Yes**			
October	Vegetative	Yes			
	Reproductive	Yes			
	Seed dispersal	**Yes**			
November	Vegetative	Yes	Yes	Yes	Yes
	Reproductive	Yes	Yes	Yes	Yes
	Seed dispersal	**Yes**			
December	Vegetative	Yes	Yes	Yes	Yes
	Reproductive	Yes	Yes	Yes	Yes
	Seed dispersal	**Yes**	**Yes**	**Yes**	**Yes**
January	Vegetative	Yes	Yes	Yes	Yes
	Reproductive	Yes	Yes	Yes	Yes
	Seed dispersal	**Yes**	**Yes**	**Yes**	**Yes**
February	Vegetative	Yes	Yes	Yes	Yes
	Reproductive	Yes	Yes	Yes	Yes
	Seed dispersal	**Yes**	**Yes**	**Yes**	**Yes**
March	Vegetative	Yes	Yes	Yes	Yes
	Reproductive	Yes	Yes	Yes	Yes
	Seed dispersal	**Yes**	**Yes**	**Yes**	**Yes**
April	Vegetative	Yes	Yes	Yes	Yes
	Reproductive	Yes	Yes	Yes	Yes
	Seed dispersal	**Yes**	**Yes**	**Yes**	**Yes**
May	Vegetative	Yes	Yes	Yes	Yes
	Reproductive	Yes	Yes	Yes	Yes
	Seed dispersal	**Yes**	**Yes**	**Yes**	**Yes**
June	Vegetative	Yes			
	Reproductive	Yes			
	Seed dispersal	**Yes**			
July	Vegetative	Yes			
	Reproductive	Yes			
	Seed dispersal	**Yes**			
August	Vegetative	Yes			
	Reproductive	Yes			
	Seed dispersal	**Yes**			

Leaving management aside, plant mortality is usually frost or moisture stress related, although individual plants may die after particularly heavy periods of seed set during late summer and early autumn. Plants appear to be somewhat sensitive to cotton defoliants with leaf and head loss commonly recorded in in-field trials around these times.

Wide leaf bladder ketmia (yellow flower centre type only)

The yellow centre flower type of wide leaf bladder ketmia grows throughout spring, summer and autumn. Emergence has been recorded from October-May and is possible in late

September as well. Again, emergence is strongly linked to rainfall and irrigation during these months. While seedling numbers in excess of 150/m^2 have been observed, seedling mortality is high. Both vegetative and reproductive plants are found from late spring to late autumn (November-May). Wide leaf bladder ketmia plants appear to be very frost sensitive with emergence and growth not occurring in the frost-prone period, generally varying from late April-late October. The absence of recruitment of this species over winter suggests a temperature/dormancy-linked mechanism in the seed that requires further investigation.

Glasshouse studies indicate that this type of wide leaf bladder ketmia can flower in an average of 32 days (Table 2) with some populations flowering in as little as 28 days. Although mature seed dispersal may start around seven weeks after emergence in the glasshouse, the earliest mature seed observed in the field was in mid to late December. Seed production peaks in February and generally continues into May.

If a large weed seedling flush occurs and seedling mortality is not high, the smaller individual plants will produce a similar number of seed heads as a few larger plants. Plants as small as 5 cm high have been observed producing 1-2 seed heads containing viable seeds. Leaving management aside, plant mortality is either moisture stress and/or frost related, although the severe action that common defoliants appear to have on this weed in removing all leaf and reproductive material probably contributes to plant mortality.

There were no observations made for the red flower centre type of bladder ketmia in the field. This was largely due to the distances involved in regular trips to the nearest suitable field sites on the Darling Downs and St. George areas where the weed naturally occurs. To overcome this deficiency, the comparative lifecycle trial evaluating a single population of each bladder ketmia variety and type, and anoda weed and velvetleaf, was established in the glasshouse at ACRI. Further details on these trials can be obtained from Objective 4.

Anoda weed

Anoda weed grows throughout spring, summer and autumn. Emergence has been recorded from September-May and is linked with rainfall and irrigation. Seedling numbers of in excess of 100 seedlings/m^2 have been recorded although drying soil profiles result in substantial mortality. Both vegetative and reproductive plants can be found from November-

May. Anoda weed is somewhat frost sensitive and will not grow through winter.

Although small numbers of mature seed heads have been recorded in December and January (far less than one per plant), mature seed heads commonly appear in late February and early March, peaking in the period late March-May. Although mature seed can be produced 10 weeks after emergence, the weed appears to require a certain number of hours of darkness for floral initiation. It appears that this floral initiation requirement is satisfied in the late summer/early autumn period when daylight hours are decreasing (and conversely when night length is increasing). It also appears that plants that have emerged during the period mid September-mid October may briefly grow under conditions when the minimum number of hours of dark are sufficient to initiate floral development and hence produce small amounts of seed in December, January and February. Plant mortality is generally frost and moisture stress related. Cotton defoliants appear to remove reproductive growth and some leaves.

Velvetleaf

Velvetleaf grows throughout spring, summer and into mid autumn. Emergence has been recorded from October-April but is likely in September as well. This weed generally emerges after rainfall and irrigation, but also in uncultivated areas in drying profiles after periodic flooding of melon hole, channel or swamp country. Although seedling recruitment can be large (up to 100/m^2), seedling mortality reduces this number to around 10/m^2. Both vegetative and reproductive plants can be found from November-May. Mature seeds are produced within nine weeks of emergence, during December-May, peaking anywhere from January-April. Plant mortality is usually moisture stress related, with some frost injury and death. Individual plants may die after particularly heavy periods of seed set earlier than normal during late summer and early autumn, as is the pattern in many annual plants. Plants appear to be slightly sensitive to cotton defoliants with some leaf and head loss being common.

2. The effect that seed burial has on seed viability for narrow and wide leaf bladder ketmia, anoda weed, velvetleaf and marshmallow (continuing study).

This study aims to provide data on the seed longevity on a number of troublesome cotton weeds, buried at different depths for different time periods up to three years in the field. The

first phase of the experiment was started in December 2002 and involved the use of narrow and wide leaf bladder ketmia, anoda weed, velvetleaf and marshmallow. Although the viability of seed from only three times has been assessed to date, that is from the start, four and eight month dates, early data shows promising reductions in viability at all depths with time. Although reductions of between 9-93% in viability have been achieved after only eight months of burial (across species and depths), clear trends have not yet been observed. Given these promising results however, the number of species is likely to be expanded in a trial in the new weeds project *Reducing weed control costs by better understanding the biology and ecology of problem weeds*.

Objective 6

Comparing **germination and growth responses to temperature** of the three weeds under controlled-environment conditions.

Germination trials

It is important to know how to break the dormancy of various weeds so that plants can then be grown for experimental purposes. A series of laboratory experiments evaluated 21 different dormancy-breaking treatments to achieve germination of various weed species.

Acid or sandpaper scarification of the seed coat was the most successful means of breaking dormancy in a variety of species (Table 7). This result is consistent with the dormancy breaking achieved in commercial cotton cultivars, also in the family Malvaceae, by acid scarification. Good germination was achieved for the various bladder ketmia varieties and types, anoda weed and velvetleaf after five days. In contrast, poor germination was achieved in native rosella, spiked malvastrum and marshmallow after five days, with some improvement after 30 days. Untreated seed had germination percentages of far less than 10% after 30 days in most cases, except anoda weed at 14%. All seed had been collected and stored for at least 18 months before these experiments were undertaken.

Although the treatments applied do not occur in cotton fields, they gave some important clues as to how dormancy breaking may occur. For example, some form of damage to the hard

seed coat was required to ensure that germination occurred. Although the factors contributing to the break in dormancy of many weed species in the soil is poorly understood,

Table 7. A summary of the dormancy breaking requirements for a range of Malvaceae weeds. Germination was assessed after 5 and 30 days at 30°C.

Weed species	*Best treatment*	Germination achieved (%)	
		5 days	30 days
Narrow leaf bladder ketmia	Sandpaper (2 min.)	85	92
Wide leaf bladder ketmia (yellow flower)	Conc. H_2SO_4 (20 min.)	88	92
Wide leaf bladder ketmia (red flower)	Conc. H_2SO_4 (15 min.)	100	100
Anoda weed	Conc. H_2SO_4 (15 min.)	96	99
Velvetleaf	Sandpaper (2.5 and 3 min.)	82	91
Native rosella	Conc. H_2SO_4 (20 min.)	17	32
Spiked malvastrum	Sandpaper (2.5 and 2 min.)	17	50
Marshmallow	Sandpaper (1.5 and 3 min.)	11	64

this could correspond to one of two naturally occurring phenomena. For example, temperature fluctuations may cause the seed coats of weeds to crack. Alternatively, some form of soil scarification may occur due to natural soil movement or cultivation. Further work is needed to better understand the dormancy breaking mechanisms of these and many other weed seeds. This work is currently being drafted into a scientific journal publication.

Germination and growth response to temperature

Although the CRDC provided money for the purchase of germination and growth cabinets in the 2002-03 funding round (*Capital funding - germination/plant growth cabinets* DAN165C), various technical difficulties prevented the successful operation of these cabinets before early 2003 (germination cabinets) and August 2003 (growth cabinets). While various researchers have a backlog of experiments to complete, it is hoped that some information on the germination and growth responses of bladder ketmia, anoda weed and velvetleaf can be obtained during the next few months.

There are two clear benefits of pursuing work in this area. The first benefit is that the lifecycle of bladder ketmia, velvetleaf, and to some extent anoda weed, all appear to be strongly linked to the day degrees to which plants in successive flushes are exposed. By knowing the day degree requirements of each species, variety or type, a manager can accurately predict when weed seed production will occur. Knowing that germination flushes of each of these weeds (and many others) occur after rainfall and irrigation events, management can be aimed at vegetative plants that are easier to control, eliminating or reducing new seeds from being added to the seed bank. The floral initiation requirements for

anoda weed, and a select number of other species, could also be investigated in similar experiments.

The second benefit of these experiments would be to shed light on the apparent clear demarcation of narrow leaf bladder ketmia in the more eastern and cooler areas, yellow flower centre wide leaf bladder ketmia in southern areas and red flower centre wide leaf bladder ketmia in the northern areas as highlighted in Objective 1. As mentioned previously, it is likely that either seed germination or plant development stages of the weed populations are specific to the various areas where the weeds currently occur.

Objective 7

Quantifying the **competitive impact of bladder ketmia** on cotton yield (and the relative competitiveness of the three weeds), and where possible, establish economic threshold values, through field experiments over at least two seasons.

The competitive impact that narrow and wide leaf bladder ketmia types, anoda weed and velvetleaf had on the growth and yield of a normal and okra leaf type cotton was assessed in a glasshouse trial. Unfortunately, previous attempts to assess the economic thresholds of these species in the field were hampered by:

a. field collaboration (both growers and ACRI staff were not willing or not able to host trials in which plants were either planted or allowed to grow unchecked) and

b. by a failure to successfully establish narrow and wide leaf bladder ketmia from planted seed at ACRI due to flooding, and then extremely hot temperatures.

A range of different growth parameters was assessed throughout the trial and at harvest, 63 days after planting. The trial was fully replicated with treatments of two plants in each pot representing all possible species combinations, for example, normal leaf cotton was grown with itself, okra leaf cotton, narrow leaf bladder ketmia, wide leaf bladder ketmia (yellow flower centre type), wide leaf bladder ketmia (red flower centre type), anoda weed and velvetleaf. Only plant height and total shoot dry weight data have been presented at harvest (Tables 8 and 9). Data were $\log_{10}$ transformed to enable suitable statistical analysis.

Table 8. Height of cotton and Malvaceae weed species when grown in combination with normal leaf (Sicot 189) and okra leaf (Siokra V16) cotton. Only pairwise comparisons of weed species with both cotton types have been included. The mean data has been $\log_{10}$ transformed. Means within a column followed by the same letter are not different at the 5% level of significance (least significant difference, l.s.d.).

Plant species	Normal leaf cotton	Okra leaf cotton
Normal leaf cotton	4.26^{a}	4.01^{bc}
Okra leaf cotton	3.96^{c}	4.25^{a}
	4.27^{a}	4.19^{ab}
Narrow leaf bladder ketmia		
Wide leaf bladder ketmia (yellow type)	4.25^{a}	4.23^{a}
Wide leaf bladder ketmia (red type)	4.29^{a}	4.12^{abc}
Anoda weed	4.23^{ab}	4.12^{abc}
Velvetleaf	4.03^{bc}	3.98^{c}

Table 9. Total shoot dry weight of cotton and Malvaceae weed species when grown in combinations of pairs with plants of the same and other species/types. The mean data has been $\log_{10}$ transformed. Means within a column followed by the same letter are not different at the 5% level of significance (least significant difference, l.s.d.).

Plant species	Normal leaf cotton	Okra leaf cotton	Narrow leaf BK	Wide leaf BK (yellow)	Wide leaf BK (red)	Anoda weed	Velvetleaf
Normal leaf cotton	2.29^{ab}	2.19^{ab}	2.47^{a}	2.04^{ab}	2.09^{ab}	2.75^{ab}	2.70^{ab}
Okra leaf cotton	2.18^{abc}	2.42^{a}	2.37^{ab}	1.94^{ab}	2.16^{ab}	2.83^{ab}	2.49^{ab}
Narrow leaf bladder ketmia	2.33^{ab}	2.21^{ab}	1.85^{c}	1.78^{ab}	2.29^{ab}	2.94^{a}	2.50^{ab}
Wide leaf bladder ketmia (yellow type)	2.32^{ab}	2.04^{ab}	2.26^{abc}	2.15^{a}	1.88^{b}	2.63^{ab}	2.88^{a}
Wide leaf bladder ketmia (red type)	2.52^{a}	2.07^{ab}	2.36^{ab}	1.98^{ab}	2.40^{a}	2.49^{b}	2.52^{ab}
Anoda weed	2.02^{b}	1.90^{b}	2.04^{bc}	1.86^{ab}	2.03^{ab}	2.79^{ab}	2.89^{a}
Velvetleaf	1.74^{c}	1.95^{b}	1.84^{c}	1.68^{b}	2.19^{ab}	1.99^{c}	2.36^{b}

Similar plant height reductions were observed in normal leaf cotton when it was grown with velvetleaf and okra leaf cotton, and okra leaf cotton when it was grown with velvetleaf and normal leaf cotton, in comparison to when two normal, or two okra leaf plants were grown together (Table 8). The height reduction when growing a normal leaf cotton plant with another normal leaf cotton plant was not significantly different to the height reduction in

normal leaf cotton when it was grown with wide leaf bladder ketmia (yellow and red flower centre types), narrow leaf bladder ketmia and anoda weed ($P<0.05$). The same result was observed for okra leaf cotton. These results indicate that velvetleaf is the most competitive weed species in terms of height reductions at harvest and that each of the other weed species was similar with respect to their competitive influence on the height of cotton plants at harvest. Normal and okra leaf cotton were significantly more competitive in terms of height reductions on their opposite types, i.e. normal on okra and okra on normal than they were on each other, i.e. normal on normal and okra on okra ($P<0.05$).

There were significant reductions in total plant dry weights at harvest when normal and okra leaf cotton was grown with velvetleaf ($P<0.05$, Table 9). There was no significant difference when either normal or okra leaf cotton were grown with themselves, with the other cotton type, or with any variety or type of bladder ketmia ($P<0.05$). Anoda weed had significantly less effect on normal leaf cotton dry weight then velvetleaf, but a similar effect to velvetleaf in okra leaf cotton. Greater dry weight reductions tended to occur in other weed species when paired with velvetleaf, for example in anoda weed and narrow leaf bladder ketmia. These results again indicate that velvetleaf is the most competitive weed species in terms of dry weight reductions at harvest, followed by anoda weed, and that each of the other weed species was similar with respect to their competitive influence on the dry weight of cotton plants at harvest.

Figure 9. *Abelmoschus ficulneus.* Native rosella flowers (a) and mature seed heads (b).

Objective 8

Elucidating the principles for managing these problem weeds based on an understanding of the weaknesses of the weeds and other aspects of their ecology.

The following section is a collation of information from the other objectives. This information is based on an understanding of the various weeds' biology, ecology and weaknesses in their lifecycles and aims to pinpoint how management for these species can be improved.

Narrow leaf bladder ketmia

Narrow leaf bladder ketmia can emerge, grow and produce seeds throughout the year. The weed appears to be easily spread by poor machinery and personnel hygiene, and in water. It is therefore desirable to manage it in all situations when and where it occurs, for example in cotton crops, in winter and summer fallows, along irrigation systems, and on uncultivated land. Plants can produce mature seed in 45 days or less, with an average of 5500 seeds produced per plant. Information from overseas suggests that seeds have a strong seed dormancy allowing the weed seeds to survive for many years in the soil and this may also be the case in the studies outlined in objective 6 even though the trends are not yet clear.

Narrow leaf bladder ketmia needs to be managed in three general ways. On weedy fields management should be aimed at firstly reducing or eliminating the successive seedling flushes that occur after rainfall and irrigation events, and then secondly in removing plants that escape in-crop management before seed set. Management of the weed when it is vegetative is desirable, both because herbicide efficacy is likely to be greater on vegetative plants and because competition from the weed on cotton is likely to be less. However, the narrow window of 30 days before flowering occurs often makes this difficult.

The third general means of management for bladder ketmia is good farm hygiene. This is particularly pertinent in areas or fields where narrow leaf bladder ketmia does not yet occur, or does so at low densities. A discussion of how specific management practices fit with the three general management principles outlined above follows. The management information outlined below has not been substantiated by this research but has been drawn from herbicide labels and databases, from the Best Bet Management section in WEEDpak and from other

anecdotal evidence from consultants, agronomists and growers.

Reducing and eliminating seedling flushes

Although there are a number of pre-plant management options to reduce or eliminate seedling flushes of narrow leaf bladder ketmia, the number of options to manage seedling flushes in-crop is somewhat limited.

Pre-plant and planting - both broadacre cultivation and herbicide applications should be considered to reduce seedling numbers pre-plant, whether that be in winter fallow fields or in the days immediately prior to cotton planting. Seedling flushes in summer fallows should also be treated the same way. Pre-irrigation to initiate a seedling flush is one management practice that should also be considered. Herbicides and mixtures containing glyphosate, glyphosate and oxyfluorfen, diuron, paraquat/diquat and 2,4-D amine have been shown to be the most effective, registered pre-plant options for control of this weed. Diuron and paraquat/diquat are effective registered herbicides that may be used at planting. Although the action of fluometuron/prometryn or fluometuron alone on narrow leaf bladder ketmia is not clear, the use of herbicides containing these active ingredients is recommended on weedy fields that may contain bladder ketmia.

Post-planting - the use of Roundup Ready herbicide® in Roundup Ready crops®, or glyphosate through shielded spray units in non-glyphosate resistant crops, appears to be one of the best means of management for treating successive seedling flushes of either variety of bladder ketmia early in-crop. There are currently product use limits on the amount of Roundup Ready herbicide® that can be used in-crop however. Inter-row cultivation and chipping are especially important on fields that have infestations of bladder ketmia.

Although the cotton industry has traditionally relied heavily on the use of residual herbicides at planting and one lay-by application in-crop, there may be situations where both an early and late lay-by application are needed to manage successive weed flushes (I. Taylor pers. comm.). To ensure that all weeds are controlled on 'dirty' fields, an early layby should be timed shortly after the windows for Roundup Ready® herbicide applications early season (four true leaves) and over-the-top applications of Staple® and/or Envoke® have closed (these latter two herbicides are not registered for bladder ketmia but may be for other weeds), and when the cotton plants are large enough to receive a directed application. For narrow

leaf bladder ketmia, an early layby should be timed to reduce the seedling flushes after the end of the Roundup Ready® window and before the start of the traditional standard layby window. This will help produce season-long management of the weed, assuming that very few weed seedlings emerge and produce viable seeds once canopy closure occurs. Both diuron and prometryn are effective registered lay-by herbicides that may be used to manage bladder ketmia as early lay-by applications. Label restrictions prevent the use of diuron more than once during the cotton season.

Finally, it is important to remember to practise good IWM, particularly considering the increased use of glyphosate both pre-plant and in-crop. All herbicide chemistry should be rotated to delay possible resistance buildup, and weed escapes controlled by alternative means before they set seed.

Rotation crops - narrow leaf bladder ketmia appears to be effectively controlled by the use of either atrazine or 2,4-D amine in sorghum crops. Although bladder ketmia is not a major weed during the winter cropping phase, control may be achieved in wheat crops by 2,4-D amine.

Effective control of narrow leaf bladder ketmia can also be achieved in other rotation crops. The reader is referred to the latest NSW Agriculture publication "Weed control in summer crops" and respective herbicide labels and company representatives for more specific advice on rates of application and plant-back periods.

Summer and winter fallows - there is a larger number of options for managing narrow leaf bladder ketmia in fallow situations and many of these have been outlined above. Leaving aside soil structural and moisture conservation concerns, shallow broadacre cultivation is also a very useful tool in managing the weed.

Removing plants in-crop

Competition between narrow leaf bladder ketmia and cotton will occur if seedlings are allowed to grow unchecked in-crop. There are three main means of removing narrow leaf bladder ketmia plants in cotton crops, the use of herbicides, cultivation and chipping. The successful management of this weed appears to decrease as individual plants become larger.

The most successful means of managing the weed in-crop is through the use of glyphosate whether over-the-top, directed or shielded, and increased over-the-top opportunities for glyphosate may be realised with the introduction of Roundup Flex®. While the action of bromoxynil on narrow leaf bladder ketmia appeared promising, bromoxynil resistant cotton (BXN) was withdrawn from development in Australia and will shortly be withdrawn from sale in the USA. Bayer CropScience intend to introduce glufosinate-ammonium cotton (Liberty Link®) in its place. The action of glufosinate-ammonium on bladder ketmia appears very promising in cotton system situations (I. Wickham pers. comm.), and the weed has been previously listed on the Basta® label (the trade name that glufosinate-ammonium was previously sold under). Good control of seedling bladder ketmia could be expected in Liberty Link® crops when commercialised. Further collaborative pot trials, as sought by Bayer Crop Science, may help to clarify this situation.

It is pertinent to remember that both cultivation and chipping are still very useful tools in removing bladder ketmia plants in-crop. A combined program using both approaches is important, particularly to ensure that the weeds in the plant line are removed by chipping. These approaches should form a part of any IWM program for this weed.

Good farm hygiene

Though often overlooked, good farm hygiene is an integral part of IWM and in the management of bladder ketmia. Good farm hygiene needs to include the following

1. Machinery and equipment needs to be cleaned of mud, soil and seed after working in a weedy field and before entering onto a clean field. To manage this weed effectively the message "*Come clean Go clean*" needs to be applied at a field level on farm.
2. Bladder ketmia plants need to be removed from inside storage walls, irrigation channels, head and tail water ditches and other irrigation system infrastructure. The seeds of bladder ketmia can float and will be spread in water.
3. Weeds in other non-crop on-farm areas need to be controlled so that spread does not occur to cropping areas. These areas not only include fallow country, but along roads and roadside edges, along fence lines and riverbanks, in pasture country and in other disturbed wasteland. Parking cultivation and other machinery on weedy wasteland is a sure way to spread weeds onto fields.

4. Removing dead plants from in field and irrigation system areas is important where practical. What appear to be immature green seed heads may actually produce mature seed if adult plants are pulled out and left to die.

Wide leaf bladder ketmia

Both types of wide leaf bladder ketmia emerge and grow during spring, summer and autumn. In contrast to narrow leaf bladder ketmia, the wide leaf types of bladder ketmia appear to produce mature seeds in summer and autumn only. Again, seeds of the weed are easily spread when there is poor farm hygiene. Although it is important to manage wide leaf bladder ketmia in all situations, management is especially important to prevent seed production during summer and autumn. The yellow flower centre type of wide leaf bladder ketmia can produce seeds in 51 days or less, and 61 days or less in the case of the red flower centre type, with an average of 2500 seeds produced per plant. It might be expected that wide leaf bladder ketmia also has strong seed dormancy although studies to confirm this are still under way.

Like narrow leaf bladder ketmia, both types of wide leaf bladder ketmia need to be managed in three general ways. These are firstly in preventing or eliminating seedling flushes that occur after rainfall and irrigation events, secondly in removing large plants before they set seed and thirdly by practising good farm hygiene. The management of wide leaf bladder ketmia is slightly easier than for narrow leaf bladder ketmia because mature seeds are produced later in summer and autumn.

The management of both types of wide leaf bladder ketmia largely follows that for narrow leaf bladder ketmia, and for this reason will not be repeated here. It is important to note however that because of the taxonomic confusion that has (and still does) exist around the identification of the different varieties of bladder ketmia, that no herbicide labels make the distinction between the different varieties. A distinction was not necessary in the past because the active ingredients appeared to work in a similar way. This report has highlighted research and anecdotal observations on the effects that glyphosate (an on-label registration) and bromoxynil and trioxysulfuron (both off-label) have on the different types of bladder ketmia. Because of the large amount of variation identified between different varieties, types and even populations of bladder ketmia, further herbicide screening studies may be needed to

elucidate the situation further.

Anoda weed

Anoda weed can emerge and grow throughout spring, summer and autumn. Although mature seed can be produced within 73 days of emergence resulting in very small amounts of seed under certain field conditions, mature seed is rarely produced before late February and this continues throughout autumn. Anoda weed is easily spread on dirty harvest and cultivation machinery, in cotton lint, and probably in water. Because of this, it is desirable to manage this weed in cotton crops, in fallow country, in waste areas beside fields and in irrigation systems. Plants can produce an average of 1200 seeds and limited information from overseas indicates that the weed has strong seed dormancy. This allows seed survival in the soil for a number of years.

There are two main aspects that need to be considered in the management of anoda weed. The first is management of the weed within the cropping system, especially after successive emergence events after rainfall and irrigation. This will involve the management of the weed in fallow and off-field locations to ensure that the problem is reduced with time. The second aspect is the practice of good farm hygiene, with special attention given to harvest and cultivation machinery. Because of the very specific conditions that appear to be needed for flowering to occur, the vegetative phase of the weed is relatively long and this presents a number of opportunities for management.

Each of the general management aspects outlined above will be discussed in relation to information derived from the Best Bet Management section in WEEDpak and from other anecdotal evidence from consultants, agronomists and growers. It is important to note that unless specific label registrations are stated that the information outlined below has not been substantiated by this research but drawn from other sources.

Management of anoda weed within the cropping system

There are a limited number of pre-plant and in-crop management options to reduce or eliminate both seedling flushes and adult anoda weed plants.

Pre-planting - both broadacre cultivation and herbicide applications need to be considered to reduce seedlings that emerge prior to planting or in summer fallows. Pre-irrigation to initiate a seedling flush is one management practice that should also be considered. Zoliar® (norflurazon) is registered for the control of anoda weed and should be used at label rates pre-plant.

Post-planting - the use of inter-row cultivations combined with applications of Staple® (pyrithiobac-sodium), registered for over-the-top cotton applications on small anoda weed plants, represents the best option for managing the weed in crop at present. Although the cost of Staple® is high, sequential applications are recommended to manage successive emergence events throughout the season, particularly on heavily infested fields.

Chipping is also recommended to manage this weed although the difficulty in detecting this weed amongst similarly coloured and shaped foliage in the cotton crop represents a challenge. For this reason it may be important to educate chippers about this weed, explaining the similarities in foliage colour and shape and having pot specimens for them to observe. This practice may also help in achieving better weed management for a range of other weeds as well.

In general, fields should be chipped twice during the season. The first chip should be during November and December to rogue out as many plants as possible missed by cultivation and herbicide applications. The second chip is needed before late February, before mature seed is set. Anoda weed plants are easier to identify at this stage in the season as they tend to break through the cotton canopy. It is necessary to remove adult plants with green seed heads on them from the field after they are chipped because anecdotal evidence suggests that seeds are viable and able to mature on dead plants and thereby contribute to the soil seed bank. These plants should be carefully collected and burnt, and the burning area inspected regularly to ensure seedlings have not re-emerged from any unburnt seed.

Although there is some evidence to suggest that the use of Roundup Ready herbicide® in Roundup Ready crops®, glyphosate through shielded spray units in non-glyphosate resistant crops and salvage applications of glyphosate at defoliation appear to be effective against this weed, no product containing glyphosate is registered for the control of anoda weed. In

addition, the action of diuron on the weed appears promising but is not registered. Whether these applications are indeed effective requires further research, because if this evidence can be substantiated, these herbicides offer important additional in-crop herbicide management tools for this weed.

It is also important to remember to practise good IWM, even with the limited number of options available in-crop to delay buildup in herbicide resistance.

Rotation crops - the use of management practices to control anoda weed in alternative crops is very limited. There is a window of opportunity to manage small anoda weed seedlings in peanut crops using paraquat, and using metribuzin in soybean crops, but these applications should be carried out according to label restrictions.

Summer fallows - there is a limited number of options for managing anoda weed in fallow situations although the use of paraquat, norflurazon and fluroxypyr are all registered options that appear to have some action against anoda weed. It is important to ascertain application restrictions and plant-back periods before herbicide application occurs however. Leaving aside soil structural and moisture conservation concerns, shallow broadacre cultivation is also a very useful tool in managing the weed.

Good farm hygiene

Anoda weed is easily spread on harvest machinery used for grains and cotton, cultivation machinery, on dirty vehicles, equipment or clothing, in cotton lint and probably in irrigation water. The key to isolating anoda weed infestations is likely to occur with good farm hygiene and will include the following:

1. All harvest machinery that may have been working in 'dirty' areas should be cleaned before it enters 'clean' areas. Anecdotal evidence suggests that failure to do this has resulted in the spread of the weed to many new areas. The message "*Come clean Go clean*" needs to be applied at a field level on farm to prevent anoda weed from spreading. In addition, consider cultivating and harvesting fields infested with anoda weed last so that the spread of seeds is minimised and machinery can be cleaned properly afterwards.
2. Anoda weed seed is easily spread in cotton lint because the weed produces mature seed around cotton harvest. Areas where waste lint falls or is left beside fields require special attention to ensure that these populations do not act as weed seed reservoirs. This is

especially the case in previous module pad areas.

3. In the same way controlling weeds in other non-crop on-farm areas is critical to stop spread to cropping areas. These areas include fallow fields, roads and roadside edges, along fence lines and riverbanks, in pasture country and in other disturbed wasteland. Parking cultivation and other machinery on weedy wasteland is a sure way to spread weeds onto fields.

4. As already mentioned, removing dead plants with green seed heads on them for burning will help prevent seeds being added to the seed bank.

5. Plants should be removed in all irrigation system infrastructure, for example around storage walls, supply and return channels, where practical. This will help prevent weed seed being moved around in irrigation water.

Velvetleaf

Velvetleaf can emerge and grow throughout spring, summer and autumn. The weed appears to be easily spread in irrigation and flood water, and probably on dirty machinery. Mature seed can be produced within 62 days throughout summer and autumn with an average of 4900 seeds produced per plant. Again, it is desirable to manage this weed in all situations when and where it occurs, for example in cotton crops, along irrigation systems and floodways, on uncultivated land and in summer fallows. This weed has strong seed dormancy and data from overseas indicate that seed is able to persist for up to 50 years in the soil seed bank. Interference from this weed on cotton is likely to be a combination of plant competition for resources and allelopathy, where velvetleaf produces chemical compounds that inhibit the cotton growth.

There are two key aspects that are important in the management of velvetleaf. The first is the management of the weed in-crop, especially to prevent successive seedling flushes after rainfall and irrigation. The management of the weed in non-crop areas is also an important aspect to help manage this weed. The second aspect is good farm hygiene, in particular in the maintenance of a weed free irrigation system and floodways on farm. Because there is a moderate amount of time before seed production occurs (in comparison with narrow leaf bladder ketmia), there are a number of opportunities in which to manage this weed prior to seed set in December.

Velvetleaf is recognised as one of the most serious summer cropping weeds in the USA and there are many means to manage the weed, including both herbicides and bioherbicides in that country. Some of the herbicides that achieve good control in various cropping situations include glyphosate, oxyfluorfen (e.g. Goal®), norflurazon (e.g. Zoliar®), 2,4-D ester, atrazine, flumetsulam (e.g. Broadstrike®), imazethapyr (e.g. Spinnaker®), linuron (e.g. Afalon®), clomazone, lactofen and mixes of MSMA with either lactofen or cyanazine (e.g. Bladex®). Although velvetleaf causes serious problems in Australia, the isolated nature of most infestations, and the lack of rapid spread until quite recently has meant that no herbicides are currently registered for the control of the weed in Australia. Herbicide evaluation trials need to be considered as a matter of utmost urgency to ensure that relatively cost-effective and legally defensible management can be achieved for this weed.

The following information has been drawn from the Best Bet Management section in WEEDpak and from other anecdotal evidence from consultants, agronomists and growers. An evaluation of herbicide management options for velvetleaf was outside the scope of this study however.

Management of velvetleaf within the cropping system

There are relatively few pre-plant and in-crop management options to reduce or eliminate both seedling flushes and adult velvetleaf plants that are known to be effective.

Pre-planting and fallows - in these situations the broadacre use of high rates of glyphosate or Roundup Ready® herbicide, or a mixture of glyphosate applied at 1.5 L/ha mixed with 2,4-D amine applied at 2.4 L/ha with added wetter appears to be effective. The wetter is needed to ensure adequate penetration of the herbicide mixture into the large hairy/velvet-like leaves. Broadacre cultivation also needs to be considered to kill the number of seedlings that emerge prior to planting, or in summer fallows. Pre-irrigation should also initiate a flush of seedlings that can be controlled by broadacre herbicide applications.

Post planting - the most effective means of herbicidal control is probably the use of Roundup Ready® herbicide in Roundup Ready® crops. The common planting residual herbicides containing fluometuron, prometryn and pendimethalin may have some action on emerging seedlings of this weed. The use of inter-row cultivation combined with chipping

also represent excellent options for removing small numbers of plants. The use of pot specimens to explain the differences between velvetleaf and cotton may again be a useful tool to increase chipping success. Chipping should be carried out prior to mature seed set in December. A second chip may also be necessary to rogue out later emerging plants and prevent further seed set. Any plants with green seed heads on them should be carefully removed from the field to prevent further seed spread and burnt since anecdotal evidence suggests mature seeds can be set from green heads left to dry in the field.

It is important to remember to practise good IWM, even with the limited number of options available in-crop to delay any buildup in herbicide resistance.

Rotation crops - the use of alternative weed management practices to control velvetleaf in alternative crops is very limited. There may be some opportunity to manage velvetleaf in sorghum crops using atrazine, or metribuzin (e.g. Sencor®) and bentazone (Basagran®) in soybean crops if a registration can be obtained. It should be noted however that widespread atrazine resistance has been detected in various populations of velvetleaf found in the USA since 1985 (e.g. Andersen *et al.* 1985; Andersen and Gronwald 1987). The weedy biotypes of velvetleaf found around the world, including those in the USA, are genetically quite similar (Wood 1992). If Australian biotypes have indeed come from the USA then similar resistance could be expected here (H. Wood pers. comm.).

Good farm hygiene

Velvetleaf is easily spread in irrigation and flood water, on dirty machinery, equipment or clothing, in cotton lint and perhaps after being ingested in animals. The key to isolating velvetleaf infestations before they spread to clean fields and farms is good farm hygiene and will include the following:

1. Vigilance is required year round on any velvetleaf plants growing inside and outside storage walls, along supply channels and return ditches and within fields. A good example of how this may be implemented can be found in WEEDpak (pg. F2.5).
2. Since there is strong anecdotal evidence to suggest that seed heads and seeds are also spread in floodwater, particularly in overland flows, good farm hygiene will include treating all plants in melon hole country near rivers and liaising with neighbours who may have the problem so that overland water flows do not introduce the weed. Inspect all areas where

flood trash has settled periodically after flooding events.

3. Since velvetleaf is easily spread in water, the practice of standing pumped river water (including floodwater) in velvetleaf-free storages for up to a week should be considered. This may allow seed to settle out to some extent.

4. All machinery and equipment that has been in infested fields should be cleaned down thoroughly to remove mud, soil and seeds. The message "*Come clean Go clean*" needs to be applied at a field level on farm to prevent velvetleaf from spreading. In addition, consider cultivating and harvesting fields infested with velvetleaf last so that the spread of seeds is minimised and a proper clean down of machinery can be conducted afterwards.

5. There is some evidence that velvetleaf seed can be spread in cotton lint, especially when mature seed is shed when the field is picked. For this reason it is important to inspect areas where waste lint falls or is left beside fields to ensure that these populations do not act as weed seed reservoirs. This is especially the case in previous module pad areas.

6. It is important to pay attention to non-crop on-farm areas so that spread does not occur into cropping areas. Non-crop areas include fallow country, roads and roadside edges, along fence lines and riverbanks, in pasture country and in other disturbed wasteland. Parking cultivation and other machinery on weedy wasteland is a sure way to spread weeds onto fields.

7. As already mentioned, removing dead plants with green seed heads on them for burning will help prevent seeds being added to the seed bank.

8. There is some anecdotal evidence from Australia and the USA that animals may also ingest and spread seed in faeces. For this reason it may be necessary to keep boundary fence lines in good condition and to regularly inspect all farm areas for new outbreaks.

Objective 9

Developing **CRC Research Review publications** on all aspects of the work for distribution to growers.

Draft research reviews on many aspects of this work are currently either being collated or under review prior to publication. It is expected that this information will form part of an integrated awareness campaign on these weeds promoted through the Australian Cotton CRC

weeds focus group and WEEDpak. For further details on the publications that have been completed during the project and those planned in the future please refer to the section on Communication of Results.

Objective 10

Coordinate the production of WEEDpak and author various sections.

This objective was an addition to the original project UNE32C. Members of the weeds focus team, headed by the coordinating editor, Dr Stephen Johnson, completed the production of WEEDpak during the period May 2001 – August 2002. The end result was a multi-faceted publication that included information on the following topics all of which are important in integrated weed management systems in Australian cotton farming.

Weed identification guide.

Integrated weed management.

Herbicide resistance.

Herbicides and spray guidelines.

Roundup Ready® cotton.

Farm hygiene, controlling volunteer cotton and an examination of the interactions of cotton pathogens and insects with weeds.

Best bet management guidelines for weeds.

Management of problem weeds.

Weed management in rotation crops.

Appendices on the regional distribution of weeds, a weed species and further reading list with other supporting documents.

In addition to Dr Johnson's duties in overseeing all stages of the planning, writing, editing, production and compilation of WEEDpak, he authored and co-authored the following parts of WEEDpak.

Section A Weed identification and information guide (description, biology and lifecycle

information for species with images in WEEDpak)

Echinochloa colona, pg. A2.10
Urochloa panicoides, pg. A2.14
Amaranthus macrocarpus, pg. A2.18
Chamaesyce drummondii, pg. A2.24
Citrullus lanatus var. *lanatus*, pg. A2.28
Convolvulus erubescens, pg. A2.30
Datura ferox, pg. A2.36
Ipomoea lonchophylla, pg. A2.44
Physalis minima, pg. A2.50
Polymeria pusilla, pg. A2.56
Portulaca oleracea, pg. A2.58
Sesbania cannabina, pg. A2.66
Sonchus oleraceus, pg. A2.70
Trianthema portulacastrum, pg. A2.72
Tribulus micrococcus, pg. A2.74
Xanthium italicum, pg. A2.78
Xanthium occidentale, pg. A2.80
Xanthium spinosum, pg. A2.82.

Sub total (published): 18 species

In addition to the above weeds, Dr Johnson helped prepare description, biology and lifecycle information on the following species.

Aeschynomene indica
Ammi majus
Commelina benghalensis
Commelina cyanea

Convolvulus arvensis

Datura stramonium
Echinochloa crus-galli
Ipomoea plebeia
Ipomoea purpurea
Lamium amplexicaule
Physalis ixocarpa
Physalis virginiana
Solanum americanum

Solanum nigrum
Tetragonia tetragonioides

Tribulus terrestris

Sub total (ready for publication): 16 species

These species descriptions were not included in WEEDpak due to difficulties in obtaining suitable weed images. A number of weed images from the book *Crop Weeds in Northern Australia* are now available for integration into WEEDpak (with due acknowledgement).

In addition, draft species descriptions have been prepared for an additional 38 species, a number of which have images that are currently in WEEDpak.

Grand total: 18 published + 16 ready for publication + 38 draft form = 72 species.

Section D Herbicides

Introduction, pg. D1.1
Herbicide and formulation lists, pg. D2.1-D2.14
SPRAYpak/Spray application, pg. D3.1
(reformulating written material from SPRAYpak)

Section F Farm hygiene

Introduction, pg. F1.1

Farm hygiene in integrated weed management, pg. F2.1-2.5

Plant protection interactions, pg. F5.1- F5.2

Section G Best bet management guide

pg. G1.1-G2.37

Section H Managing problem weeds

Managing Polymeria (take-all) in cotton, pg. H4.1-H4.12

Section J Appendices

Weed species lists, pg. J3.1-J3.8

Further reading, pg. J4.1-J4.4

Introducing WEEDpak

pg. v

Total published pages authored/coauthored: **106** (36% of total pages)
(in addition to other WEEDpak duties outlined)
Total published pages in WEEDpak: **291**

Objective 11

To provide **technical support** for the **development of WEEDpak**.

This objective was an addition to the original project UNE32C. Funding for a technical officer to support the development of WEEDpak was provided for a period of 12 months. Susan Hazelwood was originally employed in this position for a period of around two months followed by Leah MacKinnon who was appointed after Ms. Hazelwood's departure. The technical officer was to provide 60% support for the production of WEEDpak and 40% support on the Malvaceae weeds part of the project UNE32C, in recognition of the time that

Dr Johnson would be spending on WEEDpak. In practice however, the technical officer spent around 80% of her time on WEEDpak because the project was much larger than anyone had anticipated. This resulted in a significant shortfall of time to the Malvaceae weeds part of the project. This has been discussed in the Appendices in the section 'Comments on time allocated to WEEDpak by UNE32C staff'. With considerable assistance from the technical officer, WEEDpak was released to the Australian cotton industry in August 2002. It is important to note that the technical officer, and the weeds focus team in general, were instrumental in achieving the largest, most coordinated and comprehensive COTTONpak in the shortest time (15 months) of any 'pak' to date.

Conclusions (Research outcomes versus objectives)

This research set out to determine the distribution and spread, biotypic variation, lifecycle and competitive impact of bladder ketmia, anoda weed and velvetleaf in Australian cotton farming systems. This information was then used to determine the principles for managing these weeds. Staff involved with this project also coordinated and helped produce WEEDpak. This section draws together the main findings from this work.

Distribution and spread

Two varieties of bladder ketmia are recognised in the Australian cotton industry. These are narrow leaf bladder ketmia (*Hibiscus trionum* var. *trionum*) and wide leaf bladder ketmia (*Hibiscus trionum* var. *vesicarius*). Wide leaf bladder ketmia has two types, best differentiated by the colour of the centre of the flower, these being the yellow and red centre flower types.

Wide leaf bladder ketmia is common in the western, 'warmer' cotton growing areas whilst narrow leaf bladder ketmia is common in the eastern, 'cooler' growing areas. The two varieties intergade to some extent. The yellow flower centre type of wide leaf bladder ketmia is commonly found throughout NSW and southern Qld while the red centre flower type is common in southern and central Qld. Given the worldwide distribution of narrow leaf bladder ketmia, it is likely that this variety will continue to spread throughout the Australian cotton industry. In contrast, wide leaf bladder ketmia being a native species, will probably not spread significantly outside its current area of distribution, but will continue to spread to uninfested fields within these areas.

Anoda weed is common throughout many Qld cotton growing areas and is becoming increasingly problematic in isolated areas of NSW. Anoda weed spreads well on dirty machinery and proactive management is needed to restrict further movement of the weed in NSW, as has been the case in Qld. Velvetleaf has a very restricted distribution in Qld, but has traditionally been found along many western rivers in NSW. There are a small number of severe but isolated infestations of this weed in NSW. Since the weed is spread by irrigation water its potential to spread downstream from existing infestations in NSW is enormous. Every effort should be made to prevent the further spread of the weed from the existing small

infestations.

Biotypic variation

In general, narrow leaf bladder ketmia has a considerably shorter vegetative period and produces flowers and mature seeds faster than the yellow centre type of wide leaf bladder ketmia, which in turn is faster than the red centre flower type of wide leaf bladder ketmia. Narrow leaf bladder ketmia produces a greater number of seed heads in contrast to wide leaf bladder ketmia types.

Anoda weed and velvetleaf have faster earlier vegetative growth than bladder ketmia but are slower to reach reproductive maturity. Anoda weed plants were much larger and produced more seeds than velvetleaf plants in the glasshouse in contrast to the field. Anoda weed is much slower to reach maturity than velvetleaf.

There was considerable variation in the various parameters measured between the different populations within a species, variety or type. This means that individual populations need to be assessed for important lifecycle information individually and managed accordingly.

Lifecycle

Emergence of all species occurs in seedling flushes after rainfall and irrigation events. Narrow leaf bladder ketmia can grow all year round, although seed production is greatest in the spring-autumn period. Narrow leaf bladder ketmia appears to be more tolerant of frost than wide leaf bladder ketmia, velvetleaf and anoda weed. These latter three species grow during spring, summer and autumn, producing seeds until frost kills the plants. Wide leaf bladder ketmia produces seeds from mid to late December onwards, velvetleaf from early December on and anoda weed from February on. Anoda weed appears to require short daylength conditions for floral initiation to occur.

Competitive impact

Velvetleaf, and then anoda weed, was the most competitive weed on both normal and okra leaf cotton in the glasshouse pot trial that assessed the relative competitive impact of the weed species. The relative competitive impact of both varieties and types of bladder ketmia was similar, and not clearly different to the impact of cotton on itself.

Principles for management

The management for both varieties of bladder ketmia is similar even though the lifecycle of the varieties and types varies to some degree. Seedling flushes need to be managed in cotton crops and in fallow situations by a range of registered herbicides, and by cultivation. Adult plants need to be managed before they set seed by a combination of techniques including registered in-crop herbicides, by inter-row cultivation and chipping. Good farm hygiene should be practised as well as IWM to delay and prevent resistance buildup.

The management of anoda weed and velvetleaf needs to be aimed at killing seedling flushes, preventing adult plants from setting seed in-crop, and by practising good farm hygiene. The window of opportunity before seed set occurs is large in anoda weed but the herbicide control options are limited with small outbreaks best controlled by chipping and plant removal from the field. All machinery should be thoroughly cleaned after working in weedy fields. The window of opportunity before seeds of velvetleaf mature is shorter. There are no herbicides registered for control of this weed in any situation in Australia. Chipping, cultivation and ensuring the weed does not spread in irrigation water are some of the best means of currently managing the weed. Further herbicide registrations should be sought for both weeds as a matter of urgency.

WEEDpak

The weeds focus team, including staff on this project, completed and released the largest, most coordinated and comprehensive COTTONpak in the shortest time (15 months) of any 'pak' to date.

Technical Developments

This section provides a very brief summary on the technical developments from the project.

1. Technical advances achieved (e.g. commercially significant developments, patents applied for, or granted licenses etc.)
2. Other information developed from research (e.g. discoveries in methodology, equipment design etc.)
3. Changes to the Intellectual Property register.

1. Although a number of scientific and extension developments were made, (see below), none of these developments have commercial significance at this stage.

   a. The differences between varieties and types of bladder ketmia were clearly understood and researched for the first time.

   b. The distribution and potential spread of bladder ketmia, anoda weed and velvetleaf were ascertained.

   c. The lifecycle of each of the above species was well elucidated.

   d. The germination responses of seeds of a number of different Malvaceae species were tested.

   e. The relative competitive impact of the species was assessed.

   f. The principles for managing these weeds were thoroughly elucidated, and

   g. WEEDpak was developed.

2. The information developed from this research generally used existing and well-established methodologies that were already in the public domain. One exception was the process undertaken to collate the information included in the Best bet management guide. This involved interviewing a range of growers, agronomists and consultants to ascertain their anecdotal observations on how to best manage a range of different weed species. Control of many of these species has not been evaluated by many chemical companies (and hence not included on labels), and alternative means of management were not available, or generally known.

3. The publication of WEEDpak needs to be recorded in any relevant intellectual property register. No other changes to the register are needed from research arising from this project.

Further research and information dissemination activities

This section provides a brief summary on the future presentation and dissemination of the project outcomes, and the future research needs. There is no information on how to further develop or exploit the project technology since there were no significant technical developments from project.

Future presentation and dissemination of the project outcomes

In addition to the future publication plan outlined in Communication of results section that follows it is hoped that presentations and papers can be made at

- The 2004 Australian Cotton CRC review.
- The 12th Australian Cotton Conference (August 2004).
- The 14th Australian Weeds Conference (September 2004).
- Cotton Consultant Australia meetings and Annual Review.
- ACGRA grower meetings.
- A north west weeds forum (I have lobbied the CRDC to initiate a meeting of northern weed scientists (NSW and Qld) but have not yet received a response.

These activities are dependent upon two factors, firstly, being invited to speak at relevant grower, consultant and other industry forums and secondly, being able to maintain experimental progress without the provision of technical assistance in the current research project.

Future research needs

1. A taxonomic revision to clarify the varieties and types currently known as *Hibiscus trionum* in Australia and around in the world (as previously outlined). Dr Lyn Craven, a Malvaceae expert at the National Herbarium in Canberra hopes to complete this taxonomic revision when time permits.
2. The germination and growth responses of bladder ketmia, anoda weed and velvetleaf to temperature under growth cabinet (controlled-environment) conditions. This research will be undertaken for these and a wide range of other species in the new project *Reducing weed control costs by better understanding the biology and ecology of problem weeds* (DAN175C). That project will involve calculating the exact number of day degrees that each species

requires before flowering and seed set occur. Since emergence events of these weeds are strongly linked to rainfall and irrigation events this will result in considerable predictive value on when to best manage these weeds. This work will also shed light on why the different varieties and types occur where they do, and may indicate which of these are able to spread in the future, that is, those that have broad temperature requirements for germination and growth.

3. A determination of the exact requirements for floral initiation in short daylength flowering species such as anoda weed. This again will allow considerable predictive value on when to manage these weeds and will be covered in the new project.

4. The depth of emergence that seedlings can come up from so that pre-emergence herbicide application can be adjusted where relevant. Depth of emergence studies will be investigated on these and a wide range of other species in the new project.

5. The continuing work on how seed viability decreases with time needs to be concluded during the period of the new trial. Another trial involving a small number of species may be initiated in the new project.

6. Further herbicide screening needs to occur for the three species examined. In the case of bladder ketmia, pot trials should examine the susceptibility of the varieties and types of weeds to glufosinate ammonium (Liberty®). Other promising herbicides should also be examined in the same way. In the case of anoda weed and velvetleaf, wide scale screening of different active ingredients is needed so that additional herbicides can be registered in Australia, or in the case of velvetleaf, so that some herbicides can be registered.

7. Further systems research on the management of these weeds is needed because each species has successive seedling flushes after rainfall and irrigation events. The use of pre-irrigation and early layby herbicide applications to control these flushes need to be validated within cotton crops.

Figure 11. *Malva parviflora.* (Marshmallow).

Figure 12. *Hibiscus trionum* var. *trionum*

Narrow leaf bladder ketmia green (a) and mature (b) seed heads.

Communication of Results

This section covers all publications made during the project period 2000-2003 in addition to outlining a future publication plan, and other extension activity conducted. For copies of these publications please contact Dr Johnson.

Publications and publication plans

Publication list

The following publications have been produced during the period of the project UNE32C (2000-2003). Note that these publications cover both Dr Johnson's PhD and Post Doctoral projects.

Refereed Journal Papers

Johnson, S. B., Sindel, B. M., Jessop, R. S. and Jones, C. E. (2003). The Biology of Australian Weeds series. 43. *Polymeria longifolia*. *Plant Protection Quarterly*, (in press).

Johnson, S. B., Sindel, B. M. and Jones, C. E. (2003). Survey of *Polymeria longifolia* (Lindley) in the Australian cotton industry. *Plant Protection Quarterly*, **18**, 120-126.

Johnson, S. B., Sindel, B. M. and Jessop, R. S. ( ). Factors promoting the growth of Polymeria take-all in cotton. *Weed Science*, (submitted for review).

Johnson, S. B., Sindel, B. M. and Jones, C. E. ( ). *Polymeria longifolia* - a difficult to control perennial weed. Reproduction studies. *Weed Research,* (submitted for review).

Refereed Conference Papers

Johnson, S. B., Charles, G. W., MacKinnon, L., Roberts, G. N. and Taylor, I. N., (2003). 'Cutting-edge' weed science. WEEDpak - A weed identification and management guide for the Australian cotton industry. *Proceedings of the Third World Cotton Conference*, Capetown, South Africa. (paper presentation delivered and paper under review).

Unrefereed Journal Papers

Johnson, S. B., Sindel, B. M. and Charles, G. W. (2003). What bladder ketmia have you got? *The Australian Cottongrower* , Volume 24, no. 5, pp. 50-54.

Johnson, S. B. and Sindel, B. M. (2003). Polymeria take-all. The rhizome story. *The Australian Cottongrower* , Volume 24, no. 2, pp. 22-25.

Johnson, S. B. (2002). Identification of Polymeria and other take-all weeds. *Australian Grain*, *Northern Focus*, Volume 12, no. 5, pp. iii - v.

Johnson, S. B. (2002). Polymeria and take-all. *The Australian Cottongrower*, Volume 23, no. 5, pp. 54 - 60.

Coordinating editor and author

Johnson, S. B., Charles, G. W., Roberts, G. N. and Taylor, I. N. (2002). *WEEDpak, A guide for integrated management of weeds in cotton*. Australian Cotton Cooperative Research Centre, Narrabri.

Unrefereed Conference Papers

Johnson, S. B. (2002). WEEDpak. An integrated weed management guide for the Australian Cotton Industry. *Proceedings of the 11th Australian Cotton Conference*, Brisbane, Queensland. pp. 147-148.

Johnson, S. B. and Taylor, I. N. (2002). Hillston weed survey. *Proceedings of the 11th Australian Cotton Conference*, Brisbane, Queensland. pp. 167-168.

Johnson, S. B., Taylor, I. N., Sindel, B. M., Charles, G. W. and MacKinnon, L. (2002). The distribution, spread and management of bladder ketmia, anoda weed and velvetleaf in Australian cotton farming systems. *Proceedings of the 11th Australian Cotton Conference*, Brisbane, Queensland. pp. 169-176.

Johnson, S. B., Sindel, B. M. and Jessop, R. S. (2000). Polymeria - trying to stop it taking all. *Proceedings of the 10th Australian Cotton Conference*, Brisbane, Queensland. pp. 343-349.

Johnson, S. B., Charles, G. W. and Sindel, B. M. (2000). The emerging problem of cotton related weeds (Family Malvaceae). *Proceedings of the 10th Australian Cotton Conference*,

Brisbane, Queensland. pp. 335-336.

Theses

Johnson, S. B. (2000). Biology and management of the 'take-all' weed, *Polymeria longifolia* (Peak Downs curse), in cotton. Doctor of Philosophy thesis. University of New England, Armidale. pp. 291.

Refereed Conference Poster/papers

Johnson, S. B., Sindel, B. M. and Charles, G. W. (2002). Lifecycle studies on Malvaceae weeds in cotton farming systems. Poster presented for the *Proceedings of the 13th Australian Weeds Conference*. September 2002. Perth, Western Australia. pp. 83.

Johnson, S. B., Sindel, B. M. and Jessop, R. S. (2002). Can the timely use of tillage reduce the prevalence of perennial weeds? A case study on the native weed *Polymeria longifolia* in cotton farming systems. Poster presented for the *Proceedings of the 13th Australian Weeds Conference*. September 2002. Perth, Western Australia. pp. 83.

Johnson, S. B., Charles, G. W., Christiansen, I. H., Hazlewood, S. M., Kerlin, S. E., Kelly, D. G., MacKinnon, L., Roberts, G. N., Spora, A. C., Sullivan, A. M., Taylor, I. N. and Watson, J. (2002) Getting the message out. WEEDpak – A developing weed identification and management guide for the Australian cotton industry. Poster presented for the *Proceedings of the 13th Australian Weeds Conference*. September 2002. Perth, Western Australia. pp. 456.

Unrefereed Conference Poster/papers

Johnson, S. B., Charles, G. W. and Sindel, B. M. (2000). The emerging problem of cotton related weeds (Family Malvaceae). Poster presented at *The 10th Australian Cotton Conference*, August 2000. Brisbane, Qld.

Other industry publications

General weed control

Johnson, A., Farrell, T. and **Johnson S.** (2003). Cotton weed control guide. *In*, Cotton Pest Management Guide 2003/2004. eds. A. Johnson and T. Farrell. NSW Agriculture, Orange.

pp. 55-64.

Johnson, S. B. and Spora, A. C. (2002). Cotton weed control guide. *In*, Cotton Pest Management Guide 2002/2003. eds. K. J. Schulze and A. R. Tomkins. NSW Agriculture, Orange. pp. 54-61.

Trial books

Johnson, S. B. (2003). The increasing problem of bladder ketmia, anoda weed and velvetleaf. Are they coming to a field near you? In, *Lower Namoi Valley Cotton trial report 2002-2003,* ed. A. Johnson. NSW Agriculture, Narrabri.

Johnson, S. B. (2003). The increasing problem of bladder ketmia, anoda weed and velvetleaf. Are they coming to a field near you? In, *Macquarie Valley Cotton trial report 2002-2003*, ed. P. van Dongen. NSW Agriculture, Warren.

Johnson, S. B. (2001). Malvaceae weeds. Are they coming to a field near you? In, *Macquarie Valley Cotton trial report 2000-2001*, ed. K. Rourke. NSW Agriculture, Warren. pp. 57-60.

Field day proceedings

Johnson, S. B. (2003). When to control, bladder ketmia, anoda weed and velvetleaf to prevent them from setting seed. Lower Namoi field day book, February 2003. NSW Agriculture, Narrabri.

Johnson, S. B. (2002). The increasing problem of bladder ketmia, anoda weed and velvetleaf. Are they coming to a field near you? Macquarie valley field day book, March 2002. NSW Agriculture, Warren.

Johnson, S. B. (2002). The increasing problem of bladder ketmia, anoda weed and velvetleaf. Are they coming to a field near you? Lower Namoi field day book, March 2002. NSW Agriculture, Narrabri

Johnson, S. B. (2001). Identification of anoda weed, velvetleaf and bladder ketmia. Macquarie valley field day book, March 2001. NSW Agriculture, Warren.

Johnson, S. B. (2000). Polymeria take-all biology and control. Twynum North field day, January 2000. NSW Agriculture, Narrabri.

Johnson, S. B. (2000). Polymeria take-all (*Polymeria longifolia*) biology and control. Lower Namoi field day, March 2000. NSW Agriculture, Narrabri.

Publication plan

The following publications arising from the PhD and Post Doctoral research are planned for submission to scientific journals during the period 2003-2005. The proposed journal of publication is outlined in the brackets. Most publications will also have a cut-down companion paper published in the Australian cottongrower magazine with a cotton tale release published either before, or around the same time. Summary papers will be published in future Australian Cotton and Weeds Conference Proceedings.

2003

- The competitive impact of Polymeria take-all on cotton (*Weed Science*).
- *Hibiscus trionum* varieties and types in Australia (*Plant Protection Quarterly*).

2004

- Lifecycle studies on Polymeria take-all. I. In cotton fields (*Austral Ecology*).
- Lifecycle studies on Polymeria take-all. II. In uncultivated areas (*Austral Ecology*).
- The distribution and spread Malvaceae species in Australia (*Plant Protection Quarterly*).
- Breaking the seed dormancy of Malvaceae weed seed (*Weed Technology*).
- Phenotypic variation in *Hibiscus trionum* in Australia (*Australian Journal of Botany*).
- Phenotypic variation in *Anoda cristata* and *Abutilon theophrasti* in Australia (*Australian Journal of Botany)*.

2005

- Competition for water and soil nutrients between Polymeria take-all and cotton (*Weed Science*).
- Anatomical studies of Polymeria take-all (*Australian Journal of Botany)*.
- Lifecycle studies on bladder ketmia, anoda weed and velvetleaf in Australia (*Austral Ecology*).
- The competitive impact of Malvaceae weeds on cotton growth (*Weed Science*).
- A taxonomic revision of *Hibiscus trionum* (*Australian Journal of Botany*, junior authorship with Dr Lyn Craven senior author).

Other extension activity

Presentations to the cotton industry

Presentations at consultants meetings	4
Presentations to grower meetings	2
Presentations to researchers	6
Presentations to CRC students	7
Presentations to the CRDC	3-4
Advice provided on farm, at meetings or telephone	50-100

Presentations to the community

Presentations to broader community	2
Radio interviews	1
Newspaper interviews/articles	3

Other written material for cotton industry

Cottontales	4

Impact of research on the Australian cotton industry

The likely impact of this research once implemented can best be understood by simple comparisons of weed control costs between fields with and without bladder ketmia, anoda weed and velvetleaf. The successful management of these weeds will rely on the use of control methods on the weeds present, for example using herbicides, cultivation and chipping, and farm hygiene practices to prevent the spread of these weeds on and around the farm. By implementing the management methods outlined in the report, the costs of controlling these weeds can be subsequently reduced and possibly eliminated from the farm budget resulting in appropriate savings and considerable benefit for producers.

Table 10 outlines the potential weed control costs for a number of different situations. Firstly 'typical' fields with both 'light' (1 weed/10m^2) and 'heavy' (1 weed/m^2) weed pressure were examined. The fields contained a range of species, as outlined in assumption 3 at the end of this section. These fields were then compared to those that contain 'heavy' (1 weed/m^2) infestations of bladder ketmia, anoda weed and velvetleaf. Mixtures of the Malvaceae weeds on fields were not considered in this simple example. Table 11 outlines the typical costing of the common herbicides, their application, cultivation and chipping costs. The data for this analysis has been drawn from various sources (Campbell 1998; Taylor and Walker 2003; F. Scott, NSW Agriculture economist, pers. comm.).

The control of bladder ketmia is likely to cost cotton growers just over $290/ha in a cotton crop (Table 10). The cost for the control of anoda weed is around $255/ha and that for velvetleaf $215/ha if all herbicides listed were registered and used. Between $74/ha and $119/ha of these costs are involved with chipping. In contrast, weed control on a heavily infested field is around $265/ha, similar to that for anoda weed and more expensive than that for velvetleaf. These costs greatly exceeded the weed control costs on a lightly infested field of nearly $145/ha. These costs would need to be increased for those control methods conducted that were not in the cotton crop, for example, in fallows and irrigation systems.

Table 10. Weed control costs on a typical field with light and heavy infestations of a range of weeds (as outlined in assumption 3), and heavy infestations of bladder ketmia, anoda weed and velvetleaf. A heavy infestation can be defined as one with 1 weed/m^2 and a light infestation as one with 1 weed/10m^2. Herbicide costing ($/ha) includes application costs, outlined in Table 11.

Weed control measure	Light field	Heavy field	Bladder ketmia	Anoda weed	Velvetleaf
Herbicides					
Planting					
Cotogard	-	1 @ $24.40 **$24.40**	1 @ $24.40 **$24.40**	1 @ $24.40 **$24.40***	1 @ $24.40 **$24.40***
Trifluralin	-	1 @ $19.29 **$19.29**	-	-	-
Over-the-top					
Roundup Ready herbicide	1 @ $15.19 **$15.19**	1 @ $15.19 **$15.19**	1 @ $15.19 **$15.19**	-	1 @ $15.19 **$15.19***
Staple	-	-	-	1 @ $32.55 **$32.55**	-
Layby					
Diuron (early)	-	-	1 @ $30.21 **$30.21**	-	-
Gesagard	1 @ $24.17 **$24.17**	1 @ $24.17 **$24.17**	1 @ $24.17 **$24.17**	1 @ $24.17 **$24.17***	1 @ $24.17 **$24.17***
Shielded					
Roundup Ready herbicide	1 @ $17.80 **$17.80**	-	1 @ $17.80 **$17.80**	1 @ $17.80 **$17.80***	1 @ $17.80 **$17.80***
Cultivation	0	2 @ $6.31 **$12.62**	2 @ $6.31 **$12.62**	2 @ $6.31 **$12.62**	2 @ $6.31 **$12.62**
Chipping					
Rogue	1 @ $37.07 **$37.07**	-	-	1 @ $37.07 **$37.07**	2 @ $37.07 **$74.14**
Heavy	-	2 @ $59.30 **$118.60**	2 @ $59.30 **$118.60**	1 @ $59.30 **$59.30**	-
Roundup Ready License fee/ha	**$49.00**	**$49.00**	**$49.00**	**$49.00**	**$49.00**
Total cost/ha	**$143.23**	**$263.27**	**$291.99**	**$256.91**	**$217.32**

*Unregistered herbicides for these weeds, but may be registered for other weeds present.

Table 11. Costing of weed control operations used in Table 10.

Herbicide/operation	Rate/ha	Unit cost/ha	Total cost/ha
Herbicides			
Cotogard	4.0 L (50% band)	$11.73	$23.46
Trifluralin	2.3 L	$7.98	$18.35
Roundup Ready herbicide	1.5 kg	$9.50	$14.25
Staple	0.06 kg (50% band)	$1053.76	$31.61
Diuron	1.9 kg	$14.03	$26.66
Gesagard	3.5 L (50% band)	$11.78	$20.62
Herbicide application			
Broadacre	NA		$0.94
Shielded	NA		$3.55
Inter row cultivation	NA		$6.31
Chipping			
Light (rogue)	$15/hr		$37.07

Heavy	$15/hr	$59.30

This analysis indicates that infestations of bladder ketmia, anoda weed and velvetleaf increase weed control costs from between 150-200% when compared with weed control costs on lightly infested fields. This cost will have a serious impact on gross margins of cotton growers and this can best be illustrated by considering bladder ketmia as a worst case scenario. Taylor and Inchbold (2001) indicate that 80% of all Australian cotton farms have infestations of bladder ketmia present. Assuming that around 50% of these farms have serious enough infestations on them to need treatment as outlined in Table 10, and that 500,000 ha of cotton are grown, then the total cost of control for bladder ketmia alone represents in excess of a $58 million impost to the industry. This amount represents nearly a $30 million increase in weed control costs when compared with clean fields. It is important to note that these values are very conservative and only represent weed control in-crop and not in other on-farm areas, and do not allow for yield losses.

The benefits of this research will be achieved when these weed control costs are reduced and/or eliminated. Ensuring that farms and fields remain free of these weeds by practising good farm hygiene and by controlling these weeds when they are present, thereby reducing the problems they cause will ensure these benefits are achieved.

Assumptions made for weed control costs

1. Only in-crop control has been examined. No attempt has been made to determine the cost of controlling these weeds in fallows, in irrigation channels or storages. Such control measures will be important to ensure that successful integrated weed management is achieved.
2. The seed bank of the weed has not been considered. The seed bank may be increased or decreased on a yearly basis depending on the success of the control measures undertaken in that year. A large seed bank will result in an on-going problem over many years while good control aims to deplete the seed bank and hence the problem in future years.
3. The 'light and 'heavy' weed pressure fields are taken to contain a broad mixture of broadleaf, and to a lesser extent, grass weeds. It was assumed that nutgrass was not present. The weeds present could include Hunter burr (*Xanthium occidentale*), Bathurst Burr (*X. spinosum*), fierce thornapple (*Datura ferox*), peachvine (*Ipomoea lonchophylla*), with some barnyard grass (*Echinochloa colona*) and liverseed grass (*Urochloa panicoides*) plants.
4. On the 'typical' field with the light infestation of weeds, no pre-plant residual herbicides were used.
5. Full complements of herbicides were used on fields with 'heavy' weed infestations. All herbicides are registered and have been recommended from the information contained in Objective 8. Unregistered herbicides are marked with an *. They have been factored into the calculations because it is likely that these herbicides would be used to control other weeds present in the fields.
6. Chipping costs do not account for on-costs.
7. Since neither pre-plant or post-harvest recommendations have been included above, this data should not be used for other purposes, for example to calculate herbicide loadings or to make resistance management assessments.

Figure 13. *Hibiscus trionum* var. *vesicarius.*
Wide leaf bladder ketmia green (a) and mature (b) seed heads.

References

Andersen, R. N., Menges, R. M. and Conn, J. S. (1985). Variability in velvetleaf (*Abutilon theophrasti*) and reproduction beyond its current range in North America. *Weed Science*, **33**, 507-512.

Andersen, R. N. and Gronwald, J. W. (1987). Noncytoplasmic inheritance of atrazine tolerance in velvetleaf (*Abutilon theophrasti*). *Weed Science*, **35**, 496-498.

Campbell, S. (1998). *Weed control costs, chemical vs. chipping*. DuPont Agricultural Products Technical Data Bulletin. (For the promotion of the herbicide Staple®). pp. 7.

Charles, G.W. (1991). A grower survey of weeds and herbicide use in the New South Wales cotton industry. *Australian Journal of Experimental Agriculture*, **31**, 387-92.

Charles, G.W., Constable, G.C. and Kennedy, I.R. (1995). Current and future weed control practices in cotton: The potential use of transgenic herbicide resistance. In *Proceedings of the workshop on 'The role of herbicide resistant crops and pastures in Australian Agriculture'*. March 15-16, 1995, pp. 89-100. Canberra, Bureau of Resource Sciences.

Groves, R. (1999). Sleeper weeds. *Proceedings of the 12th Australian Weeds Conference*. September 1999. Hobart, Tasmania. pp. 632-636.

Johnson, S. B., Sindel, B. M. and Jones, C. E. (1998). Polymeria take-all: a perennial problem. *The Australian Cottongrower* 19 (5), 37-43.

Michael, P. J., Plummer, J. A. and Steadman, K. J. (2002). Agro-ecology of *Malva* species in western Australia. *Proceedings of the 13th Australian Weeds Conference*. September 2002. Perth, Western Australia. pp. 552.

Mitchell, A. S. and Norris, E. H. (1990). Malvaceae. In *Flora of New South Wales, Volume 1*, ed. G. J. Harden. University of NSW Press, Kensington. pp. 320-340.

Spencer, N. R. (1984). Velvetleaf, *Abutilon theophrasti* (Malvaceae), history and economic

impact in the United States. *Economic Botany*, **38**, 407-416.

Taylor, I. and Inchbold, B. (2001). Sustainable weed management systems for cotton, project 3.1.5AC. *Australian Cotton Cooperative Research Centre Annual Review 2000-2001.* Australian Cotton CRC, Narrabri. pp. 54-55.

Warwick, S. I. and Black, L. D. (1986). Genecological variation in recently established populations of *Abutilon theophrasti*. *Canadian Journal of Botany*, **64**, 1632-1643.

Wilson, B. J., Hawton, D. and Duff, A. A. (1995). *Crop Weeds of Northern Australia*. Queensland Department of Primary Industries, Brisbane. pp. 160.

Wood, H. (1992). Global variation in velvetleaf (*Abutilon theophrasti*). *Proceedings of the First International Weed Control Congress,* Melbourne, Australia. pp. 569-572.

Figure 14. *Anoda cristata.* Anoda weed seed head.

Appendices

There are two appendices that are covered in this section. The first section details other project linkages, outlining time spent doing other research, extension and support of projects that was not envisaged in the original application and comments on the amendment of WEEDpak to the project. The second section details the tables of glasshouse data from the biotypic variation and lifecycle glasshouse trials.

Time spent doing other activities and comments about WEEDpak

In addition to the activities already outlined in this project (Malvaceae weeds and WEEDpak), and the additional publications outlined (for example the Cotton Pest Management Guide), Dr Johnson has been involved in the following activities:

- An investigation into the susceptibility of bladder ketmia to key herbicides in the project

  The effects of bromoxynil and glyphosate on two biotypes of bladder ketmia (*Hibiscus trionum*). A Bachelor of Rural Science Honours thesis by Mr Scott Wallace and supervised by Mr Guy Roth, Assoc Prof Brian Sindel and Dr Stephen Johnson.
- The formulation of a herbicide compendium - a series of tables that industry personnel can refer to for label advice on the range of herbicides to control weeds in a variety of cotton farming system situations.

Dr Johnson has given research advice, expertise and resources to

- Dr Hanwen Wu (QDPI) - Post Doctoral Research Fellow - Dryland weeds project funded by the CRDC.
- Mr Richard Kent (UNE) PhD candidate - Interaction between Fusarium wilt and weeds project funded by the CRDC.
- Ms Leahwyn Seed, (UNE), Honours candidate - Hybridisation in *Hibiscus* (bladder ketmia) weeds.
- Ms Melinda Lie (NSW Agriculture/Sydney University) - Honours candidate - An investigation into the capacity of native Malvaceae weeds to host important cotton diseases. (Cotton CRC Summer Scholarship).
- Ms Lynn Madden (UNE) - Honours student - "The potential of utilising the allelopathic effects of undesirable plant species such as pale beauty head

(*Calocephalus sonderi*) and Polymeria take-all (*Polymeria longifolia*) to control weeds" (Weeds CRC Honours Scholarship).

- Ms Pippa Michael (UWA) - PhD candidate - "The agro-ecology of *Malva parviflora* (small-flowered mallow) in Western Australian farming systems".
  (GRDC 38185000).

Dr Johnson has provided informal advice to the following people involved in research

Mr Graham Charles, NSW Agriculture, ACRI.
Dr Ian Taylor, NSW Agriculture, ACRI.
Mr Grant Roberts, CSIRO PI, ACRI.
Mr Jeff Werth, CSIRO PI, ACRI.
Dr Steven Walker, QDPI, Toowoomba.
Dr Michael Widderick, QDPI, Toowoomba.
Mr Jim Barnes, QDPI, Kingaroy (formerly).
Ms Vikki Osten, QDPI, Emerald.
Mr Andrew Storrie, NSW Agriculture, Tamworth.
Mr Keith Pengilley, NSW Agriculture, Condoblin.
Associate Professor Brian Sindel, UNE, Armidale.
Dr Glenda Vaughton, UNE, Armidale.
Dr Mike Ramsey, UNE, Armidale.
Mr Mark Trotter, UNE, Armidale.
Dr Lyn Craven, National Herbarium, Canberra.
Dr Robyn Barker, South Australian Herbarium, Adelaide.
Dr Rod Hendersen, Queensland Herbarium, Brisbane.
Mr Tim Capp, Bayer CropScience, Narrabri.
Mr Ian Wickham, Bayer CropScience, Narrabri.
Mr Denis Harvey, Syngenta, Narrabri.
Mr Scott Campbell, DuPont, Moree.

Comments on time allocated to WEEDpak by UNE32C staff

The final scope of WEEDpak was far greater than either the weeds focus team or the CRDC anticipated and this resulted in the technical officer spending around 80% of her time on WEEDpak, in addition to 80% of the time that Dr Johnson spent on WEEDpak in the twelve month period prior to its release. This resulted in a significant short fall in the time able to be allocated to the Malvaceae weeds part of the project (a shortfall of 20% for the Technical Officer and 40% for Dr Johnson over one year of the project). In partial recognition of this fact the CRDC extended Dr Johnson's contract for 5.5 months project, but this only partially made up the projected short fall of time. The CRDC have been notified that Dr Johnson will continue to publish research from the Malvaceae weeds project in the new project.

Figure 15. *Abutilon theophrasti.* Velvetleaf seed heads.