FINREP96

"Management of Cotton Following Damage By Hail"

C. R.& D. C. Project No: CDL3C
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Although having the misfortune of experiencing hail strikes, growers were still willing to contribute to industry research by providing trial sites for hail management trials and assisting in the management of these trials and I would like to thank the following growers:-

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Jerry Killen and family of Narrabri
Hugh Mackey and family of Narrabri
Paul McDonald and family of Emerald
Paul McVeigh and family of Dalby
John Palmer and family of Wee Waa
Paul Thomas and family of Warren

A long list of cotton growers and cotton consultants also assisted the project by providing case studies covering the agronomic management of their hail damaged cotton during the period of the project and their assistance is greatly appreciated.

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Background and Introduction:

Over the period from 1990 to 1993, research was carried out investigating the regrowth of Australian cotton varieties after damage by hail. The work was funded by the Cotton Research and Development Corporation and carried out in co-operation with the loss adjusters to the Australian cotton industry, Agricultural Loss Management Group.

By comparing the regrowth characteristics of Australian cotton varieties, following simulated hail damage at various stages of plant development, the aim was to test the accuracy of the loss assessment procedures currently used in cotton hail loss adjustment and determine whether it was appropriate to apply these procedures to loss adjustment for the whole range of new Australian bred varieties now grown.

No differences in regrowth were found between varieties when allowed to mature fully following simulated hail damage. Looking at the deviation of actual loss from assessed loss, there was little difference between varieties tested when loss percentages were averaged across damage dates. Hence, it was not appropriate to modify the loss assessment procedures for the Australian bred cotton varieties included in the research program.

But, it should be kept in mind that the loss calculation does not estimate the actual loss in yield but provides an estimate of the proportion of the plant lost at the time of damage.

It was identified that following damage a number of factors come into play which affect the final yield and the full affect of the hail damage and hence contributed to differences between assessed loss and actual yield loss. These factors all act post damage and are not taken into account in loss assessment.

Factors affecting the relationship of assessed loss in yield from hail damage to actual yield after hail damage include:

a. Disease susceptibility of cotton varieties.
b. Weather conditions following damage.
c. Cotton Production Area.
d. Management of cotton crops following damage.

These factors may contribute to a difference between assessed and actual yields after hail either between cotton varieties or yield recovery between fields.

Cotton varieties differ in their susceptibility to diseases such as Bacterial Blight and Verticillium Wilt. Susceptible varieties may show an increased yield loss after hail due to the development of disease within the crop when weather conditions favouring development of that disease occur following hail damage. It should be recommended that growers not plant large areas to disease susceptible varieties if producing their cotton in high hail risk areas.

Hail delays the growth of the crop. The degree of yield recovery of a variety or crop depends on its ability to replace lost vegetative material and replace and mature fruit in the season remaining. The length of season differs with cotton production area and the effective growing season is reduced with adverse weather conditions following damage. Hence, crop recovery from hail differs considerably across damage date and season length of a cotton production area.

In managing a hail damaged crop, growers not only have to take into account the requirements of the hail damaged crop but also the resources available for management of the whole cropping enterprise. Management options are restricted depending on the time of the season of the hail strike and the inputs available to the grower. A number of problem areas in managing hail damaged crops have been identified and this work aims to investigate these areas and provide guidelines to assist growers in managing hail damaged crops.

A three year project investigating the agronomic factors of prime importance in managing a crop following hail damage, instigated and funded by the Cotton Research and Development Corporation, was begun in the 1993/94 cotton season. The aim being to develop a set of criteria which will help growers with decisions on whether to carry on with a crop after a hail strike. The base of data on hail damage generated in this project will be used to evaluate the current yield models and their response to hail and determine their potential for use in damage assessment and yield prediction for loss adjustment purposes.

Aims and Objectives:

1. To identify optimum management strategies for cotton crops after hail damage, with the aim of maximising returns to growers.

2. To develop guidelines to help growers with decision making and risk management after a hail strike.

3. To evaluate the responsiveness and usefulness of current fruit and yield models to hail damage, using data generated from this work.

Selected growers and consultants experienced with hail damaged cotton were interviewed as a means of identifying problem areas in the management of hail damaged cotton crops. Management problems were identified from the information gathered and management strategies developed for testing on hail damaged cotton crops.

As hail damaged occurred over the three seasons covered by the project. opportunity trials of these strategies were carried out on suitably damaged crops located in the different Australian cotton production areas.

With every hail strike being different and inflicting various levels and types of damage, trials were not able to be laid out covering every damage situation. In an attempt to collate data on the range of possible types of crop damage and management options employed, case studies were collated on hail damaged crops and their management over the period covered by the project.

Trial results combined with data collated from case studies has been used to produce guidelines and discussion points on the management of hail damaged cotton.

The opportunity has also been taken to evaluate the use of crop yield models in loss assessment of hail damaged cotton. Data generated in earlier work (CDL1C) has been used in the OZCOT yield prediction model to evaluate the response of the model to data from hail damaged crops. Computer yield models have a potential use in loss assessment for hail damaged crops if they are able to predict the yield potential of a crop had hail damage not been inflicted. This would have the potential substantially increase the accuracy of loss assessment.

Chapter 1

Options Following Early Season Hail Damage

1.1: Introduction

Although hail storms are recorded at any time during the cotton growing season, hail storm activity is more prevalent in the spring and early summer. This period corresponds to the crop establishment in cotton and historically a large number of hail strikes are recorded for the period.

With the crops being predominantly in vegetative growth stages, damage symptoms incurred consist of plant cut-offs, stem bruising and defoliation. Where the main stem cut-off is below cotyledon level or severe bruising occurs, plant death is the result and therefore the stand is reduced. Stem cut-offs and/or stem bruising at higher nodes may not result in plant death but a large portions of plant material can be removed with such damage and the crop must replace this material before continuing with development. This damage is most usually combined with defoliation and so acts to reduce plant vigour and the overall effect of the damage combined with reduced crop vigour is delayed crop development. Following such damage, crop management decisions revolve around whether to replant the crop or not.

1.2: Economically Viable Plant Populations for Cotton

Generally, lint yields increase with increased population up to the optimum population then gradually decrease (Bridge *et al.*, 1973; Constable, 1977a). Hearn (1972) states that lint yield increases until a plateau of maximum yield was reached between 4-10 plants per metre.

As plant populations increase above optimum, plant height increases, more barren plants per metre are recorded, the node of the first fruiting branch is higher and boll size is reduced (Bridge *et al.*, 1973; Constable, 1977b; Low *et al.*, 1975). At lower plant stands the cotton plant can compensate to some degree by producing a larger plant with larger bolls and seed (Bridge *et al.*, 1973). But as plant stands drop lower than optimum, yield is decreased, as maturity is delayed and late bolls show reduced size and lower ginning turnout percentages. Yields can be maintained at higher plant populations with earlier maturity varieties or under narrow row cultivation (Constable, 1977a, 1977b; Low *et al.*, 1975).

Work carried out in both Australia and the United States recommends a plant stand of 8-10 plants per square metre for optimum growth of cotton under conventional cultivation, but yields remained economic with stands between 6-14 plants per metre (Constable, 1977b; Bridge *et al.*, 1973; Marshall *et al.*, 1994 and Smith *et al.*, 1979).

Under dryland cultivation in Australia, row configuration has been found to be more of a limiting factor to yield than plant population, with no significant yield reductions with stands of 12 plants per metre or if hail or insect damage reduces stands down to 3-4 plants per metre. The uniformity of the stand is of greater importance as a 'gappy' stand will reduce yields and require increased weed control (Marshall *et al.*, 1994; C. R. C. for Sustainable Cotton Production, 1993).

Following an early season hail strike, a grower needs to determine if the plant stand remaining following the strike remains economically viable. A simple matter of counting the viable plants remaining following the hail strike. Note that immediately following a hail strike only those plants cut off below the cotyledons would actually be classified as dead. It usually takes 10-14 days (average 450 GDDs) before new growth appears in a crop following a hail strike and plant development is able to continue (West, 1996). The production of new growth requires the presence of healthy meristematic material and a continuous pathway for photosynthates to reach the young shoots. As it becomes evident that bruising injuries were sufficiently severe to cut vascular tissue, plant death will continue. In determining the number of viable plants remaining, severely bruised plants should be included as possible lost plants and hence further reducing the plant stand.

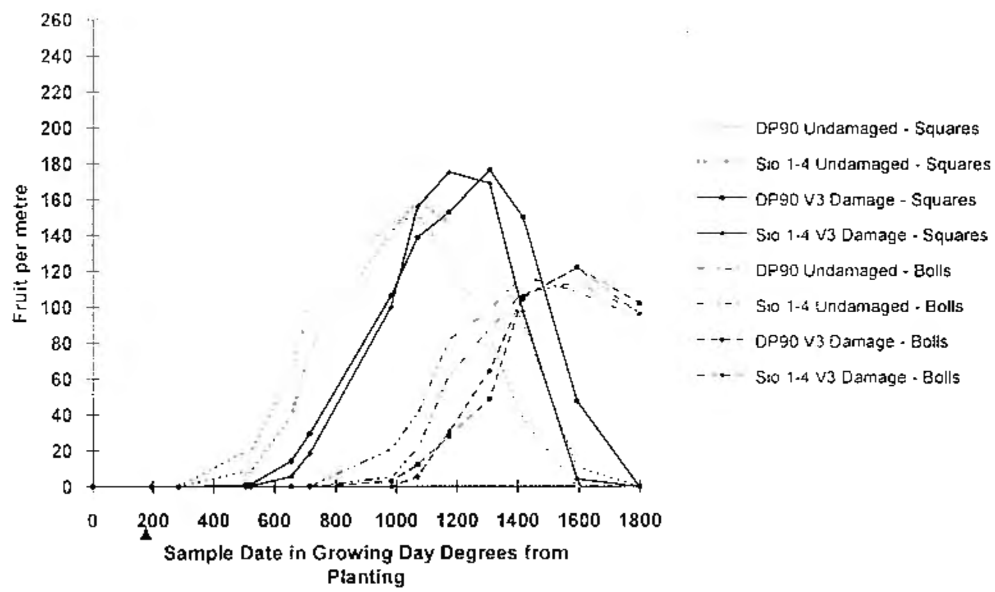
Plant disease also plays a part in reducing plant stands in the period following the initial damage. Damaged plants have low vigour and therefore are more disease susceptible and wounds and injury points inflicted by the hail provide infection access for disease pathogens.

Growers may accept a lower than optimum plant stand following a hail strike for a number of reasons. A primary point to consider is the date of the hail strike as replanting at a much delayed date can incur significant losses in yield potential and the existing stand may have the yield potential advantage (Refer to Section 1.3). In short water years, as experienced over the previous four years in Australian cotton production areas, following a hail strike there may be insufficient water available to the grower to enable establishment of a new stand or correspondingly in the dryland situation new planting rain events may not occur. Alternatively, excessive rain occurring with a hail storm may prevent replanting being attempted until well past an economic replant date.

Continuing with a hail damaged stand of cotton also incurrs losses related to delayed crop development. In a hail strike, the crop has lost a proportion of the material produced up to the date of damage and hence has lost a proportion of the growing season directly related to the date of damage. Immediately following a hail strike it has found that an average period of 450 GDDs passes before new vegetative material develops or fruiting is re-initiated (West, 1996) (Figures 1.1 & 1.2, Table 1.1). Once regrowth is initiated the crop must then replace lost plant material to reach the same stage of development to which it had reached on the date of the hail strike. The overall effect is to shift the entire crop development curve to later in the cotton season. The rate of replacement and initiation of new material is dependent on weather conditions following damage and with adverse weather conditions development is further delayed, ie. the development curve is shifted further into the season again.

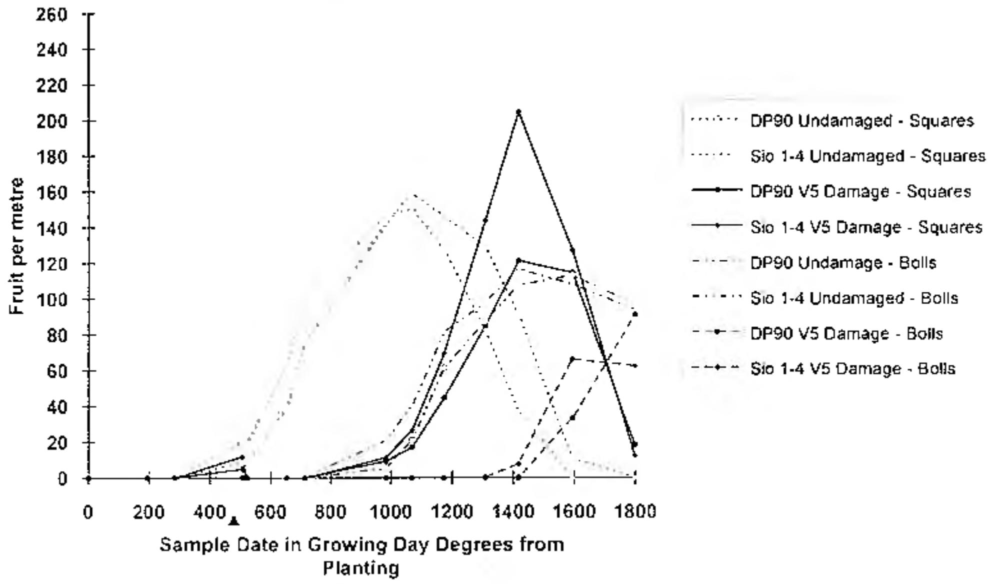
If the development curve is shifted further into the season then the crop is setting and maturing fruit later in the season. Grower experience illustrates that protection of new fruit necessitates insecticide spraying later into the season where insect pressure is heavier and insect resistance levels require the use of 'heavier' and more costly insecticides, late irrigations are often required and defoliation is carried out under cooler temperature conditions when defoliants are less active (Refer to Section 1.4).

Figure 1.1: **Regrowth of Deltapine 90 and Siokra 1-4 Cotton Varieties Following Simulated Hail Damage in the V3 Growth Stage**
Site: A. C. R.I., Myall Vale 1991/92



V3 Damage Simulation

Figure 1.2: **Regrowth of Deltapine 90 and Siokra 1-4 Cotton Varieties Following Simulated Hail Damage in the V5 Growth Stage**
Site: A. C. R.I., Myall Vale 1991/92



V5 Damage Simulation

Table 1.1: **Initiation of Squaring Following Simulated Hail Damage**
Site: A. C. R. I. 1991/92, 1992/93.

Growth Stage of Damage	Damage Date (GDDs from Planting)	Start of Squaring (GDDs from Planting)	Delay in Squaring Compared to Undamaged Cotton (GDDs)	Delay to Squaring Following Damage (GDDs)
UNDAMAGED				
1991/92	Nil	506	0	0
1992/93	Nil	404	0	0
Mean	Nil	455	0	0
V3 DAMAGE				
1991/92	203	653	147	450
1992/93	190	675	271	485
Mean	197	664	209	468
V5 DAMAGE				
1991/92	521	983	477	462
1992/93	338	764	360	426
Mean	430	874	419	444

1.3: Estimating Yield Depletion with Delayed Planting or Early Season Hail Damage in Cotton

1.3.1: Introduction

The cotton plant develops indeterminately until either boll load or stress from nutrients, water or climate imposes cut out. Our main cotton production areas are of temperate climate and temperature determines the start and finish of the growing season. Minimum temperatures for germination of cotton is reached by early October in most cotton production areas. Growth is terminated by the occurrence of first frost. Table 1.3.1 summarises the average dates for the start and finish of boll setting in cotton production areas as determined from historical climatic records.

Vegetative growth in cotton is predominantly temperature driven and as a cotton plant must grow vegetatively to produce fruiting sites on which the seed cotton is borne, the potential yield of a crop can be estimated using heat unit summations (Growing Day Degree units). Plant development can also be limited by cold shock or heat stress, soil properties impeding germination/establishment, or plant growth may be retarded by water, nutrient or disease stress. Fruit set or survival is also affected by insect pressure and so yield predictions based on Growing Day Degree summations are subject to some inaccuracies. But as temperature is considered a primary growth rate determining factor in cotton, yield predictions based on temperature can be used as a guide to yield depletions which can be expected with delayed planting of cotton.

Each stage of development of the plant has a specific heat unit requirement, but an overall seasonal heat unit requirement cannot accurately be calculated due to the indeterminate growth habit of cotton. But the relationship between heat unit accumulation and lint yield can be estimated. Constable *et al.* (1976a) determined the relationship between Lint Yield and Growing Day Degrees in a series of planting date experiments in the Namoi Valley using two varieties of cotton. The decreased day degree accumulation post planting with delayed planting produced decreasing lint yields. The relationship between planting date and lint yield was determined by regression analysis. With hail damage at progressively later dates through a growing season there is also progressively less heat units able to be accumulated post damage and similar decreases in yield recovery are seen.

In this exercise, the relationship between heat unit accumulation and cotton lint yield is examined for all cotton production areas of Australia with the aim of estimating yield depletion with delayed planting for each area. This work re-examines the work of Constable *et al.* (1976a), employing their computer methods, but with the advantage of using the longer term climatic data for each cotton production area which is now available.

Table 1.3.1:

Dates for Boll Setting Set by Temperature		
Production Area	**First Flower** (Start of Flowering 1st October Planting)	**Last Effective Flower** (Limited by Frost)
Namoi	25 Dec	4 Mar
Gwydir	21 Dec	7 Mar
Macquarie	7 Jan	19 Feb
Lockyer	22 Dec	22 Mar
Darling Downs	25 Dec	6 Mar
St. George	10 Dec	15 Mar
Theodore	13 Dec	23 Mar
Biloela	13 Dec	23 Mar
Emerald	3 Dec	6 Apr
Mc Intyre	15 Dec	13 Mar
Bourke	10 Dec	15 Mar
Mungindi	10 Dec	15 Mar
Walgett	21 Dec	7 Mar
Boggabri	26 Dec	1 Mar
Breeza	7 Jan	19 Feb

Source: SIRATAC Manual 1987

1.3.2: Methods

The C.S.I.R.O. unit at the Australian Cotton Research Institute, Myall Vale, Narrabri maintains a database of weather data collated from its weather stations set up in all cotton production areas. This information was considered the most representative of climate in the cotton production areas and was used for this analysis (Table 1.3.2).

Accumulated Day Degree values were calculated for each season at a series of planting dates, at each location using the computer program developed by G.A. Constable. The season being terminated at first frost. Note that the computer program discounts for the effect of cold nights. Predicted lint yields were then calculated using the exponential relationship between Lint Yield and Day Degrees defined by Constable *et al.*, (1976). The lowest and highest 10% of yields were deleted from the calculations and Mean Accumulated Day Degrees and Mean Predicted Yields for each planting date determined.

Regression of Predicted Yield against Julian Day of Planting for each site produced highly correlated regression equations. These equations can be used to predict lint yield for planting at any date. Regression Analyses are presented in Appendix 1.1.

Table 1.3.2:

Summary of Climatic Data Available			
	Years	**Total No. of Years**	
Emerald	1895-1989	94	
Biloela	1966-1989	23	
Dalby	1890-1989	99	
St. George	1963-1990	27	
Goondiwindi	1895-1989	94	
Moree	1965-1989	24	
Myall Vale	1961-1993	32	
Breeza	1975-1990	15	
Walgett	1958-1989	31	
Bourke	1958-1989	31	
Warren	1970-1982	12	Incomplete data set
Trangie	1949-1993	44	
Hillston	1958-1989	31	

1.3.3: Results and Discussion

The following charts display the depletion in lint yield which could be expected from planting at a range of planting dates at each of the twelve locations tested. The dotted lines display the range of yields which were calculated with the climatic data which was available.

Predictions can be made as to the average date at which planting is not an economically viable option depending on which yield a particular grower believes is uneconomic in his situation.

Figure 1.3.1: Yield Depletion with Delayed Planting - Location: EMERALD

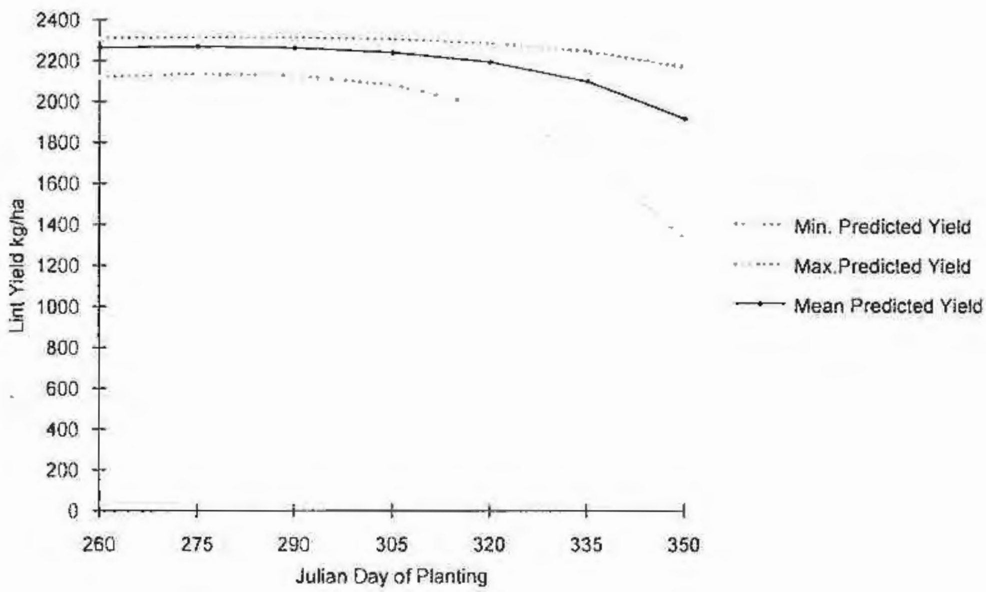


Figure 1.3.2: Yield Depletion with Delayed Planting - Location: BILOELA

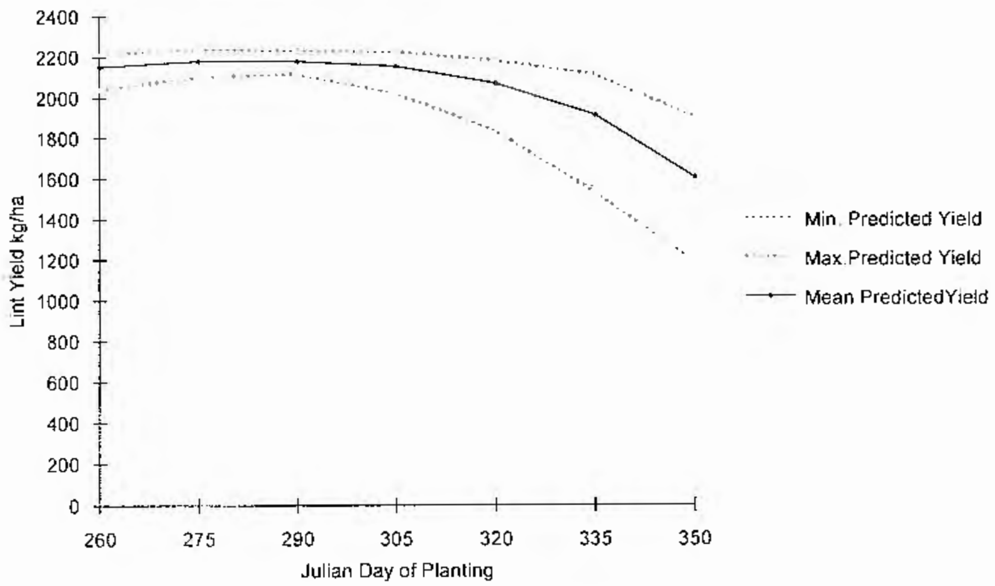


Figure 1.3.3: Yield Depletion with Delayed Planting - Location: DALBY

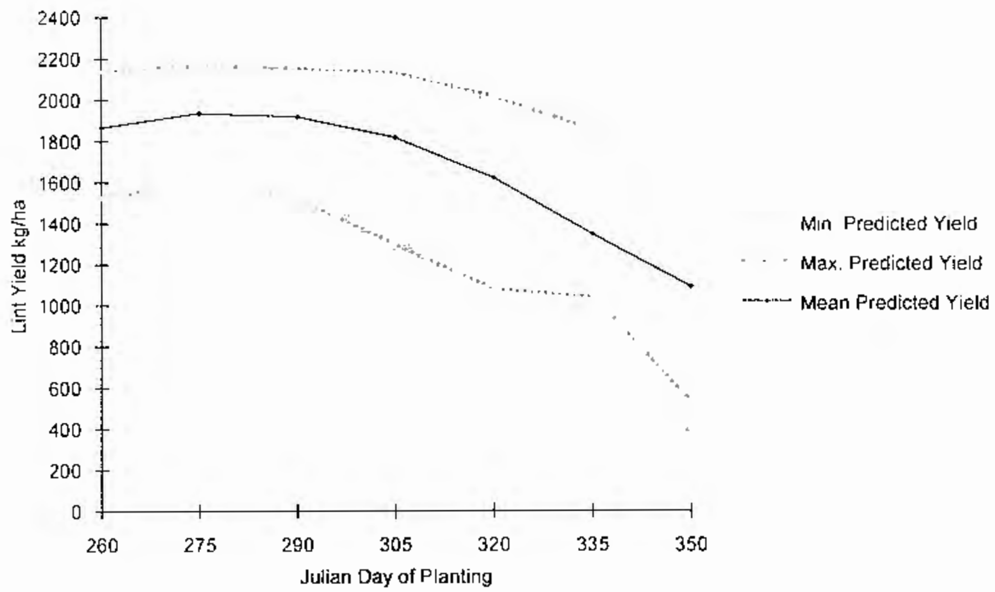


Figure 1.3.4: Yield Depletion with Delayed Planting - Location: ST.GEORGE

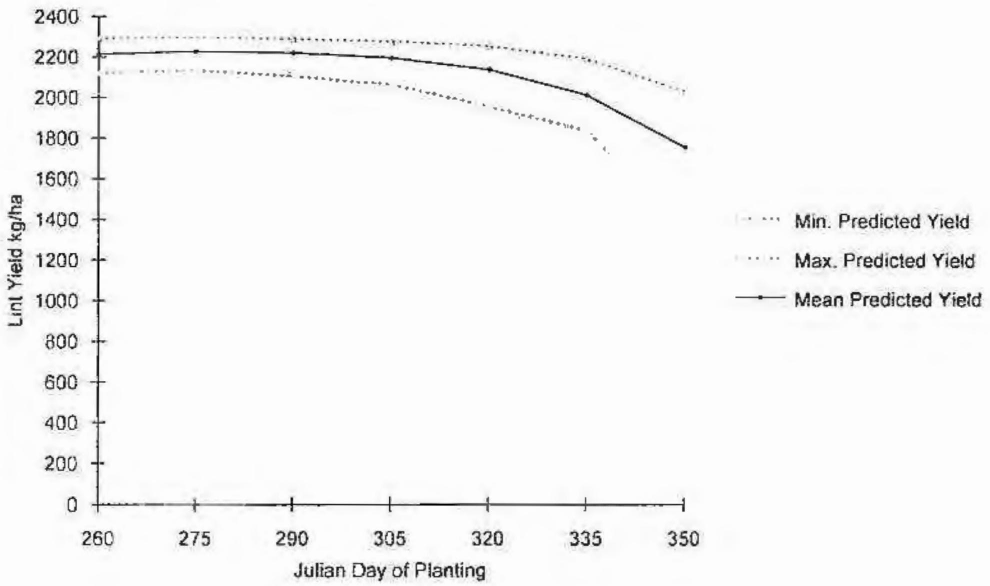


Figure 1.3.5: Yield Depletion with Delayed Planting - Location: GOONDIWINDI

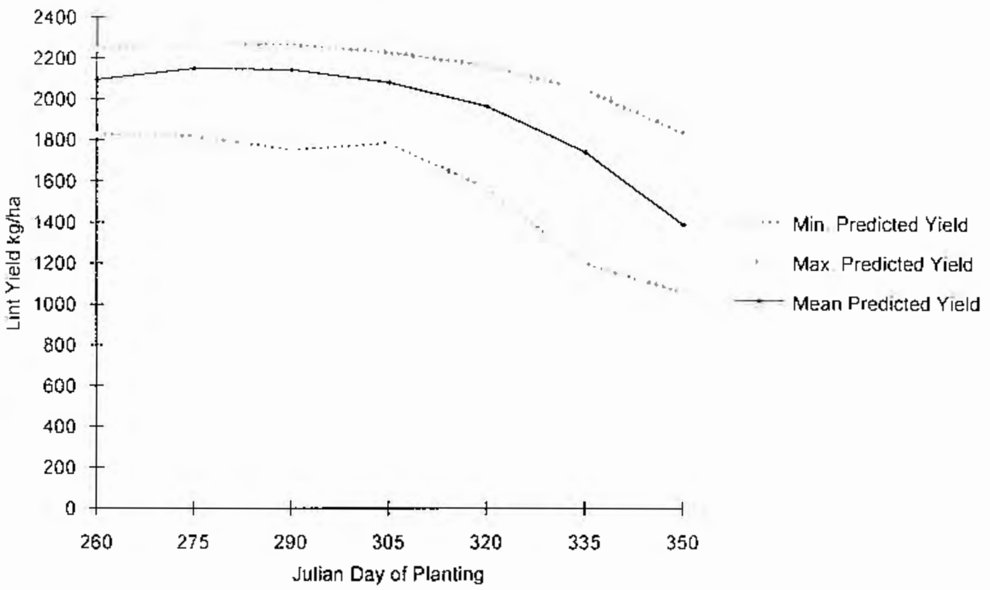


Figure 1.3.6: Yield Depletion with Delayed Planting - Location: MOREE

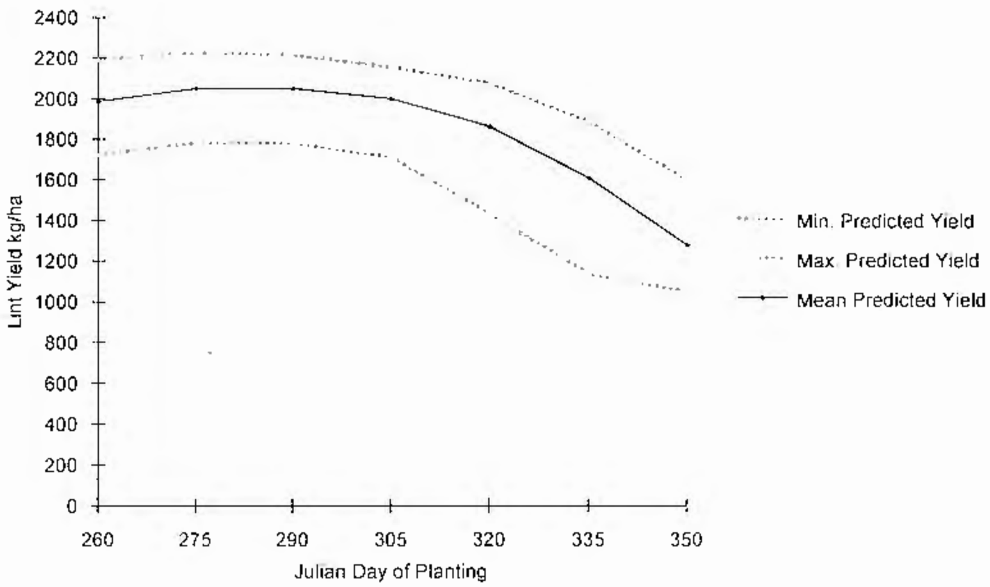


Figure 1.3.7: Yield Depletion with Delayed Planting - Location: MYALL VALE

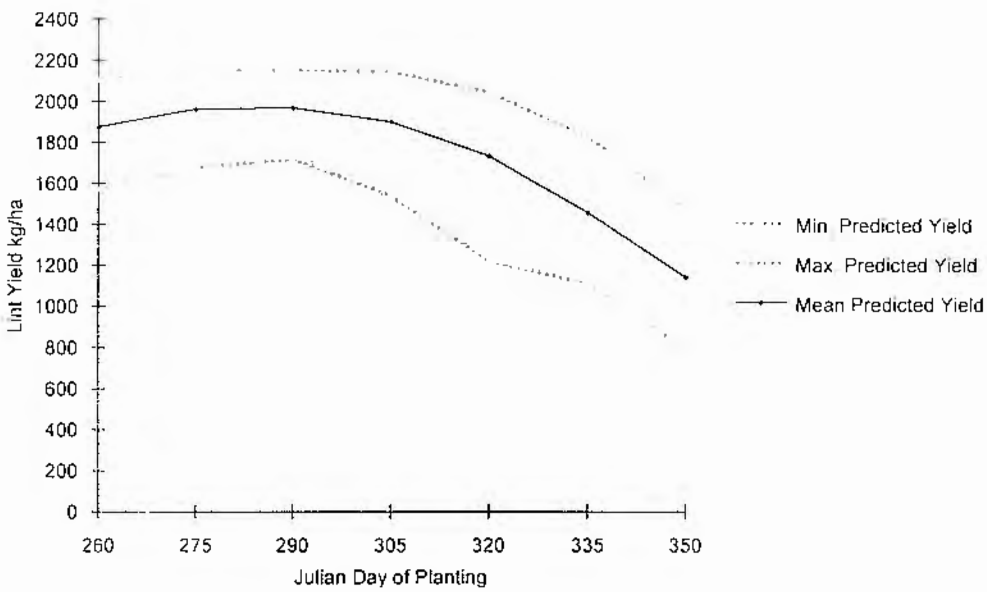


Figure 1.3.8: Yield Depletion with Delayed Planting - Location: WALGETT

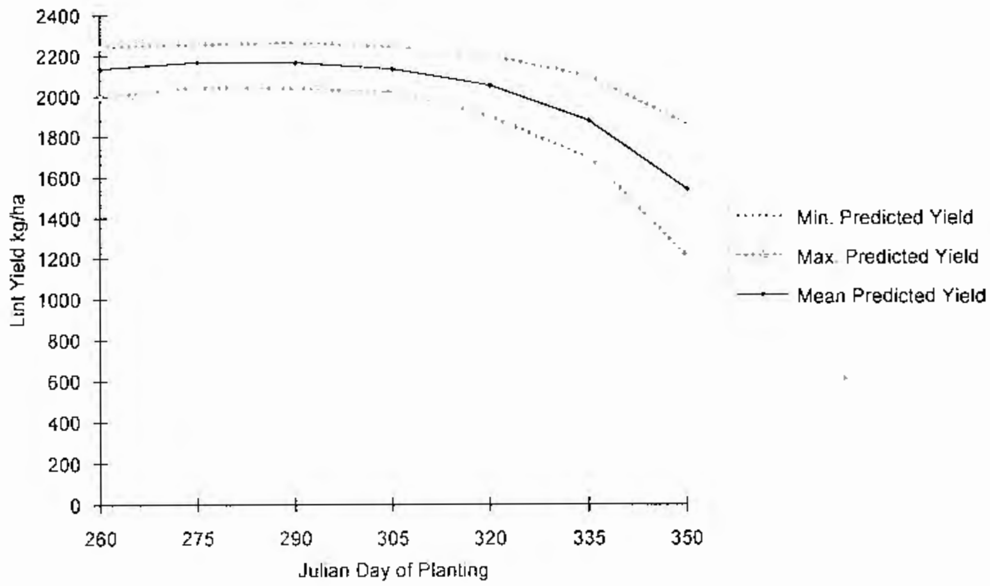


Figure 1.3.9: Yield Depletion with Delayed Planting - Location: BREEZA

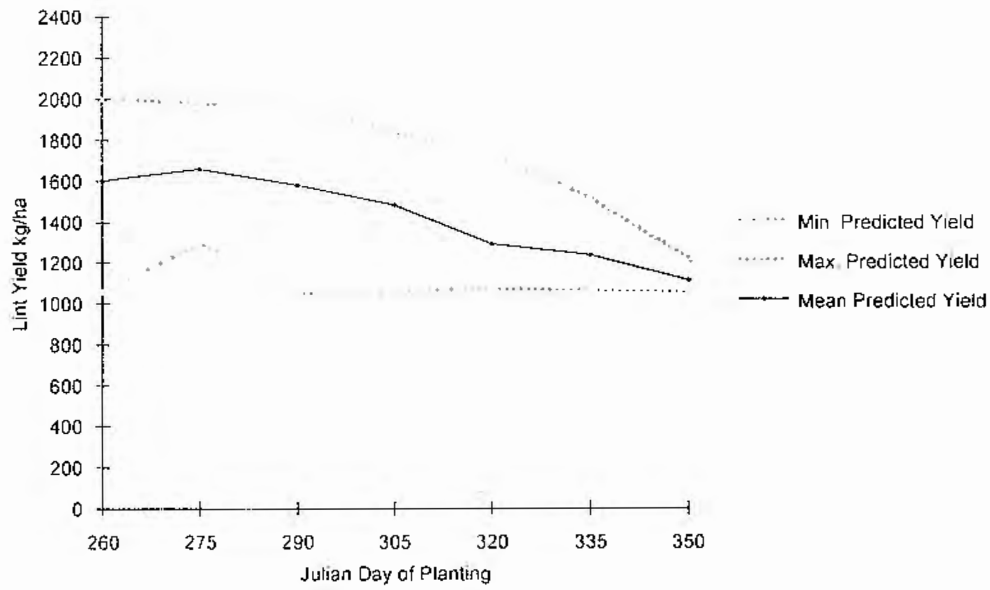


Figure 1.3.10: Yield Depletion with Delayed Planting - Location: BOURKE

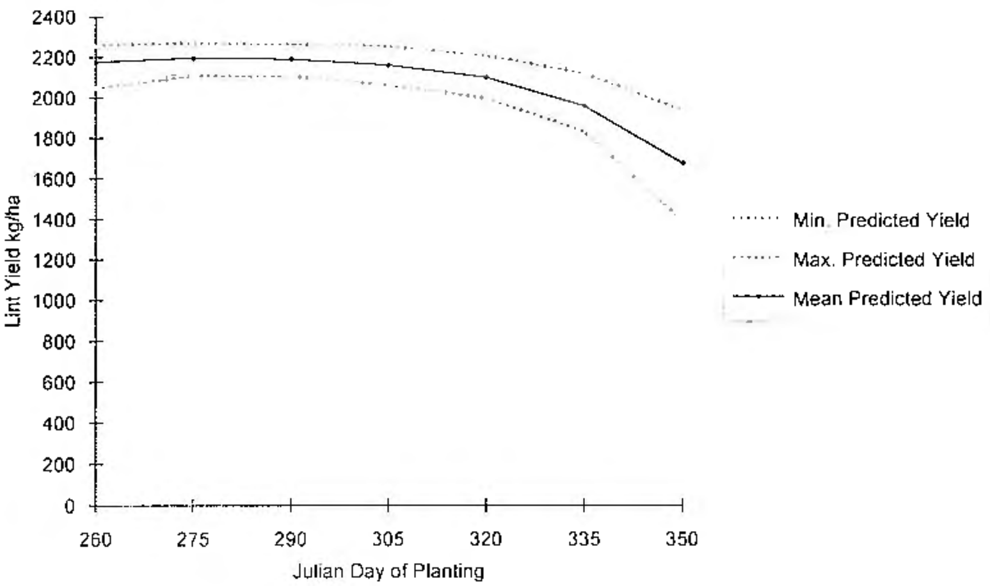


Figure 1.3.11: Yield Depletion with Delayed Planting - Location: TRANGIE

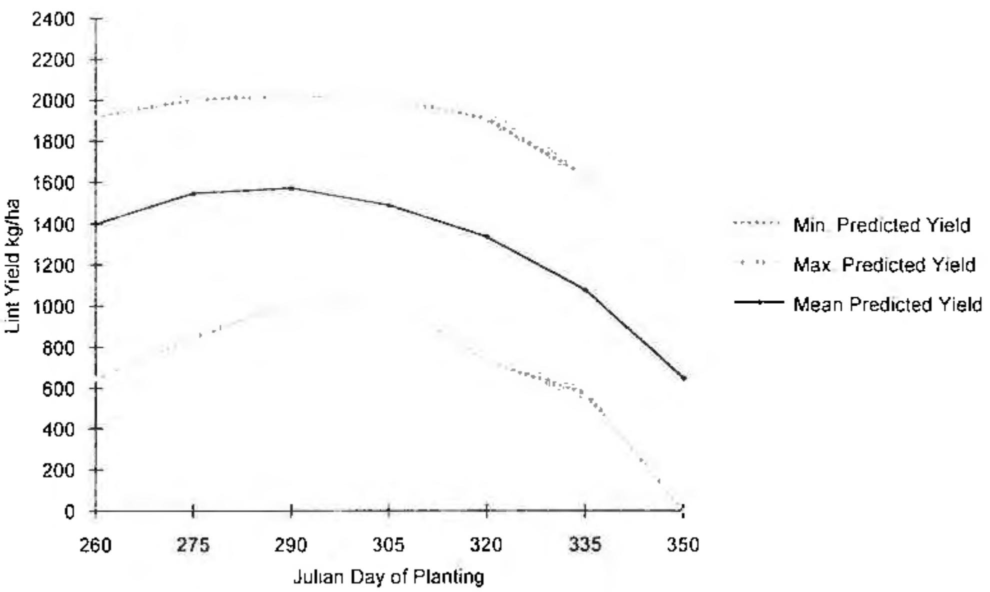
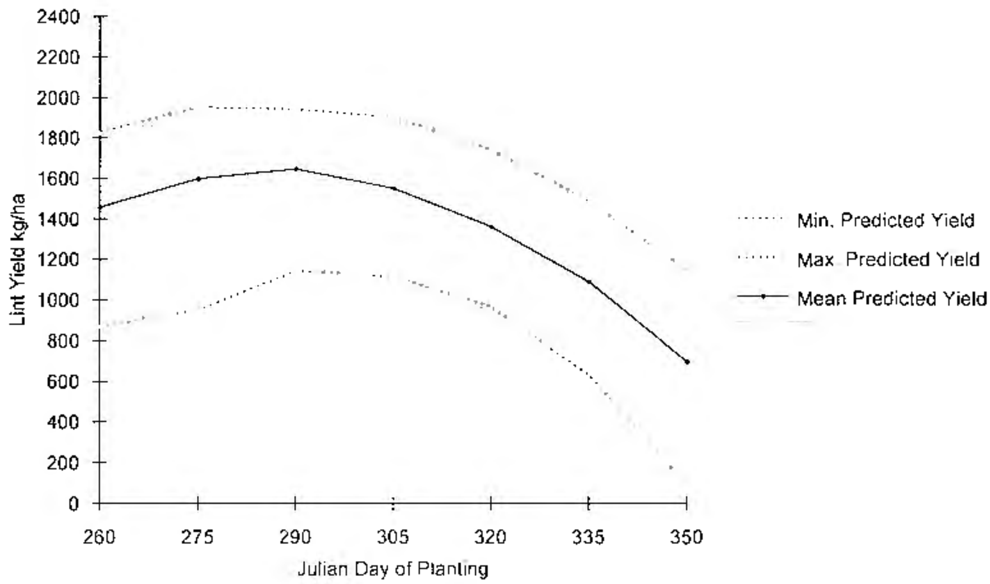


Figure 1.3.12: Yield Depletion with Delayed Planting - Location: HILLSTON



If Julian Day 290 (October 16th) was considered an earlier planting date, the yield at the latest planting date tested, Julian Day 350 or December 16th, is expressed as a percentage of the yield at JD 290 in Table 1.3.3. The ranking of these values gives us an indication of the comparative length of season and comparative yield potential at each site.

Looking at the rate of yield depletion over the range of planting dates JD 290 - JD 350, the shorter season areas of Trangie, Hillston and Dalby show the greatest rates of yield depletion but are closely followed by areas such as Moree, Myall Vale and Goondiwindi which are usually considered good longer season areas. This is a reminder that there is an optimum planting period for cotton and significant yield depletions can occur with greatly delayed planting or re-planting after hail damage in all cotton production areas.

Note that the Breeza site data gives us an unexpectedly high predicted yield and low rate of yield depletion. This is due to gaps in the available climatic data and emphasises the need to have accurate climatic data for yield predictions made using these methods. With such anomalies appearing, it is obvious that the predicted yield potential for a particular planting date needs to be looked at in to relation to an economic yield eg. 1668 kg/ha (ie. 3.0 bales/acre). In Table 1.3.3, the predicted yield at JD 350 is expressed as a percentage of 1668 kg/ha. These values gives us a direct comparison or ranking of cotton growing areas for predicted yield potential.

Based solely on temperature, this method has predicted a low rate of yield decline for the Emerald area, where in practice, heat stress is reported to limit production. Also, in these northern areas, insect pressure makes production of late crops uneconomic and hence, it is economics which places a limitation to the productive season rather the temperature.

It should be noted that calculating yield depletions with delayed planting using solely temperature and Accumulated Growing Day Degrees has limitations. Although the computer program takes into account the effect of cold shock on growth, no research has been carried out to looking at the effect of extremely high temperatures on yield. Other limiting factors may be soil type, water availability and insect pressure. Where climatic data available is inaccurate or only covers for a short period, yield predictions may also be inaccurate as illustrated at the Breeza site.

Table 1.3.3: Comparison of Predicted Relative Yield Potential for Cotton Growing Areas.

	Predicted Yield at JD 350 as % of Yield at JD 290	Rate of Yield Depletion from JD 290 - JD 350 kg/ha/day	Predicted Yield at JD 350 as % of Yield of 1668 kg/ha (ie. 3.0 ba/ac)
Emerald	86.13	5.20	114.78
Biloela	77.04	8.14	63.13
Dalby	56.64	13.59	63.13
St. George	81.47	6.77	105.79
Goondiwindi	67.87	11.14	83.63
Moree	65.22	11.44	76.21
Myall Vale	60.47	12.35	67.16
Breeza	66.06	9.30	64.37
Walgett	74.83	8.85	93.49
Bourke	79.40	7.39	101.24
Trangie	47.55	12.21	39.35
Hillston	47.42	12.81	41.05

NB: JD 290 = October 16th
JD 350 = December 16th

1.4: Case Studies on Early Season Hail Damage in Australiau Cotton Crops (1993/94 - 1995/96)

Introduction:

In interviews prior to beginning this work, growers and consultants were asked to list the criteria they used in decision making in regard to replanting following early season hail. They were asked to nominate minimum viable plant populations and last replant dates for their particular production area and production type. Data was then collated in case studies of actual early season hail strikes in cotton crops over the following three years. From this data we can summarise the actual criteria used by growers in deciding to replant following hail damage in the early part of the season and summarise the success of late replanting.

1.4.1: Plant Populations

In the initial interviews, grower opinion on optimum and minimum plant stands varied considerably.

In case studies following hail damage, where hail damage reduced the viable plant stand to below an average of 4-6 plants per metre, the preferred option among growers was to replant the damaged area. The evenness of the stand was considered important at these lower plant populations and hence, where large gaps existed in stands growers did not expect adequate compensatory growth and replanting was considered the better option.

The decision to replant was not only based on the viable plant population remaining, growers took into account the date of the hail strike (See Section 1.4.2). A key factor affecting replanting decisions over the period covered by these surveys was water supply. With drought conditions existing in most cotton production areas, few growers had extra water available for replanting purposes and hence, were forced to either suffer a less economic plant population or abandon moderately or severely damaged areas of crop where in some instances replanting would have been otherwise carried out.

1.4.2: Replanting Dates

In surveys prior to beginning this work, growers and consultants nominated last replant dates for their particular production area and under dryland or irrigated cultivation. Late November was nominated by the majority of growers as the latest date for replanting following hail damage under irrigated cultivation. Replanting of dryland cotton after hail damage depends on available moisture. If surface moisture is depleted at the time of the hail strike and insufficient rain occurs with the storm, growers need to wait for the next rain event to replant. In initial surveys, growers nominated last replant dates for dryland cotton up to as late as late December.

When faced with actual hail damage, growers replanting decisions were different. Case studies in the period from 1993/94 to 1995/96 collated on early season hail damage show that economically viable decisions in regard to replanting following hail damage followed the same successful criteria used in normal replant decision making ie. taking into account the plant population and depleted yield potential with delayed planting (Section 1.2 and 1.3).

In the case studies collated, decisions as whether to replant or leave the stand as is, or to abandon damaged areas following early season hail damage were based on:-

1. The severity of the damage.
2. The date of the hail strike.

and/or 3. Replanting opportunities with respect to available water, weather conditions and other crop options.

Severity of the Hail Damage.

Where damage reduced the viable plant stand to below an average 4-6 plants per metre, the preferred option was to replant damaged areas. But decisions were also related to points 2 and 3 as follows.

Date of the Hail Strike.

Growers with irrigation in any production area, did not replant after hail strikes later than 20th November. Crops damaged severely after this date were abandoned or the grower may have elected to carry on with the reduced plant stand. The crops damaged in central Queensland, Mc Intyre valley and on the western Darling Downs were at squaring or approximately first flower stage of growth in mid-late November. Whereas crops in the Gwydir, Namoi and Macquarie were in late vegetative stages of growth.

In the dryland situation, case studies show that growers were willing to replant up to the end of November.

There was no differentiation of last replant dates into short season and long season areas. This suggests that in the longer season areas where we would expect growers to take the risk with later planting dates that the economics of growing late cotton are an overriding factor in deciding whether to replant or not. In the cotton production areas of central Queensland and other northern areas, the rate at which yield potential depletes as planting is delayed is slow if calculated based solely on temperature restrictions, but growing late planted cotton is not economically viable and hence, no late replanting was recorded in these areas.

Earlier research work simulating hail damage in the vegetative stages of cotton crop development produced delays in maturity of 63-143 GDD (6-13 days) following V3 stage damage depending on weather conditions following the damage. Delays of 161-243 GDDs (15-23 days) were produced following V5 growth stage simulated hail damage (West, 1994).

Case studies show that hail damage in the early vegetative stages (eg. V2-V4) had either no effect on crop maturity or produced delays in maturity estimated as up to 10 days depending on weather conditions following the damage. These growth stages corresponded to damage up to mid November in the case studies collated. Overall, delays in maturity of this magnitude did not cause crop management problems. In dryland crops on the Liverpool Plains in 1993/94, the delay did expose crops to rain in February which produced a flush of late growth which proved to be difficult to manage.

Once crop development proceeded into later vegetative stages from mid to late November, delays in development recorded following hail damage were extended. Delays in development up to 30 days were recorded with moderate levels of damage at the V4-V6 growth stages in most production areas. Delays in development of this magnitude caused a range of management problems. These included late irrigations (1-2), late insecticide sprays (number depending on insect pressure but all being heavier 'Stage III" insecticides), defoliation was late and therefore more difficult under cooler conditions, late set fruit were slower to mature and maturing under cooler conditions induced low micronaire in many situations and hence heavy price discounts. The delay in development also exposed the crops to late rain and frosts making picking of the crops difficult and expensive.

Replanting Opportunities with respect to Available Water, Weather Conditions and Other Crop Options.

Case studies were collated over a period when drought conditions occurred in most growing areas. Replanting decisions were affected by the lack of available water for replanting or the lack of water for late irrigations which are required by the late developing hail damaged cotton. Growers either abandoned the hail damaged areas and diverted water to cotton crops which were potentially more productive or suffered with a less than economic plant stand.

Weather conditions following the hail damage acted to decrease replanting options. Where rain occurred with the hail storm and/or wet conditions followed, replanting was delayed well past economically viable dates and hence replanting was not practical and not carried out. Or in contrast, with low soil moisture present when the hail strike occurred and insufficient rain occurring with the storm, replanting was delayed until new planting rain events and due to the lack of such events was not carried out in most situations. This was particularly applicable to dryland crops.

In some production areas such as the Darling Downs and Liverpool Plains, growers have other summer crop options and after experiencing hail damage to cotton, took the option to replant to these crops where herbicide programs allowed and crops prices were attractive. This option was also used by growers where water was limited and water would be more productively used by another crop eg. Severe damage on 27/11/95 in Gwydir Valley saw replanting to sorghum as water was not available for replanting nor late irrigations for cotton.

1.5: Discussion Points and Guidelines in Managing Early Season Hail Damage in Cotton

In general, from case studies, hail damage to cotton in the early vegetative growth stages does not pose difficult management problems nor increase production costs beyond that of the cost of replanting as long as the weather conditions allow replanting at an early date and within the normal planting period for the production area. Delays in development due to damage versus delays due to establishment and development of a new stand are similar.

Hail damage in the later part of the cotton planting window when established cotton is in the later vegetative growth stages poses more significant management problems as delays in crop development due to damage are significant and yield depletion with delayed replanting date are significant.

Late vegetative stage damage causes a number of management problems:-

1. Delays in development of up to four weeks are recorded whether growers are regrowing a hail damaged stand or have replanted following hail damage. This does not include delays in defoliation or picking which are incurred should the delayed crop be exposed to late rain etc.

2. Delays in development increase crop production costs. In general, case studies show that late vegetative stage damaged crops replanted or regrown from damage require:-

   - 1-2 extra irrigations. Water usage may be low immediately following the damage as the crop recovers from the hail damage. But once growth recovers and development continues water usage returns to that of a normal crop. As development is now delayed, late irrigations are required if the damaged crop is to mature fully.
   - Extra insecticides and applied later in the season when insect resistance levels are higher and hence 'heavier' and more expensive sprays are required. The number of extra insecticide sprays is dependent on insect pressure in an area.
   - With a larger proportion of the boll load developing later in the season and under cooler conditions low lint quality and in particular low micronaire is an inherent problem in hail damaged cotton. Low micronaire lint is heavily discounted in the marketplace.
   - Late defoliation under cooler conditions is usually more difficult and more expensive as multiple application of defoliants is required.
   - Late development exposes the crop to late rain and frosts which potentially increase defoliation and picking costs and make picking less efficient. Downgrading of lint quality may occur due to rain damage and frosts, growers returns are reduced with price discounts especially in respect to lint colour and leaf trash.

3. Insurance payments for early season hail damage assume reasonable levels of crop recovery or assume that close to the original yield potential is achievable following replanting. Most policies are shown not to cover the increased production costs inherent in regrowing a hail damaged and therefore late developing cotton crop.

All growers of irrigated cotton replanted following mid-November hail damage found similar problems as crops yielded poorly and were expensive to grow and hence, were marginally economic if they produced a profit at all. The general recommendation from growers was to manage the damaged crops to minimise the delay in development and minimise production cost increases. It should be noted that in these case studies, the tendency of many producers was to maximise inputs into these crops and attempt to regrow the original potential yield. But in hindsight, the same producers stated they would not do the same again as the significant delay in development increases production costs dramatically and crops quickly become uneconomic. Few growers had the financial and water resources and luck with the weather to regrow the crop totally and profitably.

Dryland producers are even more reliant on weather conditions and were also more willing to wait to see what the weather will do in respect to providing rain for replanting or recovery from damage. Case study growers recommend making clear decisions immediately in regard to continuing with a reduced stand or not. They found that by putting off replanting decisions or playing around with badly damaged cotton trying to encourage growth did not work but saw high input costs accumulate and delayed development exposed the crops to late rain and frosts and the associated picking problems. If replanting to other crops was not an option, there were strong recommendations to continue with reduced stands rather than waiting for further late rain events for replanting.

Some growers elected to replant to shorter season varieties following late vegetative stage or early squaring stage hail damage. Growers did not find a maturity advantage. This would be due to the fact that in the period covered by this work, the short season varieties available were not of sufficiently short maturity to compensate for the loss of growth season. Cotton varieties currently being developed in the short season breeding programs may provide better opportunities for replacing yield potential when replanting following hail damage.

In respect to guidelines for managing early season damage, options depend on the growers acceptance of risk.

1. You require an economically viable plant population and guidelines are agronomically proven in respect to optimum plant populations (Section 1.2).

2. If the viable plant stand is low then a grower needs to weigh up the yield depletion from carrying on with the reduced stand and hail damage and compare this to the potential yield depletion from replanting at a much delayed date (Section 1.3).

3. Delayed development is a feature of both carrying on with a hail damaged crop and replanting. The extra costs and risks associated with growing late crops are high and not necessarily covered by hail insurance.

4. Both yield depletions and increased production costs should be examined in determining the full cost associated with early season hail and compared to other cropping options and transferring resources to undamaged cotton.

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Chapter 2

Mid Season Hail Damage - Hail Damage When Replanting is Past being an Option?

2.1: Introduction

Once the last economic replant date has passed, if a hail strike is to occur, a grower needs to regrow the crop and replace lost yield potential. This is possible to some extent in all except the most severe damage situations but the ability of a crop to recover and replace lost yield rapidly declines to zero by Last Flower Date. In the average year, any flower appearing after the historical last flower date will not have sufficient time available to it to mature completely. Case studies show that growers are often overly optimistic as to the yield that can be replaced in the reduced season available to them. In only a small percentage of cases will a grower get away with pushing a crop to replace the total lost yield.

Following hail, crop growth is delayed and once growth restarts, it needs to mature within the remaining season if the grower is to avoid the problems associated with late crops ie. late high cost spraying, late/extra watering, difficult defoliation and low quality cotton.

A few points should be kept in mind when regrowing a cotton crop following mid-season hail damage.

1. The hail damage has removed part or all of the yield set as bolls to the date of the hail strike.
2. There is a reduced season available to the grower over which to replace lost yield and a reduced overall crop yield potential.
3. Costs have been incurred in getting the crop to the stage of growth at which it was at the time of damage.
4. Costs will be now be incurred to regrow and mature the crop following the damage.
5. In regrowing a crop following hail damage, crop development is pushed into a later part of the growing season.
6. Growing late season crops involves problems with late watering, late insect control in a period of the season when insect control is difficult and expensive, late set bolls are maturing under cooler conditions and hence time to maturity is extended and lint quality problems are inherent, defoliation of late crops is difficult under the cooler conditions.

Case studies show that not all these points are taken into account when growers are regrowing a crop following mid-season damage (Refer to Section 2.6). Many growers attempt to regrow the same yield that they were expecting prior to the hail strike and incur a series of problems and extra costs. The suggested strategy is to attempt to replace a realistic yield potential and mature it within the growing season which remains available whilst containing input costs and hence reducing the overall financial loss.

Cotton crop management is complex and for the purposes of this study crop management was broken down into separate areas.

Firstly, insect and water management were considered whole farm strategies. The development of hail damaged cotton is pushed later into the season and will require later irrigations. As you need to replace lost plant material and regrow the crop, more irrigations than normal may be required. In limited water situations, a grower will achieve a greater return by allocating water to undamaged cotton rather than pushing hail damaged cotton to regrow and hence the decision is made on a whole farm basis.

In regard to insect management, with a reduced season available to replace lost yield, all fruit initiated will need to be protected from insect damage and hence the usual strategy in regard to insect control is to reduce spray thresholds accordingly. Note, that with the crop development curve shifted to later in the season, insect sprays will be applied later in the season, and hence 'heavier' and more expensive sprays may be necessary. Hence, both water and insect management involve increased production costs following hail damage.

With the aim being to get the crop regrowing following hail damage and then maturing it in the remaining season available, nutrients and growth regulators can play an important part in managing a hail damaged crop. In this part of the study, a series of field trials concentrating on these two areas of management were carried out on hail damaged crops over the previous three seasons. With the assistance of cotton growers, case studies covering crops damaged by hail during the mid-season period were collated to illustrate the variable strategies employed by growers in their attempts to encourage recovery following the hail damage.

2.2: Nitrogen Fertilisation of Hail Damaged Cotton Crops

2.2.1: Introduction

The cotton plant contains more nitrogen than any other mineral nutrient. Nitrogen is a key component of plant proteins, enzymes and of course, chlorophyll and hence, plant size and growth rate are affected by nitrogen status. Nitrogen deficiency is identified as the first limiting factor to yield in regard to fertilisers (Maples and Keogh, 1965).

Nitrogen fertilisation increases yields by prolonging growth and increasing the number of bolls set, ie. delays cut out. Increasing applied nitrogen above an optimum level is found to induce excessive vegetative growth and delayed maturity, as reported by Basinski *et al.* (1975), Boquet *et al.* (1993), Constable and Rochester (1988) and Hearn (1981). Excess nitrogen is also found to carryover to subsequent crops and hence, accurate application rates are important (Maples and Frissell, 1985).

Nitrogen is taken up rapidly and early in the growth cycle and in excess of the plant's requirement at that time. The leaf canopy acts as reservoir of nitrogen, then as plant nitrogen requirements increase to a peak in early boll set, nitrogen is re-mobilised from the leaves to supply young fruit (Constable and Rochester, 1988). Fertilisation programs are designed to have nitrogen applied and available to the plant at times to match peak requirements. As nitrogen is stored in the leaves and then re-mobilised for use by growing bolls, nitrogen needs to be applied approximately three weeks before peak usage. Hence, current Australian recommendations (Constable, 1986, 1988, 1990) are to apply all nitrogen prior to the first irrigation so that nitrogen is available to the plant for its peak requirement period which corresponds to early January in the Namoi Valley (Table 2.2.1).

Following a crop rotation eg. cotton/wheat or fallowing, higher levels of nitrogen are found in the soil and available to the crop and a reduced quantity of fertiliser is required (Constable *et al.*, 1992). In contrast, nitrogen recovery from fertiliser is reduced by denitrification, leaching and ammonification (Humphreys *et al.*, 1988), waterlogging and water stress (Hearn and Constable, 1984) and in these situations fertiliser requirements may increase.

The aim with nitrogen fertilisation should be to obtain a maximum yield while minimising the problems of rank growth and delayed maturity. Soil nitrogen testing and petiole testing are key tools in optimising nitrogen application and methods are reviewed by Burhan and Babikir (1968), Constable (1987, 1988a and b), Constable *et al.* (1991), Constable and Rochester (1992) and Hartizan (1988). In general, soil nitrogen testing combined with monitoring of crop nitrogen levels during the growing season with the use of petiole nitrate tests provides the means by which to best optimise nitrogen fertilisation.

Table 2.2.1: Average Nitrogen Application Rates For Cotton After Various Crop Rotations

Previous Crop	Nitrogen Rate (kg/ha)
Cotton or Sorghum	130-160
Third Year Cotton	150-180
Soybean	80-110
Wheat	70-100
Fallow	60-80
Factors Which Increase These Rates: - long growing season - compacted soil - heavy, flat country	Factors Which Decrease These Rates: - river loam soils - short season - good soil structure

Source: Constable (1988b)

Soil samples taken in September to a depth of 30 cm in unfertilised soils give the best correlation with subsequent cotton crop response to nitrogen fertiliser. Levels of 20-25 ppm nitrate indicate that adequate nitrogen can be supplied by the soil itself. Soil nitrate test levels of 5 -10 ppm nitrate indicate that 200 - 100 kg N/ha are required. In practise, many growers apply nitrogen fertilisers before September and hence, nil strips need to be left for soil nitrate tests to determine if side dressing of nitrogen will be required (Constable, 1988a).

Petiole nitrate tests give a 'snapshot picture' of the nitrogen status of a growing crop. The absolute value of petiole nitrate at any date is affected by the stage of growth, agronomic factors such as water status, by plant variety and weather conditions. The critical petiole nitrate value at first flower is approximately 20,000 ppm, and where values are below this, the crop may require extra nitrogen (Figure 2.2.1). One approach is to petiole nitrate test at three sample dates one week apart from squaring to early flowering . If values remain below critical levels then further N may be required.

Concentrations of nitrate in petioles are as high as 30,000 ppm at squaring and fall linearly to as little as 1000 ppm 900 growing day degrees from sowing (Constable 1988b). A more accurate picture of nitrogen usage is gained by noting the decline in petiole nitrate from squaring to flowering with optimum rates of decline of 31.8 ppm/GDD $\pm$ 1 ppm/GDD for adequately fertilised Grey Clays (Constable *et al.*, 1991). Concentrations decline more rapidly in nitrogen deficient crops (Constable and Rochester, 1992) (Figure 2.2.2).

The nutritional status of a crop is of primary importance in determining the ability of a crop to recover from hail damage. Following hail damage, a variety of fertiliser strategies have been used by growers with varying results (Refer to Section 2.6). Growers have either left the nutrient status as is and let the crop regrow, or applied small and large amounts of nitrogen and other nutrients to replace or boost nutrient levels in the crop. Resulting problems have included lack of regrowth due to less than optimum nutrient levels or excessive vegetative growth adding to the lateness and delayed maturity of hail damaged cotton.

Figure 2.2.1 Relationship between Petiole Nitrate at 750 GDD (First Flower) and Fertiliser Requirement.
Source: Constable (1988b).

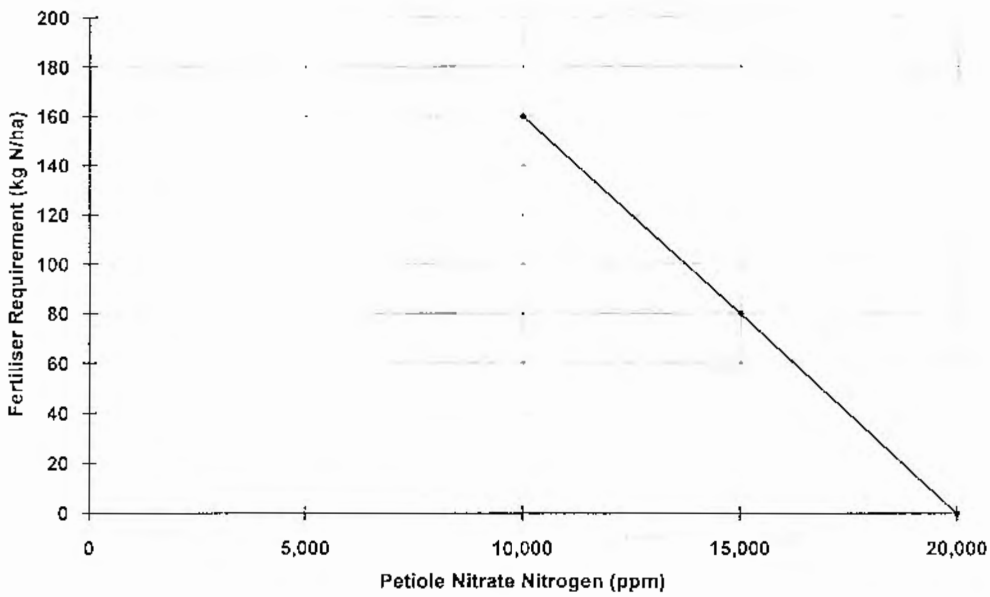
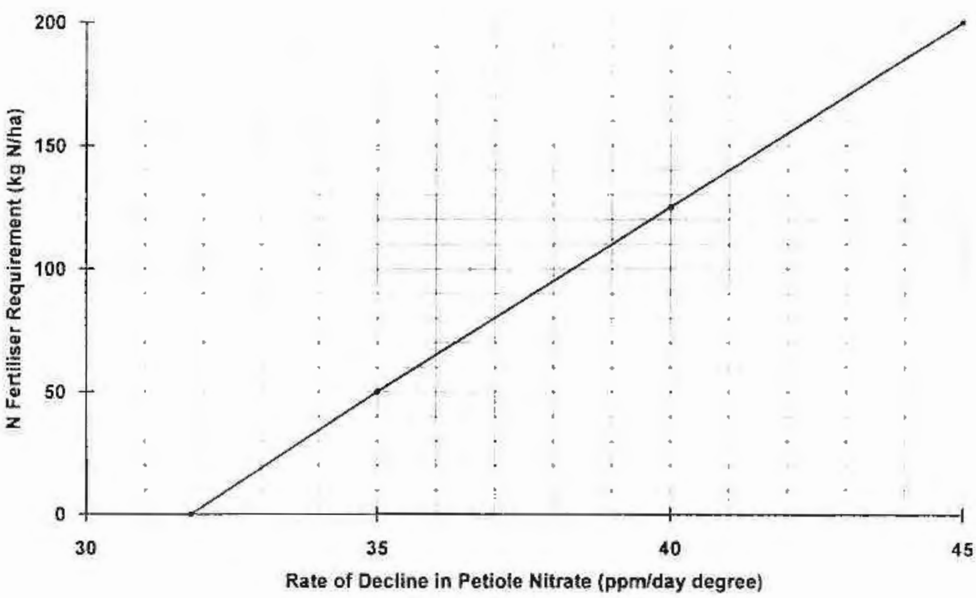


Figure 2.2.2 Relationship Between Rate of Decline in Petiole Nitrate and Fertiliser Nitrogen Requirement
Source: Constable and Rochester (1992).



2.2.2: Monitoring of Petiole Nitrate Levels in Hail Damaged Cotton

Aims:

The aim of this exercise is to determine what would be considered optimum nitrogen strategies for use on hail damaged cotton. Nitrogen deficiency or stress was identified by monitoring nitrogen levels in hail damaged crops as they recovered following a hail strike.

Methods:

Petiole nitrate levels were monitored in crops following damage by hail at six trial sites in the 1994/95 and 1995/96 cotton seasons. Petiole sampling was carried out at 7-14 day intervals over the period from squaring to two weeks after first flower on regrowth.

At Site A, hail damage (averaging an assessed 28% loss) was simulated at the R3 growth stage of a Sicala V2 cotton crop. Petiole nitrate levels were monitored in simulated hail damage treatments compared to undamaged adequately fertilised cotton as part of a combined nitrogen and growth regulator trial.

Sites B through to F were sites which had incurred natural hail damage. At these sites, field trials relating to growth regulator use were carried out and petiole nitrate levels were monitored in untreated plots to identify problems in nitrogen levels. Water, insect and other agronomic management was carried at trial sites as per the normal commercial program as outlined in Appendix 2.2.

Four replicates of 40-50 petioles of the youngest fullest expanded leaf (3rd - 4th leaf from terminal) of a cotton plants were collected from trial sites. Samples were dried at 70 - 80 ^{0}C for 12 hours or where travel time to dehydrators was more than 12 hours, samples were dried by microwave. Samples were then ground using a cyclotec grinder and stored in air tight plastic vials for analysis. Nitrate levels were measured using standard international techniques, with 0.1 g of the sample extracted in 50 ml of distilled water, filtered for one hour and analysed for nitrate using an auto analyser method (Technicon method 487-77A).

Results and Discussion:

Following a hail strike, new squaring and flowering phases are initiated on regrowth plant material. Vegetative growth and fruiting patterns are similar to that in undamaged cotton but overall crop development is delayed compared to development in undamaged cotton (West, 1996). It is suggested that when nitrogen is not a limiting factor, nitrogen uptake or usage should follow similar patterns as for the original fruiting phase of undamaged cotton. Concentrations of nitrate in petioles are found to fall linearly from squaring through flowering in cotton unaffected by hail (Constable 1988b), similar rates of decline of petiole nitrate should be observed as the crop regrows after hail damage if nitrogen is not limiting.

Constable *et al.* (1991) showed that in adequately fertilised cotton crops growing on grey clay soils. rates of decline of petiole nitrate in the order of 31.8 ppm/GDD $\pm$ 1 ppm/GDD occur between squaring and flowering (approximately 700 - 900 GDDs from planting). This rate of decline has been used as an "optimum" rate of decline for the purposes of this work.

The new fruiting phase which occurs following damage is delayed compared to the normal fruiting pattern and depending on the date of the hail strike at each site in these trials, occurs from 1000-1450 GDDs from planting.

Uptake of nitrogen declines past peak flowering as the undamaged cotton crop matures, and hence, petiole nitrate readings taken at sample dates from 1000-1450 GDDs from planting would have decreased significantly compared to the squaring to flowering period. This is indicated in plotting the nitrate level decline through to 1450 GDDs in undamaged cotton growing on a grey clay ie. 'optimum' decline as in Figure 2.2.3.

The crop regrowing after hail damage re-initiates the fruiting phase and rapid growth following damage sees levels of uptake of nitrogen closer to that seen in the 750-100 GDD period in undamaged cotton. Rates of decline should indicate whether there is sufficient nitrogen available to meet the growth requirements of the regrowing hail damaged crop.

Petiole nitrate readings in these trials were found to be linearly related to time from planting (Growing Day Degrees or GDDs) as in the work of Constable *et al.* (1991). Regression of petiole nitrate readings against time from planting was used to calculate the rate of decline in petiole nitrate for each trial and treatment (Table 2.2.2).

Table 2.2.2: Regression Equations Relating Decline in Petiole Nitrate to Time from Planting in Growing Day Degrees.

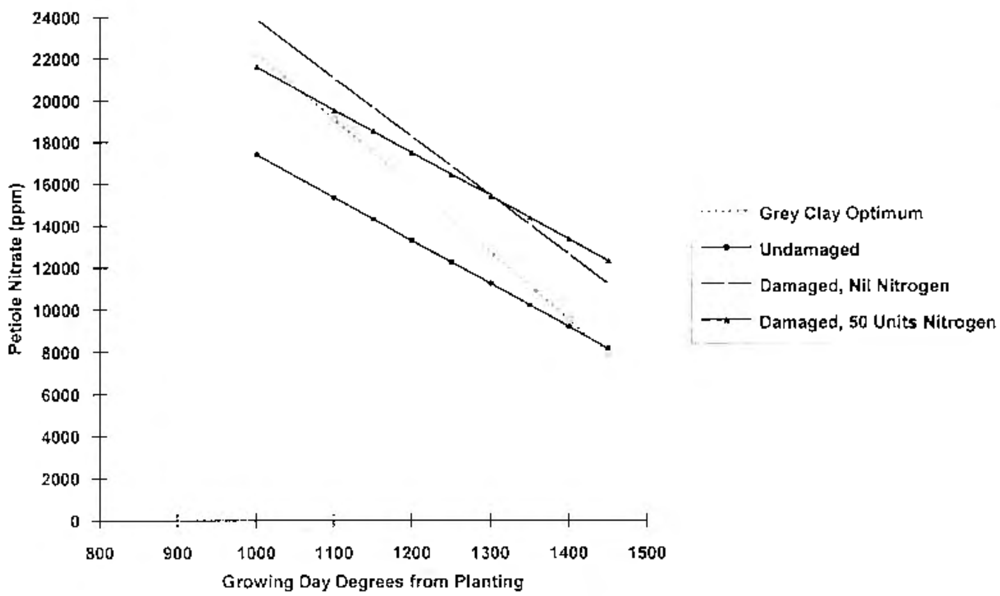
Site	Regression Equation	r^2	Rate of Decline in Petiole Nitrate (ppm/GDD)
A - A.C.R.I. 1994/95 Undamaged	Nitrate = 37905 - 20.5 x GDD	91.5%	20.5
A - A.C.R.I. 1994/95 Nil Nitrogen	Nitrate = 51990 - 28.1 x GDD	90.7 %	28.1
A - A.C.R.I. 1994/95 50 Units Side-dressed Nitrogen	Nitrate = 42290 - 20.6 x GDD	92.4 %	20.6
B - Abbey Green 1994/95	Nitrate = 69080 - 33.4 x GDD	97.4 %	33.4
C - Wild Willows 1994/95	Nitrate = 99846 - 56.0 x GDD	99.7 %	56.0
D - Auscott Narrabri 1995/96	Nitrate = 50357 - 28.2 x GDD	78.5 %	28.2
E - Coolabah 1995/96	Nitrate = 34104 - 23.4 x GDD	88.2 %	23.4
F - Willawood 1995/96	Nitrate = 79219 - 53.7 x GDD	97.8 %	53.7

The 1994/95 Australian Cotton Research Institute (A. C. R. I.) trial or Site A was carried out on a grey clay soil and was considered to be adequately fertilised with 100 units of nitrogen applied pre-plant. Due to lack of hail events in the region, hail damage was simulated at the R3 growth stage at an average level of 28% assessed damage. Figure 2.2.3 illustrates the decline in petiole nitrate from squaring to flowering on regrowth following simulated hail damage at Site A.

It is found that the uptake of nitrogen in the simulated hail treatments is higher than in undamaged cotton in petiole nitrate levels measured at any sample date. This is an indication of the more rapid growth rate of cotton during the squaring - flowering phase compared to growth rates in more mature cotton.

Petiole nitrate levels declined at a rate of 20.5 ppm/GGD in the undamaged cotton. The rate of decline in petiole nitrate from squaring to flowering in simulated hail damaged cotton is more rapid than in undamaged cotton. But uptake levels do not decline below levels which would be considered critical for growth by comparing values to either the undamaged treatment in the Site A trial or to the recorded optimum uptake levels defined by Constable *et al.*, (1991) and so do not indicate that an additional application of nitrogen would have been required (Figure 2.2.3). With the side dressing of 50 units of nitrogen as urea following the simulated hail damage, the rate of decline in petiole nitrate returns to the same rate as in undamaged cotton.

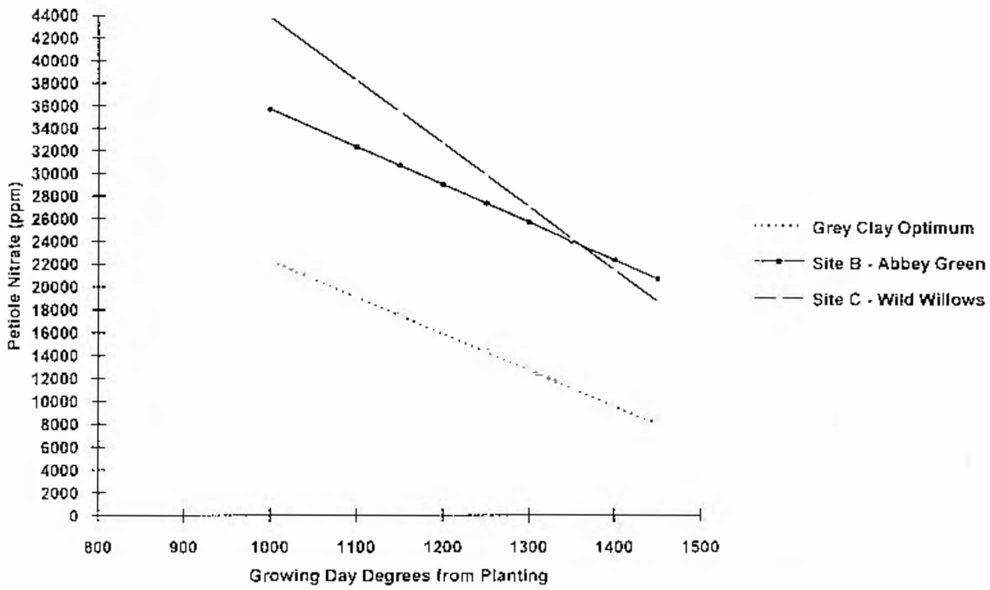
Figure 2.2.3: Decline in Petiole Nitrate in Cotton Following Simulated Hail Damage (Site: A - A. C. R. I. 1994/95).



The brown clays, on which Sites B and C were located, are generally more fertile with greater amounts of nitrogen at depth and show a greater degree of nitrogen mineralisation and hence, more nitrogen is available to the plant (Rochester pers comm.). Constable and Rochester (1988, 1991) have found that the brown clays display a lower critical nitrogen level and show a lower rate of decline in petiole nitrate than that seen in grey clays. Trials at Site B and C, compare the rates of decline of petiole nitrate in two crops of different maturity at the time of the hail strike but growing on the same soil type and under the same growing conditions (Figure 2.2.4). Both sites had sufficient nitrogen remaining under the crops to support good regrowth following the strike as indicated by the high petiole nitrate readings measured following the damage in spite of waterlogging.

Vegetative regrowth following damage was not extensive at Site B - Abbey Green due to the fact it was at a more mature growth stage at the time of damage (R8-R9 growth stage). Whereas, the crop at Site C - Wild Willows was at only the R2-R3 growth stage at the time of damage. Nitrate levels declined at a rate of 33.4 ppm/GDD at Site B compared to 56.0 ppm/GDD at Site C. Nitrogen requirements and uptake would have been greater at Site C, as it re-initiated development following damage and nitrate concentration would have been rapidly diluted by the increased vegetative material with the result that the rate of decline in petiole nitrate at Site C was rapid at 56.0 ppm/GDD. But note that nitrate levels are still above critical levels indicating additional nitrogen would not need to be applied in either situation. It should be noted that in both trials B and C, prolonged waterlogging in the three weeks post hail damage should have contributed to a decreased uptake of nitrogen. This is not indicated by the petiole nitrate readings taken which remained above critical levels during this period.

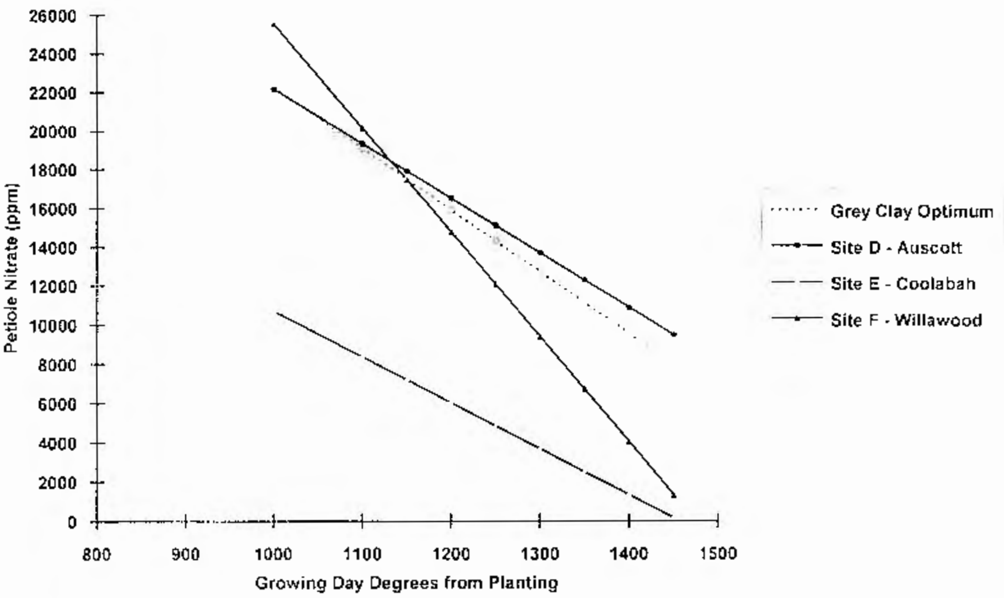
Figure 2.2.4: Decline in Petiole Nitrate in Cotton Regrowing After Hail Damage (1994/95)
Sites: B (Abbey Green) and C (Wild Willows)



Warm growing conditions and good drainage in 1995/96 season saw vigorous regrowth following hail damage at Site D (Auscott Narrabri) in spite of heavy rain in the January of 1996. The rate of decline in petiole nitrate of 28.2 ppm/GDD at this site is comparable to that reported by Constable *et al.* (1991) for grey clay soils. The soil type at Site D would be considered intermediate between the brown and grey clays and hence a slightly slower rate of decline in nitrate levels would be expected. The damage experienced at this site was early in the growth cycle at the R2 growth stage, and with good growing conditions following damage, the reproductive phase was re-initiated within 100 GDDs of the damage. Rates of nitrogen uptake during the new squaring and flowering phase were similar to that expected for an undamaged crop ie. little delayed compared to undamaged cotton, as indicated in Figure 2.2.5.

Sites E and F being situated on grey clays and rates of petiole nitrate decline of 23.4 and 53.7 ppm/GDD were measured for the sites, respectively. The crop at Site E was very mature at the time of damage (R10-R12 growth stage) and within 14 days of cutout. Little regrowth appeared following the hail damage due to the combined effect of the growth stage at time of damage and weather conditions which did not induce rapid growth. Hence, little nitrogen was required by the crop and little was taken up as indicated by the low levels of petiole nitrate measured at each date. The Site F trial (Willawood) was younger cotton (R2-R4 growth stage) at the time of damage and regrowth should have been rapid but due to severe waterlogging for a prolonged period following damage regrowth was slow. Although nitrogen was applied the waterlogged conditions made uptake impossible and hence petiole nitrate levels declined rapidly.

Figure 2.2.5: Decline in Petiole Nitrate in Cotton Regrowing After Hail Damage (1995/96).
Sites: D (Auscott Narrabri), E (Coolabah) and F (Willawood).



Conclusions:

Crop growth stage at the time of damage and the timing of the hail strike within the available growing season will dictate that amount of regrowth that can be expected following a hail strike. Mature cotton has a reduced requirement for nitrogen as regrowth following damage is minimal compared to younger cotton following hail damage, as cotton physiology dictates that the crop will mature the fruit remaining on the bush before initiating any regrowth and climatic conditions will dictate if there is sufficient time remaining in the season to initiate and mature regrowth. A crop at a less mature growth stage at the time of damage under optimum weather conditions will initiate vegetative regrowth quickly and hence will have a greater nitrogen requirement.

The nutrient status of the crop will dictate how much of the regrowth potential can be achieved under suitable weather conditions. At each of these sites, nitrogen applied prior to the hail strike was considered adequate for production of a normal cotton crop. Following the hail strike, petiole nitrate levels and the rate of decline of petiole nitrate indicate that nitrogen was not limiting for growth. Hence, further nitrogen fertilisation would not have inceased yields. Only where waterlogging was imposed on young cotton attempting to regrow following damage, did nitrate levels reach critical levels. In this situation, nitrogen was applied to the commercial field and as indicated by the overall lack of regrowth, it is suggested that the applied nitrogen was not able to be utilised by the crop due to waterlogging.

2.2.3: Post Hail Damage Application of Nitrogen Fertiliser

Aims:

The aim of this exercise was to determine what would be considered optimum nitrogen strategies for use on hail damaged cotton. Previous trials had indicated that where normal fertiliser inputs for a given yield potential were applied prior to damage no deficiency was indicated in crops regrowing following a hail strike. With a crop damaged by hail prior to the application of its full nitrogen requirement, a suitable site was available to test the response of a hail damaged crop to varying rates of applied nitrogen fertiliser.

Methods:

Auscott Narrabri (Field 5) was damaged by hail on 10/12/95 at a level of 43% assessed damage when at the R3-R4 growth stage. The crop was squaring well and damage saw approximately 70% defoliation, with most plants tipped out at the 6th -7th node level removing the major proportion of fruiting limbs and squares, and stem bruising was evident. At this stage Field 5 was yet to receive its full nitrogen application. A replicated trial (Randomised Complete Block Design) was set up applying 30 and 60 units of nitrogen as side-dressed urea compared with no side-dressing of nitrogen.

Note that the field was planted to the variety Sicala V2 in skip row configuration with a double skip every 16 row on double beds to minimise water usage. The previous cotton crop was 1993/94. 96 units of nitrogen applied prior to planting of the 199/96 crop consisted of 30 units of nitrogen applied to a wheat crop in the fallow which failed to establish and 30 units N which were applied in July prior to sowing the cotton crop. This is an equivalent of 96 units of N available to the crop as 62.5% of the cropping area is planted to cotton with N applied over 100% of area.

Urea was side-dressed by ground rig immediately the ground was trafficable following the hail storm. All water, insect and other agronomy management was as per the commercial field in which the trial was situated (Appendix 2.2).

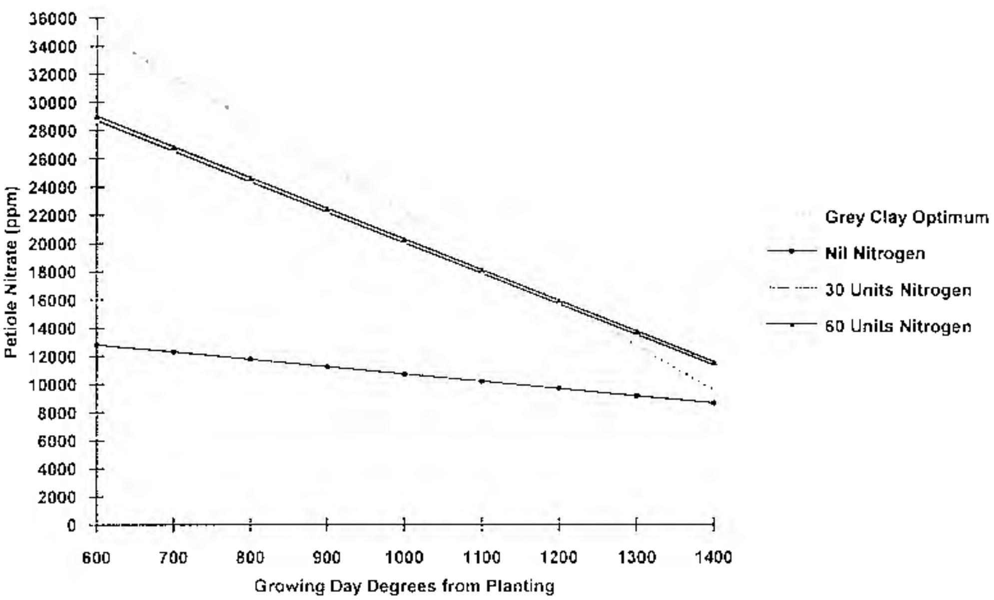
Petiole nitrate levels were monitored in the crop as it regrew following the hail damage. Petiole sampling was carried out at 7-14 day intervals over the period from squaring through to two weeks after first flower on regrowth. Four replicates of 40-50 petioles of the youngest fullest expanded leaf (3rd - 4th leaf from terminal) of a cotton plant were collected from trial sites. Samples were dried at 70 - 80 ^{0}C for 12 hours then ground using a cyclotec grinder and stored in air tight plastic vials for analysis. Nitrate levels were measured using standard international techniques, with 0.1 g of the sample extracted in 50 ml of distilled water, filtered for one hour and analysed for nitrate using an auto analyser method (Technicon method 487-77A).

Fruit numbers were monitored at 6, 10 and 14 weeks following damage by fruit counts over one m^2 areas. Lint yields were determined by sequential hand picking over 2 m^2 areas at maturity. Sub-samples were ginned to determine ginning percentages and fibre quality was determined by H. V. I. techniques at the Australian Cotton Research Institute, Myall Vale, Narrabri.

Results and Discussion:

Petiole nitrate levels were monitored as the hail damaged crop re-initiated vegetative and reproductive growth. Regression of petiole nitrate readings against time from planting was used to calculate the rate of decline in petiole nitrate for each treatment. Petiole nitrate levels at each sample date indicate that nitrogen was limiting to growth in the Nil Nitrogen treatments (Figure 2.2.6). Uptake at each sample date was below critical levels for growth. Examination of the rate of decline was not applicable as uptake of nitrogen was minimal. Application of 30 and 60 units of nitrogen saw uptake levels rise above critical levels and rates of decline of petiole nitrate of 21.7 and 21.8 ppm/GDD were measured, respectively. Such rates of decline would be expected for the brown clay soil type and slightly slower than for a grey clay soil type. No significant difference in rates of decline in petiole nitrate are observed between the two treatments of 30 and 60 units of side-dressed urea.

Figure 2.2.6: Decline in Petiole Nitrate in Cotton Regrowing After Hail Damage (1995/96) Site: Auscott Narrabri (Field 5) Nitrogen/Zinc Trial



Regression Equations:

Side-dressed Nitrogen (30 units) Nitrate = 41730 - 21.7 x GDDs r^2 = 76.2%.

Side-dressed Nitrogen (60 units) Nitrate = 42105 - 21.8 x GDDs r^2 = 62.4%.

No differences were found between treatments in regard to fruit numbers at any sampling date, with final plant height and boll numbers being similar across the three treatments.

No differences were found in final lint yield nor in maturity of the nitrogen treatments as measured by sequential picking. H.V.I. testing revealed no differences in lint quality due to nitrogen treatments.

Conclusions:

The average lint yield over the entire trial area was only 4.5 bales/hectare and therefore, factors other than nitrogen were acting to limit yield or acted to limit the uptake of nitrogen. The crop was planted skip row to be able to take full advantage of the limited irrigation water originally expected. The rain of December and January allowed watering to optimum requirements, but the crop could not take full advantage of the available row space and it is suggested did not utilise the full quantity of available nitrogen.

Application of urea was carried out within seven days of the hail strike, as the field was quickly trafficable since there was little rain was recorded with the hail. Initial regrowth was quite rapid but the initiation of flowering corresponded to wet weather conditions with rainfall for January totalling 425 mm for the Myall Vale weather station compared to a long term average for the month of 104 mm. This included a fall of 221 mm in 24 hours which caused water to backup into the trial area and the area remained waterlogged for an extended period. During the same period average temperatures also remained moderate (Appendix 2.1 Climatic Averages 1995/96). Hence, uptake and utilisation of nitrogen and other nutrients was hampered by climatic conditions and crop regrowth was reduced. This precluded any conclusions being drawn as to the response of the crop to applied nitrogen.

Petiole sampling results suggest that nitrogen would have been a yield limiting factor for the nil nitrogen treatments under normal growing conditions. Note that there was little difference in petiole nitrate readings for the two side-dressed nitrogen treatments. 30 units of nitrogen applied post damage would have been sufficient nitrogen to bring the nitrogen applied up to normal crop requirements. The application of a further 30 units of nitrogen (ie. 60 units N treatment) has produced no increased nitrogen uptake as recorded in the petiole nitrate data and it is suggested may have been in excess to crop requirements in a normal growing season.

2.3: Foliar Fertilisation of Hail Damaged Cotton Crops

2.3.1: Introduction

In modern cotton production, nutrients are supplied to a crop firstly from the soil and secondly from applied fertilisers. The amount supplied by the soil is influenced by the amount returned to the soil in crop residues versus the quantity removed with the crop product and the cropping history of the field. If residues are burnt, then the non-metallic elements nitrogen, phosphorus, and sulphur are lost to the atmosphere. If residues are incorporated into the soil, they decompose and become available to a subsequent crop. Hence, of the elements taken up in large quantities by a cotton crop, N and P are more frequently needed as fertilisers than K, Ca and Mg (Hearn, 1981). Hearn (1981) reviewed in detail the nutrient requirements of cotton, deficiency symptoms, critical levels, plant tests and nutrient application. A summary of uptake of nutrients by cotton and nutrient removal is presented in Table 2.3.1.

Most of Australian cotton growing soils are relatively fertile. Cotton crops, of course, have a high nitrogen requirement and hence, nitrogen is routinely applied to all soils. Phosphorus is also required on some soil types. With a high crop demand and depletion of nutrients with long term cropping we may see deficiencies of other nutrients such as potassium and sulphur. Soil tests for N, P, K and Na can help to identify fertiliser requirements before sowing but soil levels for trace elements bear little relationship to crop status. Plant tissue levels provide a better indication of possible deficiency problems for trace elements and critical levels for these nutrients are outlined in Table 2.3.2.

Trace elements seem to be present in adequate levels in Australian soils with the exception of zinc which can become unavailable due to specific soil conditions, eg. in areas cut in laser levelling, high pH soils or fields displaying long fallow disorder (Constable, 1988a; Daniells and Larsen, 1991).

Foliar fertiliser mixes are often applied to boost micronutrient levels in high yielding crops or to alleviating part of that stress imposed by waterlogging, hail damage etc.

Table 2.3.1: Essential Nutrients for Cotton and Typical Values for Total Plant Uptake and Removal at Harvest

	Typical Uptake kg/ha	Typical Removal* kg/ha
Nitrogen	110	11
Potassium	125	6
Phosphorus	30	2
Calcium	90	1
Magnesium	30	1
Sulphur	10	0.1
Iron	0.600	0.066
Manganese	0.450	0.012
Boron	0.200	0.021
Zinc	0.060	0.013
Copper	0.020	0.003
Molybdenum	0.003	Trace

* Removal refers to that removed by a crop including seed and lint and assuming a 38% gin out turn.

Source: Constable (1988a).

Table 2.3.2: Plant Tissue Levels Which May Indicate Deficiency for Cotton Growth

a) LEAF BLADE DURING EARLY FLOWERING				
NUTRIENT		UNITS	CRITICAL LEVEL	NORMAL RANGE
Nitrogen	N	%	3.0	3.0-4.5
Phosphorus	P	%	0.2	0.3-0.5
Potassium	K	%	1.0	1.0-3.0
Calcium	Ca	%	0.4	0.4-3.0
Magnesium	Mg	%	0.2	0.4-0.9
Sulphur	S	%	0.2	0.2-0.4
Iron	Fe	ppm	30	50-350
Manganese	Mn	ppm	13	50-350
Boron	B	ppm	10	20-60
Zinc	Zn	ppm	11	20-60
Copper	Cu	ppm	2	5-25
Molybdenum	Mo	ppm	0.4	0.4-0.9
b) PETIOLE AT FIRST FLOWER				
NUTRIENT		UNITS	CRITICAL LEVEL	
Nitrogen	NO_3	ppm	20,000	
Phosphorus	P	ppm	12,000	
Potassium	K	ppm	10,000	

Source: Constable (1988a).

2.3.1: A Comparison of the Response of Hail Damaged Cotton to Foliar Application of Zinc and Micronutrients.

Aim:

The aim of this trial was to investigate the response of hail damaged cotton to the application of a foliar micronutrient fertiliser mix and foliar application of zinc as means of alleviating the stress imposed on cotton by hail damage.

Methods:

Auscott Narrabri (Field 5) was damaged by hail on 10/12/95 at a level of 43% assessed damage when at the R3-R4 growth stage. The crop was squaring well and damage saw approximately 70% defoliation, with most plants tipped out at the 6th -7th node level removing the major proportion of fruiting limbs and squares, and stem bruising was evident.

A Randomised Complete Block Design trial with four replicates was set up on the hail damaged cotton to investigate the response of the cotton to a foliar application of zinc and a micronutrient mix. Treatments being 1. Nil applied foliar fertiliser, 2. Foliar Zinc (230 g/ha) and 3. "Triple 7" foliar fertiliser (1500 ml/ha). Plot size was 10m by 4m allowing use of a hand held pressurised spray rig for application of foliar sprays. Agronomic management of the crop area was as per the whole commercial field as outlined in Appendix 2.2.

Leaf blade samples were taken for analysis of zinc levels immediately prior to application of foliar sprays. Analyses carried out by INCITEC Ltd showed zinc levels ranging from 14 - 17 ppm (Average 15.75 ppm) which is considered low and indicates a deficiency of Zinc. The critical leaf blade zinc level at early flowering is 11 ppm with 20-60 ppm being normal levels (Constable *et al.*, 1988).

Foliar Zinc Heptahydrate was applied at a rate of 1 kg/ha (ie. 230g Zn /ha) on 16/1/96 or 430 GDDs after the hail damage when sufficient leaf area was replaced for adequate fertiliser uptake. The micronutrient mix "Triple 7" was applied at a rate of 1500 ml/ha on the same date. "Triple 7" contains on a percentage weight per volume basis, 7.0% nitrogen as urea, 7% iron as ferrous sulphate, 7.0% zinc as zinc sulphate, 0.5% copper as copper sulphate and 7.5% sulphur as sulphate. (See Label - Appendix 2.3). Both foliar fertilisers were applied using a hand held pressurised spray unit.

Leaf blade samples were taken for zinc analysis at 2, 4 and 6 weeks after application of foliar fertilisers and analysis carried out using standard international techniques by the Biological and Chemical Research Institute, Rydalmere. Leaf area samples were taken at three and six weeks after application of the foliar fertilisers and leaf area determined using a Li-Cor area meter.

Fruit numbers were monitored at 7, 10 and 14 weeks following damage by fruit counts over one m^2 areas, as weather conditions allowed. Lint yields were determined by sequential hand picking over 2 m^2 areas at maturity. Sub-samples were ginned to determine ginning percentages and fibre quality was determined by H.V.I. at the Australian Cotton Research Institute, Myall Vale, Narrabri.

Results and Discussion:

Leaf blade zinc analysis at 2, 4 and 6 weeks after the application of the foliar fertiliser showed no significant differences between treatments. Zinc levels for each treatment and sample date were in the range of 18.5 - 29.0 ppm and hence, were within the optimum range. But variability between samples does not allow accurate assumptions to be made in regard to zinc uptake. It should be noted that zinc levels improved in all three treatments suggesting that uptake was limited in the initial sampling a factor other than a deficiency of zinc.

In monitoring the regrowth of the leaf canopy following the hail damage and application of foliar fertilisers, it was found that hail damaged cotton showed an initial response to applied zinc. At the first sample date, three weeks after the application of the foliar mixes, the LAI for the Foliar Zinc treatment was significantly higher than that measured for the other treatments (Table 2.3.3). By the 6 week sampling date, the foliar zinc treatment still had a marginally larger LAI but the difference compared to the other treatments was no longer statistically significant. No difference was measured between the nil treatment and the "Triple 7" treatment.

Table 2.3.3: Changes in Leaf Area Index in Hail Damaged Cotton Following Application of Foliar Fertiliser.

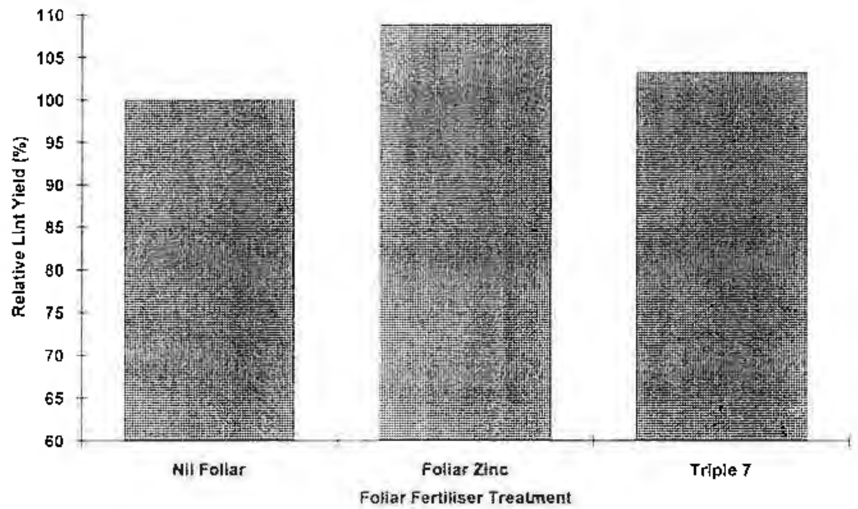
Treatment	LAI at Sample Date 1	LAI at Sample Date 2
1. Nil applied foliar fertiliser	1.70	2.17
2. Foliar Zinc (230 g/ha)	2.40 *a*	2.33
3. Triple 7 (1500 ml/ha)	1.95	2.17

a - Indicates significant difference compared to other treatments at this sample date (10 % Level).

Final plant height measured at 14 weeks after the hail damage shows a height advantage of 6-7 cm for two treatments where foliar fertiliser was applied, although replicate variability has decreased the statistical significance of this result. Hence, the data suggests that there is some advantage in applying foliar fertiliser following a hail strike, in that it may assist in overcoming the stress imposed by the damage and increase the rate of early vegetative regrowth. But variability between replicates has reduced the statistical significance of these results and hence, reduced the confidence in drawing this conclusion. Further trialing of foliar fertilisers is required to investigate possible differences in rate of regrowth.

Although the Foliar Zinc treatment produced an 8.8% relative yield advantage over the control treatment and 3.3% relative yield advantage over the use of "Triple 7", replicate variability has meant that this result is not statistically significant (Figure 2.3.1). The Foliar Zinc and "Triple 7" treatments showed an increased rate of boll opening in the early stages of opening by reaching 40% open bolls, 14.5 and 5.0 GDDs ahead of the Nil Foliar treatment. Cool temperatures affected the rate of opening from this time onwards and hence, although, still ahead in maturity by the third sequential pick, differences in time to 60% open not statistically significant. Foliar treatments did not affect lint quality.

Figure 2.3.1: Relative Lint Yield of Hail Damaged Cotton Following Foliar Fertiliser Applications.
Site: Auscott Narrabri (Field 5) 1995/96



Conclusions:

Regrowth in this trial was affected by wet weather conditions as previously described in Section 2.2.3. Together with field variability this has meant that results are not conclusive, especially in regard to any yield and maturity advantage referred to. The field showed marginal zinc levels in tissue tests carried out immediately following the hail strike and adequate levels following the application of foliar zinc. It is suggested that the applied zinc and micronutrient mix alleviated the deficiency existing in the field contributing to earlier replacement of leaf area in zinc treated areas, with further investigation needed to look at the effect of applied zinc and foliar micronutrient mixes on hail damaged cotton where zinc is not expected to be a limiting factor to growth.

2.3.2: Response of Hail Damaged Cotton to Foliar Application of Zinc

Aim:

The aim of this trial was to investigate the response of hail damaged cotton to application of a foliar application of zinc as a means of alleviating the stress imposed on cotton by hail damage.

Methods:

Auscott Narrabri (Field 5) was damaged by hail on 10/12/95 (550 GDDs from Planting) at a level of 43% assessed damage when at the R3-R4 growth stage. The crop was squaring well and damage saw approximately 70% defoliation, with most plants tipped out at the 6th -7th node level removing the major proportion of fruiting limbs and squares, and stem bruising was evident.

Foliar zinc treatments were overlaid on the nitrogen fertiliser trial described in Section 2.2.3, forming a split plot experiment. Treatments of Foliar Zinc (230g Zn/ha) and Nil Foliar Zinc were applied as treatments. Plot size was 10m by 4m allowing use of a hand held pressurised spray rig for application of foliar sprays. Agronomic management of the crop area was as per the whole commercial field as outlined in Appendix 2.2.

Foliar Zinc Heptahydrate was applied at a rate of 1 kg/ha (ie. 230g Zn /ha) on 16/1/96 or 430 GDDs after the hail damage when sufficient leaf area was replaced for adequate fertiliser uptake.

At 2, 4 and 6 weeks after the application of foliar fertilisers, leaf blade samples were taken for zinc analysis and analysis was carried out using standard international techniques by the Biological and Chemical Research Institute, Rydalmere, N.S.W. Leaf area samples were taken at three and six weeks after application of the foliar fertilisers and leaf area determined using a Li-Cor area meter.

Fruit numbers were monitored at 7, 10 and 14 weeks following damage by fruit counts over one metre square areas, as weather conditions allowed. Lint yields were determined by sequential hand picking over 2 m^2 areas at maturity. Sub-samples were ginned to determine ginning percentages and fibre quality was determined by H. V. I. techniques at the Australian Cotton Research Institute, Myall Vale, Narrabri.

Results and Discussion:

Zinc deficiency usually results from soil zinc being tied up in forms not readily available to plants, for example in some of the high phosphate high pH soils used in cotton production, especially where topsoil has been removed in ground levelling for irrigation. Zinc deficiency can also occur in cool weather and waterlogging during early growth and following a long crop fallow (Constable *et al.*, 1988). The area in which this trial was carried out was effectively coming out of a long fallow, since a fallow wheat crop failed to establish in the previous year due to drought conditions. During the cotton growing season, as previously described, wet weather conditions during January 1996 caused prolonged waterlogging during the period over which the crop was attempting to regrowth from hail damage inflicted in mid-December. These conditions prevented the uptake of applied nitrogen and we would expect the same conditions to induce a deficiency of mirconutrients such as zinc.

Leaf blade analyses for zinc sampled prior to foliar applications, showed zinc levels ranging from 14 - 17 ppm (Average 15.75 ppm) which is considered low and indicates a deficiency of Zinc. The critical leaf blade zinc level at early flowering is 11 ppm with 20-60 ppm being normal levels (Constable *et al.*, 1988). Leaf blade analyses at 2, 4 and 6 weeks after the application of the foliar fertiliser showed that zinc levels had improved in the period following the initial sampling and had reached adequate levels by two week sample date in both treatments. Zinc levels were reduced to 17.75 and 19 ppm at the 4 week sampling date which would be considered low with the reduction in measured zinc possibly due to waterlogging in the period immediately prior to the sampling, as levels increased again by the 6 week sampling date. At all samples dates, the foliar zinc treatments displayed marginally higher leaf blade analysis zinc levels although not statistically significant (Table 2.3.4).

Table 2.3.4: Changes in Leaf Blade Zinc Levels in Hail Damaged Cotton Following Application of Foliar Zinc

	Leaf Blade Zinc	
	Nil Zinc	Foliar Zinc
Initial Sampling Following Hail Damage	14 - 17 ppm	14 - 17 ppm
At 2 Weeks Following Foliar Application	26.00 ppm	27.50 ppm
At 4 Weeks Following Foliar Application	17.75 ppm	19.00 ppm
At 6 Weeks Following Foliar Application	24.00 ppm	25.25 ppm

Initial leaf area development was greater in the foliar zinc treated areas, although replicate variability ensured the difference in leaf area was not statistically significant. But leaf area development was only delayed in the nil zinc areas compared to the foliar zinc treatment, as the nil zinc areas had a significantly higher final L. A. I. at the final sampling date (5% Level of Significance) (Table 2.3.5).

Table 2.3.5: Leaf Area Development in Hail Damaged Cotton Following Application of Foliar Zinc.

Treatment	L. A. I. at 3 Weeks Following Foliar Application (1242 GDDs from Planting)	L. A. I. at 6 weeks Following Foliar Application (1489 GDDs from Planting)
Nil Zinc	1.77	2.65 *a*
Foliar Zinc	2.27	2.22 *b*

NB: Damage Date 10/12/95 or 550 GDDs from Planting.
Foliar Zinc Applied 16/1/96 or 980 GDDs from Planting.
L. A. I. followed by *a* and *b* are significantly different (5% Level).

Vegetative development in terms of plant height saw the final plant height of the foliar zinc treatments average 80 cm compared to 68 cm in areas not treated with foliar zinc which is statistically significant at the 1% level (Figure 2.3.2). Plant height differences at earlier sampling dates were small.

Fruit development saw significantly greater production of squares in the foliar zinc treated areas (1% Level of Significance) (Figure 2.9). But although early boll numbers were higher in the foliar zinc treated areas, final boll numbers were similar between the two treatments (Figure 2.3.4).

No significant difference is found in final lint yields between the two treatments, nor in lint qualtiy characteristics. There was a tendency for boll size to be increased in earlier sequential picks for the foliar zinc treatment (10% Level of Significance) and for average boll size to be overall larger for the foliar zinc treatment (5% Level of Significance).

Figure 2.3.2: Plant Height Development in Hail Damaged Cotton Following Application of Foliar Zinc
Site: Auscott Narrabri (Field 5) Nitrogen / Zinc Trial

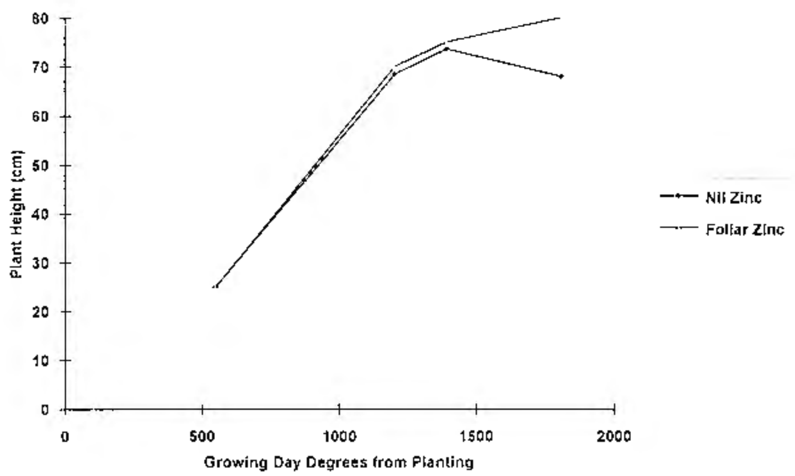


Figure 2.3.3: Square Development in Hail Damaged Cotton Following Application of Foliar Zinc
Site: Auscott Narrabri (Field 5) Nitrogen / Zinc Trial

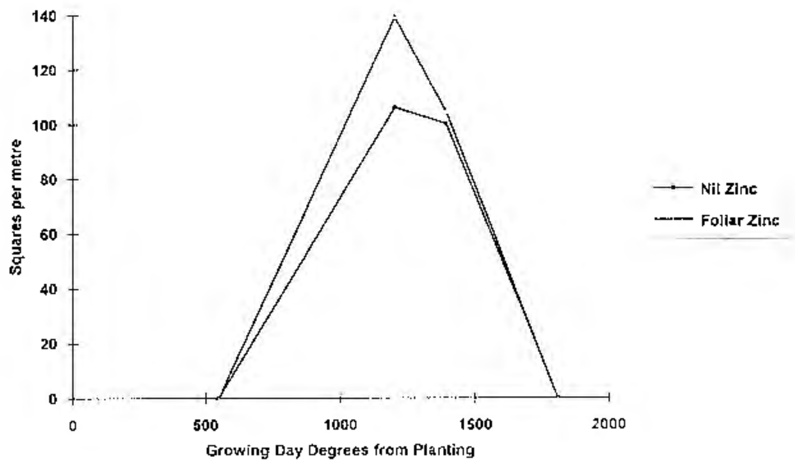
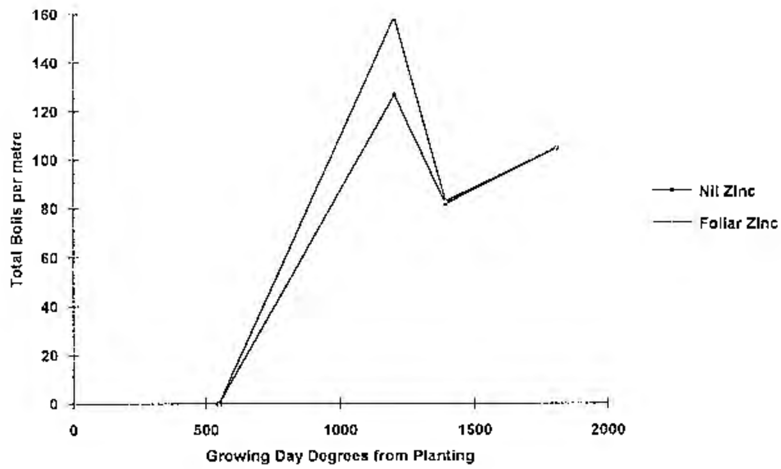


Figure 2.3.4: Boll Development in Hail Damaged Cotton Following Application of Foliar Zinc
Site: Auscott Narrabri (Field 5) Nitrogen / Zinc Trial



Conclusions:

This trial data suggests that the foliar zinc assisted in increasing early canopy regrowth and intitiation of the squaring and fruiting phases following the hail damage, with the areas not treated with zinc being delayed in development in comparison. But this does not suggest that the application of zinc to any hail damaged crop will assist in the early recovery of the crop. Leaf blade analysis had suggested that the site had low to marginal zinc levels in the first place or at least zinc deficiency induced by climatic conditions and hence, the application of zinc would have acted to remedy a deficiency situation. Further work on the use of foliar zinc on hail damaged cotton is required on sites not subject to zinc deficiency.

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2.4: Use of Growth Regulators in Management of Regrowth of Hail Damaged Cotton

2.4.1: Introduction

Excessive vegetative growth in cotton can increase fruit shed and hence, decrease lint yield, delay maturity and contribute to increased boll rot (Cathey and Meredith, 1988). Traditionally, the restriction of water supply to the crop in the early season was used to suppress vegetative growth and encourage the plant to move into the reproductive phase and retain early fruit. It is now believed that this practise can actually be detrimental to crop growth and can decrease lint yields. Pix® (Mepiquat Chloride) is now widely used as a growth regulator in cotton crops, being used to suppress vegetative growth in the same way as restricting early water supply was used, except without imposing stress (Holden, 1994).

Mepiquat Chloride, by inhibiting the enzyme involved in the synthesis of gibberellic acid (GA), alters GA metabolism in the cotton plant. GA is involved in the process of cell expansion and hence, a reduction in its concentration would reduce leaf area, internode length and plant height (Holden, 1994). Hence, Mepiquat Chloride or Pix® suppresses vegetative growth in cotton by reducing main stem and fruiting branch internode length and leaf area, producing a shorter and more compact plant (Cathey and Meredith, 1988; Cothren, 1979; McCarty *et al.* 1990; McKinnon *et al.* 1990; York, 1983a and 1983b).

In reducing main stem internode length, plant height is found to be reduced by application of Pix® (Cathey and Meredith, 1988; York, 1983a and 1983b). The level of response is proportional to the rate of Pix® applied (Holden, 1994). Kerby (1985) found that application of Pix® had a minimal effect on plant height when applied to short crops but the effect of Pix in terms of decreasing plant height was greater on taller plants and under higher nitrogen regimes.

Boll retention at primary and secondary fruiting positions is increased in Mepiquat Chloride treated plants, with the largest increases being on the lower fruiting branches (York, 1983b; McCarty *et al.*, 1990; Metzer and Wilde, 1990; Livingston and Wilde, 1990). Holden (1994) shows that while boll retention is increased on lower fruiting branches, it is unaffected in the middle fruiting branches and decreased on upper fruiting branches. With improved light penetration in the lower canopy with the reduced leaf area, Holden (1994) suggests that carbohydrate supply to lower bolls is enhanced and retention increased. The increased rate of retention of bolls in primary and secondary fruiting positions and on lower fruiting branches is expressed as earlier crop maturity.

Late planted cotton which germinates and establishes under warm growing conditions and suffers little or no cold stress during early growth will naturally grow rank. As will cotton which has suffered early insect attack and hence, has had most of its early set fruit removed is similarly delayed in development. Cathey and Meredith (1988) showed that although Pix® reduced yields in early planted cotton and had no effect on maturity, as planting becomes more delayed, pix increases yield and induces earliness. Similarly, York (1983b) found that under conditions of high nitrogen or high plant populations, plant height and number of mainstem nodes was generally increased with low retention of bolls on lower fruiting branches, but where Pix® was applied, a decrease in plant height was achieved, retention of first position and lower bolls was increased and crop maturity advanced. From this we can conclude that potentially Pix® has its greatest beneficial effects on late planted cotton or cotton delayed in maturity by high levels of nitrogen, high plant populations or suffered early insect damage or hail damage.

With sufficient heat units, ie. if the growing season is long enough, late set bolls in delayed cotton will mature and hence, any response to Pix measured at earlier dates will be reduced. This is confirmed by Kerby (1985) showing an earliness advantage to the application of Pix® is only expressed as an increase in yield in short seasons, where heat units were minimal.

In standard row spacing (100 cm or 40" rows) irrigated cotton, one application of Pix at first flower has been shown to be the optimum rate of application (Constable, 1990; Weir and Kerby, 1990). United States work has shown advantages in applying Pix in a split dose and in low multiple rates especially in narrow row cultivation (30" rows) but only where vegetative growth is excessive.(Kerby, 1990). Similar results have not been replicated in Australia (Constable, 1990).

Yield depletions are recorded where Pix is applied to cotton already stunted vegetatively due to eg. moisture stress or cool weather. The use of low multiple rates of Pix has been forwarded as a means of promoting early fruit set and retention without causing premature cutout and to assist growers in not overcorrecting plant size when drought conditions occur following the first application of Pix (Livingston and Wilde, 1990). Applications can be adjusted according to the environmental conditions.

As Pix® acts on cells currently undergoing growth and expansion, it will have its effect on the size of leaves and length of internodes of nodes yet to appear on a plant. Hence, the timing of Pix application needs to be made by predicting when the crop will enter a phase of excessive vegetative growth and not once a crop has already become excessively vegetative, if application is to control growth.

Prior to flowering, node development in cotton is primarily dependent on temperature with a new node being developed on average every 40 day degrees (2-4 days). Once flowering is initiated, the rate of production of node is modified by the production of fruiting branches but node number remains an indicator of plant age and is insensitive to such factors as drought, disease and nutrient status.

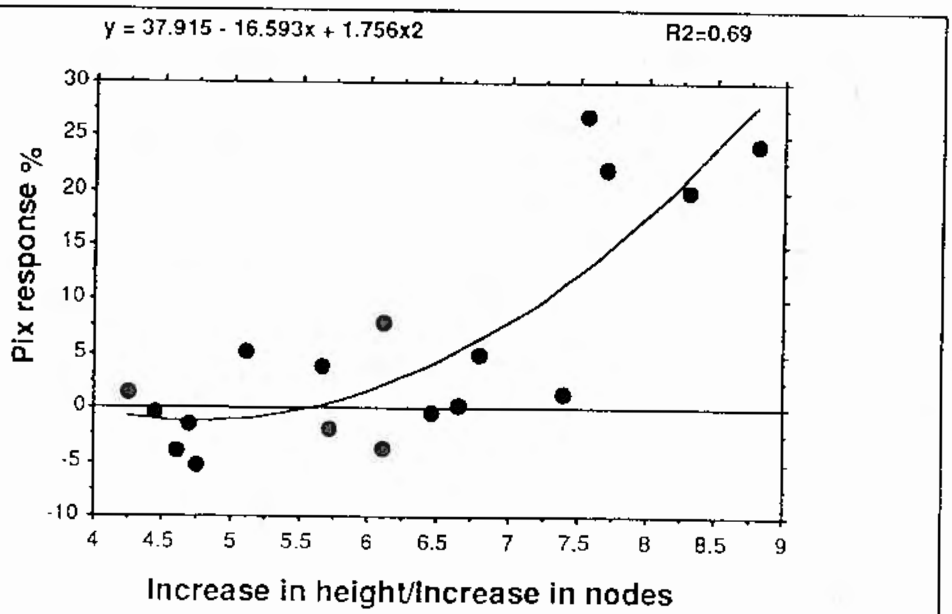
Internode length, on the other hand, is very sensitive to environmental conditions and hence, is a good growth indicator for the cotton plant. A long internode length indicates favourable growth conditions and the potential for rank growth, a short internode length results from stress encountered during the development of the associated node. Hence, the changes in length of plant internodes provides a picture of the changing growth rate of the plant. Height to Node Ratio (HNR) is the most widely accepted method for estimating plant vigour and various methods for monitoring plant vigour via internode elongation have been developed and are region and to some degree variety specific (Silvertooth *et al.*, 1996).

Regular monitoring of plant height and node development allows an evaluation of the degree of vigour in a crop's growth and a means of predicting when to apply pix. The response to Pix applications is found to increase as the growth rate of a crop increases (Figure 2.4.1) (Constable, 1992). Growth rate in this situation is measured as the rate of internode increase ie. the ratio of plant height increase to increase in node number over a given period.

ie. $$\text{Rate of Internode Increase} = \frac{\text{Change in Plant Height}}{\text{Change in Node Number}}$$

From extensive trialing in Australia (Constable, 1990, 1992, 1994), it is concluded that crops growing at a rate of internode increase less than 6.5 cm/node needs to be encouraged to grow. Rate of increase of between 6.5 - 7.5 cm/node indicate optimum growth whilst rate of increase of internodes in excess of 7.5 cm/node indicate excessive vegetative growth and that water and nutrient programs should be modified to reduce growth rates and a response to Pix application would be expected (Table 2.4.1).

Figure 2.4.1: The Relationship Between Rate of Plant Internode Increase at Early Flowering and the Subsequent Yield response of that Crop to Pix.
Source: Constable (1992).



The relationship between rate of plant internode increase at early flowering and the subsequent yield response of that crop to Pix. Pooled data for three seasons and four varieties.

Table 2.4.1: Using Measurements of Plant Height Internode Increase at Early Flowering to Make Decisions on Pix Applications.
Source: Constable (1992)

Rate of Plant Internode Increase at Early Flowering Stage	Pix Action	Other Action/Comments
Less than 5.5 cm/node	Nil	Encourage growth by judicious water and fertiliser management
5.5 to 6.5 cm/node	200 ml/ha	Do not expect much Pix response
6.5 to 7.5 cm/node	600 ml/ha	Continue good management
Greater than 7.5 cm/node	750 - 1200 ml/ha	Care should be taken with water and fertiliser management

2.4.2: Response of Hail Damaged Cotton to Applications of Pix®

Aims:

In theory, growth regulators such as Pix® should be key tools in the management of hail damaged cotton, as hail damaged crops are late developing crops and usually growing under warmer conditions conducive to excessive vegetative growth. There is also a requirement to mature the crop within a reduced growing season. Control of the rate of vegetative growth by the use of growth regulators should be important in maximising the setting, retention and maturation of fruit. To this end, these trials aimed to evaluate the use of Pix® (Mepiquat Chloride) in controlling vegetative regrowth in hail damaged cotton.

Methods:

A series of nine field trials were set up on hail damaged cotton crops in various cotton production areas during the 1994/95 and 1995/96 cotton seasons. The response of hail damaged cotton to the application of the growth regulator Pix® (Mepiquat Chloride) was measured, with applications made at various dates and rates as the crops regrew following hail damage. Pix® (Mepiquat Chloride) is a product of Hoechst Schering AgrEvo Pty Ltd., commonly used as a management tool for the control of excess vegetative growth in cotton. Commercially recommendations for use of Pix are described by the label provided in Appendix 2.3.

Commercial cotton fields damaged by hail were selected for trial sites in each cotton production area. Trials were limited to irrigated sites and where damage was relatively uniform over the area required for the trial (Table 2.4.2).

A hand held pressurised spray unit was built for the application of growth regulators. This reduced the land requirement for trials and overcame the need for commercial ground-rigs, cotton pickers, picker scales etc. and allowing flexibility in trial management.

Trials were designed as Randomised Complete Block Designs with 4 replications, with plots 4 rows (4m wide) by 10m in length. For the 1994/95 season, fruit counts and plant height determinations were carried out over 1 m^2 sample areas. Lint yield and maturity of treatments were determined by sequential hand picking of 1 m^2 sample areas. Lint quality determinations were made using H. V. I. techniques at the Australian Cotton Research Institute, Narrabri. For the 1995/96 season, trials were increased to six replications and sample areas were increased to 2 m^2 to reduce variability within the trial areas.

Table 2.4.2: Response of Hail Damaged Cotton to Applications of Pix® - Trial Sites 1994/95 and 1995/96

Site	Production Area	Trial Site	Date of Loss	Growth Stage at Date of Loss	Assessed Loss
A	Namoi Valley	"Wild Willows" Wee Waa	2/1/95	R2	77%
B	Upper Namoi	"Carnavon" Mullaley	18/12/94	R2	Est. Damage 80%
C	Darling Downs	"Arundel" Dalby	18/12/94	R2	36%
D	Namoi Valley	Auscott Narrabri	10/12/95	R3.5	43%
E	Namoi Valley	"Abbey Green" Narrabri	2/1/95	R6	74%
F	Emerald	Lot 159 Wills Rd. Emerald	19/12/94	R8	36%
G	Lower Namoi	"Coolabah" Merah North	4/1/96	R8	60%
H	Lower Namoi	"Willawood" Merah North	4/1/96	R8	72%
I	Macquarie Valley	"Kimberley" Warren	2/1/95	R9	50%

Treatments imposed were as follows:

1. Nil Pix
2. Pix 300 ml/ha at First Flower on Regrowth
3. Pix 600 ml/ha at First Flower on Regrowth
4. Pix 600 ml/ha at Last Square Date
5. Pix 1000 ml/ha at Last Square Date
6. Pix 300 ml/ha at First Flower on Regrowth and 600 ml/ha at Last Square Date.
7. Pix 600 ml/ha at First Flower on Regrowth and 1000 ml/ha at Last Square Date.

All growth regulator applications were made 7-10 days prior to the date nominated so that the compound was active in the plant by that date. Chemical was applied over the entire plot area providing treated buffer areas for the sample areas.

Insect, water and agronomic management other than application of growth regulators was carried out by the co-operating grower and as required by the field or management unit as a whole. Agronomic data for each site is summarised in Appendix 2.2.

Results and Discussion:

There is difficulty in using the standard techniques for monitoring growth rates in cotton to predict Pix application requirements in hail damaged cotton. Hail damage often removes a large portion of the plant structure and in most cases removes part of the main stem or stem bruising sees the initiation of secondary branching which modifies the overall growth rate of the main stem of plants. This means that the standard scales monitoring plant vigour using the height to node ratio (Constable, 1992) for Pix application determinations are not directly applicable to hail damaged cotton.

Other than predicting Pix requirements by use of plant vigour indices, trials have shown that the optimum timing of pix under Australian growing conditions is at First Flower (Constable, 1990) and hence, for the purposes of these trials on hail damaged cotton, First Flower on regrowth was selected as the first application date for Pix. In managing the growth of cotton following hail damage, we are attempting to prevent vegetative growth from becoming excessive so as to maximise early fruit set on the regrowth. To achieve this, the aim of early Pix applications was to "peg back" vegetative growth. Hence, the effect of applications of Pix at 300 ml/ha and 600 ml/ha at first flower on regrowth were compared.

Hail damaged cotton is delayed in development ie. late cotton. The second aim in managing the regrowth of hail damaged cotton, is to mature whatever fruit are set before the climatic end of the season. On average, no flower produced past the defined Last Flower Date for an area will mature as an open boll. If fruit set is to be maximised from the date of the hail strike through to Last Flower Date then squaring must be maximised from the date of the hail strike through to Last Square Date. Last square date occurring 21 days prior to last the average Last Flower Date, as the average period required for development of a square to a flower is approximately 21 days. In these trials, Pix applications were applied to act by the Last Square Date to attempt to reduce late vegetative growth and maximise fruit set up to that date, whilst allowing sufficient time for all fruit set to mature before first frost. Hence, applications of Pix of 600 ml/ha and 1000 ml/ha were included in these trials. In the commercial situation, split applications of Pix are commonly used as a means of moderately modifying early vegetative growth and then preventing or reducing late vegetative growth and hence, the effectiveness of single applications is compared to split applications as described.

The date of the hail damage, growth stage at the time of damage and weather conditions following the hail strikes have been an overriding factors in determining the degree of recovery achieved and the response to applications of Pix in these trials . Due to the relatively mature growth stage at the time of damage, trials at sites E through to I showed reduced recovery (Table 2.4.2). Recovery was further reduced at sites E, G and H by waterlogging and cool conditions following the hail damage.

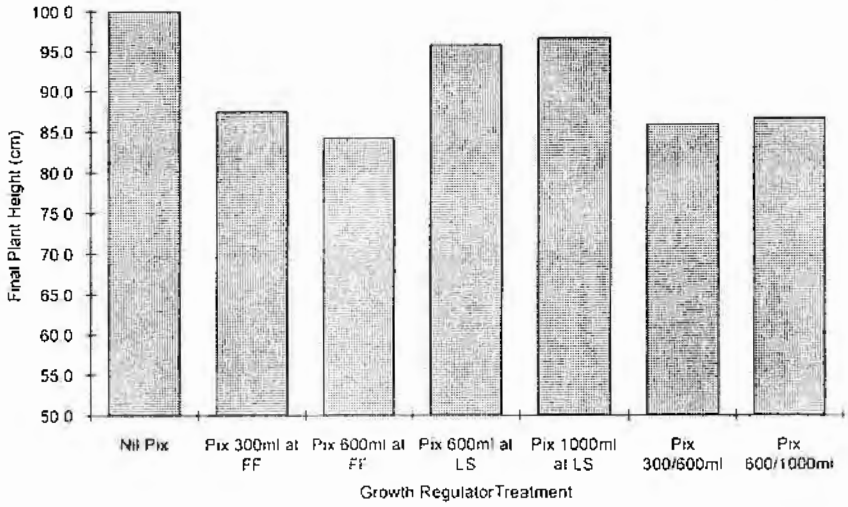
a. Vegetative Plant Response

The vegetative plant response to pix treatments in hail damaged cotton was measured by monitoring plant height in the growth regulator trials. The overall response of plant height pooled over all trials is presented in Figure 2.4.2.

It is found that application of Pix at First Flower on regrowth acted to decrease plant height compared to untreated controls and compared to late applications of Pix (5% Level of significance). This included treatments where Pix was applied as a single treatment of 300 ml/ha or 600 ml/ha, or in similar quantities as part of a split application . The decrease in plant height was proportional to the rate used in First Flower applications.

Leaving the Pix application until Last Square Date assisted in slowing late vegetative and a decreased final plant height was measured compared to untreated cotton (5% Level of Significance). Increasing the rate of Pix at Last Square Date from 600 ml/ha to 1000 ml/ha did not produce a consistent decrease in plant height, in fact the increased rate failed to decrease plant height at a number of sites.

Figure 2.4.2: Plant Height Response in Hail Damaged Cotton to Application of Pix. - Pooled results of eight trials (1994/95 and 1995/96).



The timing of the Pix application produced a similar pattern of height decrease across all trials. Minor variations from the average response to Pix occur between individual sites and reflect either the effect of weather conditions following damage on the Pix response or the growth stage of the crop at the time of damage (Figures 2.4.3a and 2.4.3b).

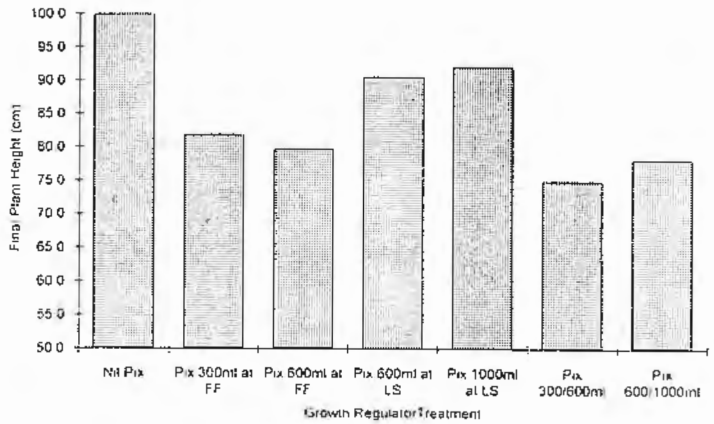
At Site B: "Carnavon" Mullaley, a severe infection by charcoal rot (*Macrophomina phaseolina*) as the crop attempted to regrow following the hail strike reduced plant vigour and caused significant plant death. Hence, recovery was slow and was reduced overall and in this situation minimal response to the Pix application was measured.

Pix applications decreased plant height to a lesser degree at Site I: "Kimberley" Warren, where vegetative regrowth following damage was less extensive. At this site the crop was quite mature at the time of damage, being at the R9 growth stage, and although damaged at an average of 50% loss, much of the main stem was still intact. Hence, vegetative regrowth was initiated at growing points along the main stem producing more lateral growth and a reduced increase in plant height.

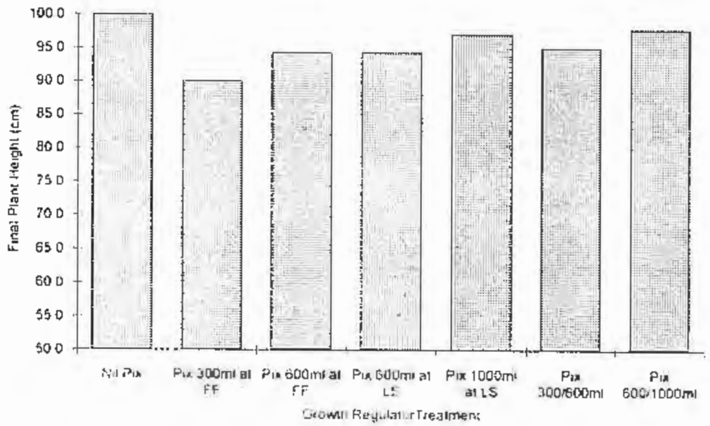
Crops at Sites C and D experienced the most ideal growing conditions following the hail strikes and under these conditions the response to applied Pix was not only related to the timing of the application but responses proportional to the rate of Pix used at each application were also observed. ie. Plant height was decreased by application of Pix at First Flower but the decrease was greater at the higher rate of 600 ml/ha of Pix, likewise higher application rates at Last Square and in Split Rates also saw a greater reduction in plant height. Holden (1994) reports a Pix response proportional to the rate of Pix used in cotton growing under normal growing conditions ie. not damaged by hail.

Figure 2.4.3a: Plant Height Response in Hail Damaged Cotton to Pix Applications

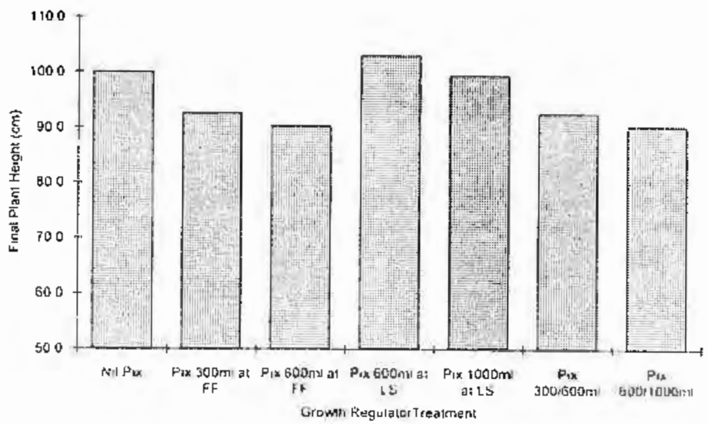
Site A: "Wild Willows" Wee Waa (1994/95)



Site B: "Carnavon" Mullaley (1994/95)



Site C: "Arundel" Dalby (1994/95)



Site D: "Auscott Narrabri Field 22" Narrabri (1995/96)

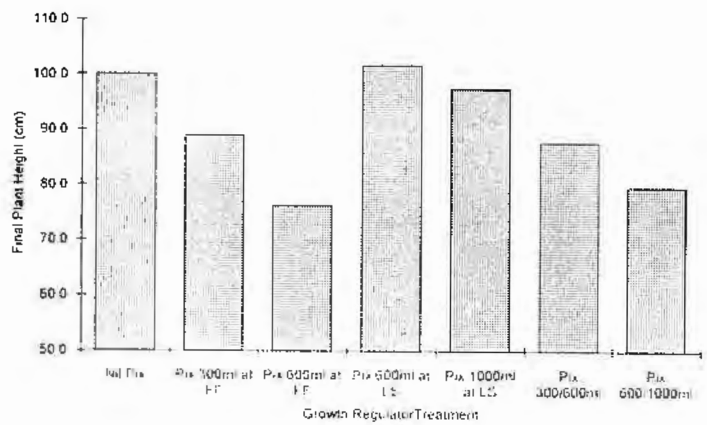
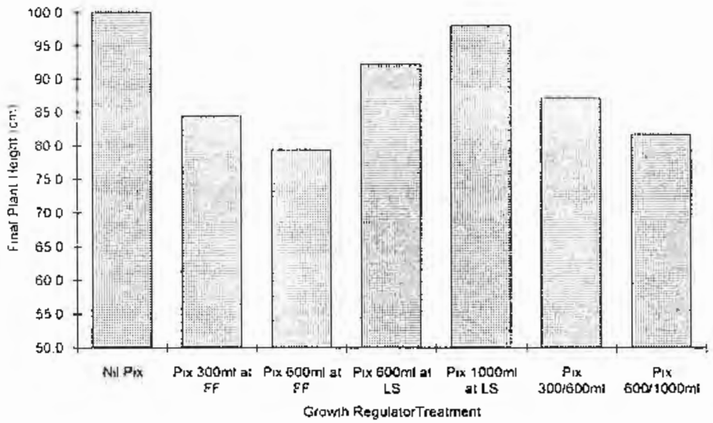
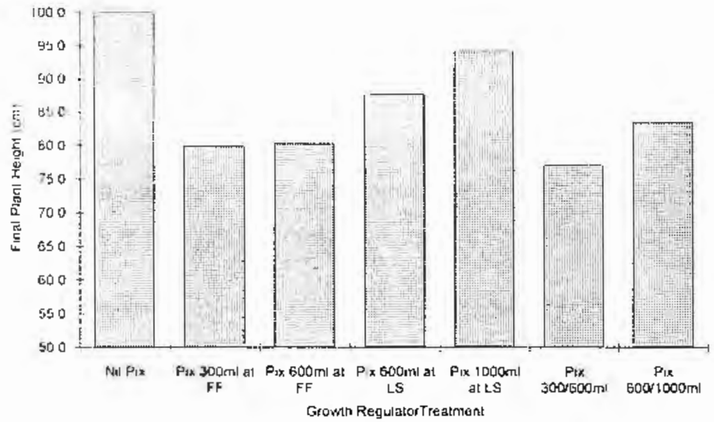


Figure 2.4.3b: Plant Height Response in Hail Damaged Cotton to Pix Applications

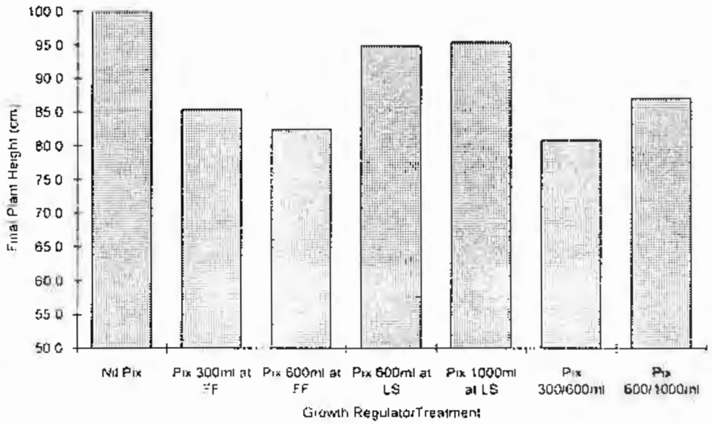
Site E: "Abbey Green" Narrabri (1994/95)



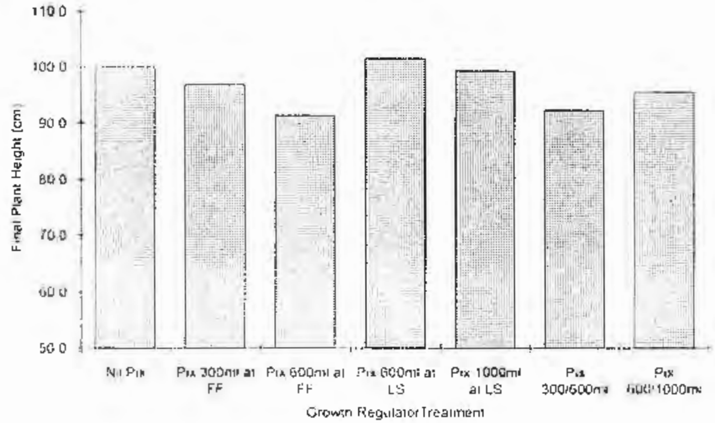
Site G: "Coolabah" Merah North (1995/96)



Site H: "Willawood" Merah North (1995/96)



Site I: "Kimberley" Warren (1994/95)



b. Lint Yield Responses

In work carried out in Australia and the United States, yield responses to Pix under normal growing conditions have been variable . Kerby (1985) and York (1983a,b) conclude that the variation in yield response is related to heat unit accumulation and a yield increase following the application of Pix can be observed where heat units are minimal. Crops regrowing following a hail strike are regrowing under conditions of reduced available heat units and a yield response to applied Pix would be expected.

The nature of hail damage itself has posed some problems in this work, in that the symptoms of hail damage and the severity can vary within small areas of crop. This made selection of sample areas for monitoring of fruit development, lint yield etc for these trials quite difficult. Although, immediately following the hail strikes, areas of uniform symptom type and severity were marked for use in crop regrowth monitoring, statistical analysis of the data collated from the trials still showed significant variation between replicates. Hence, although some large differences were observed between lint yields and maturity at some sites, the results were not statistically significant. Hence, conclusions drawn from these results can only be regarded as trends.

The vegetative response to applied Pix in these trials was much stronger than the lint yield and maturity responses. The overall effect on plant height was common to most trials. But in the case of fruit development, climatic factors have affected fruit set and maturity of fruit that are set and hence, responses differed between sites and production areas. Pooling of results over all trials ignores the fact that seasonal conditions in the different production areas will affect yield recovery potential. Hence, it is more accurate to look at individual trial sites and the yield results for trials in that year (Figures 2.4.4a and b).

Sites A, C and D were struck by hail at moderately early stages of development and there was sufficient time available to regrow the crop to some degree. At Site A ("Wild Willows" Wee Waa), the highest relative lint yields were found in treatments were Pix application was left until Last Square Date. Early growth following the hail strike would have been self regulated by the crop as temperatures were moderate and rain activity had continued. The higher dose of 600 ml/ha at First Flower acted to reduce yield and hence, the recommended strategy would have been to apply no Pix early or a smaller dose such as 300 ml/ha at First Flower. No advantage was gained by applying Pix in split rates.

Similarly at Site C ("Arundel" Dalby), initial regrowth following the hail storm was self regulating as temperatures were moderate, early Pix at 300 ml/ha produced an equivalent yield as the nil Pix treatment. Highest yields were achieved by applying Pix at Last Square Date at a moderate rate of 600 ml/ha or in a split application of 300 ml at First Flower and 600 ml/ha at Last Square. The higher doses of Pix applied at First Flower and at Last Square acted to reduce lint yields.

Temperatures and general climatic conditions following the hail strike at Site D ("Auscott Narrabri" Field 22) were optimum for growth and regrowth following the hail strike was more vigorous than at either Site A or C. Pix applied at 300 ml/ha as the single dose or as part of a split application of 300/600 ml per ha acted to peg back vegetative growth and increase boll set producing a yield advantage for these treatments. Both treatments having a yield advantage over Last Square Date application dates.

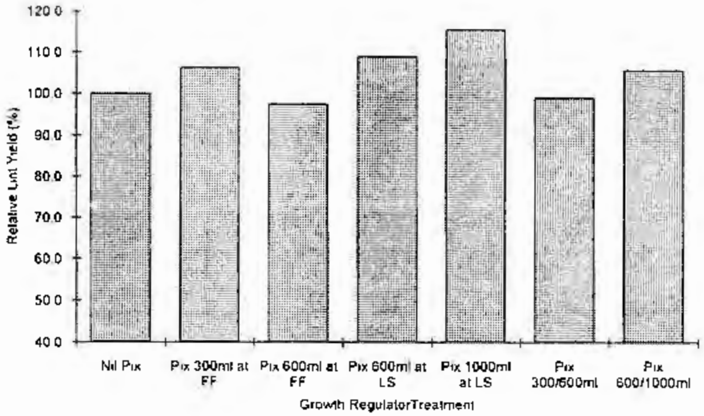
Site E ("Abbey Green" Narrabri) was at a slightly later growth stage at the time of damage than the previously mentioned sites. Again, the Last Square applications of Pix produced a yield increase, but no difference is observed between other treatments.

Responses to Pix applied to cotton damaged by hail at later dates are less defined and in a number of cases Pix application is detrimental to lint yield. At Site G ("Coolabah" Merah North), little regrowth occurred due to late stage of growth at the time of damage and no differences in response to Pix applications can be determined. At Site H ("Willawood" Merah North), lint yield was not increased by application of Pix and is actually decreased by high application rates at first flower and the high split application rate treatment. At Site I ("Kimberly" Warren) lint yields are reduced by applied Pix except where applied at 600 ml/ha at First Flower where lint yields equal the Nil Pix treatment. Hence, we can assume that vegetative growth was already being regulated / reduced by the plant itself.

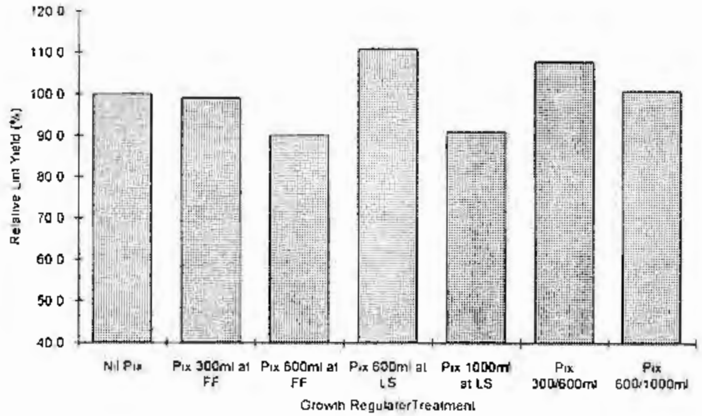
The Emerald crop was force finished early due to lack of water for the final irrigations the crop required. The 600/1000 ml per ha split rate application of Pix, had the double action of reducing early vegetative growth and stopping late vegetative growth, produced the highest lint yield. The lower split rate application (300/600 ml per ha) and the heavy single Last Square Date application of 1000 ml/ha of Pix also produced increased yield over other treatments. Any treatment which had not reduced early vegetative growth and stopped late vegetative growth produced decreased lint yields compared to the Nil Pix treatment. These treatments had allowed the crop to set fruit at its own rate and so had fewer fruit set when water supplies ran short.

Figure 2.4.4a: Lint Yield Response in Hail Damaged Cotton to Pix Applications

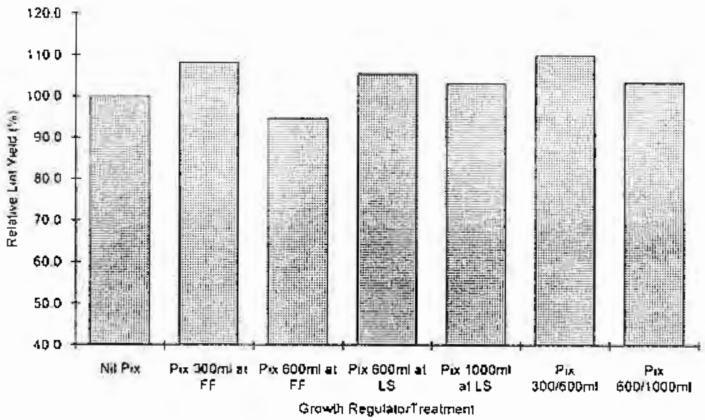
Site A: "Wild Willows" Wee Waa (1994/95)



Site C: "Arundel" Dalby (1994/95)



Site D: "Auscott Narrabri Field 22" Narrabri (1995/96)



Site E: "Abbey Green" Narrabri (1994/95)

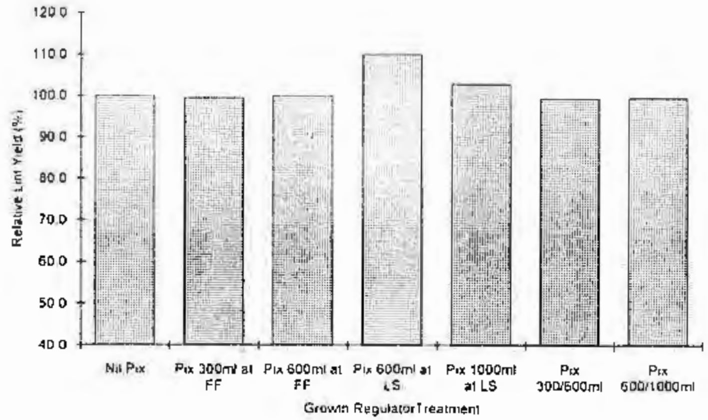
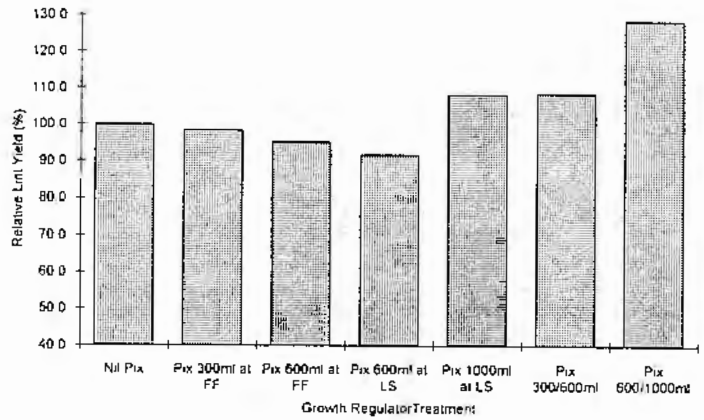
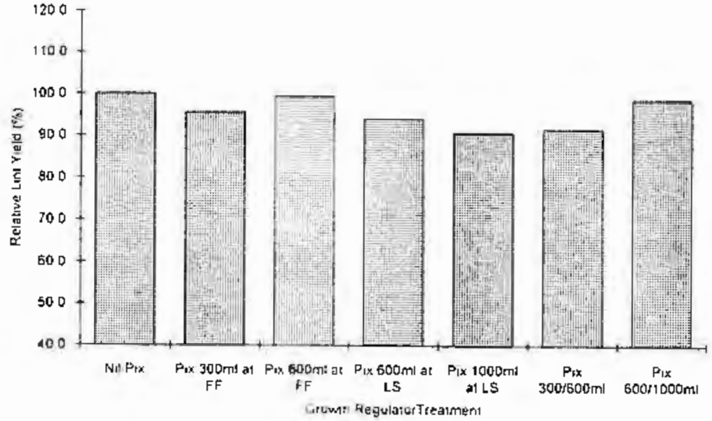


Figure 2.4.4b: Lint Yield Response in Hail Damaged Cotton to Pix Applications

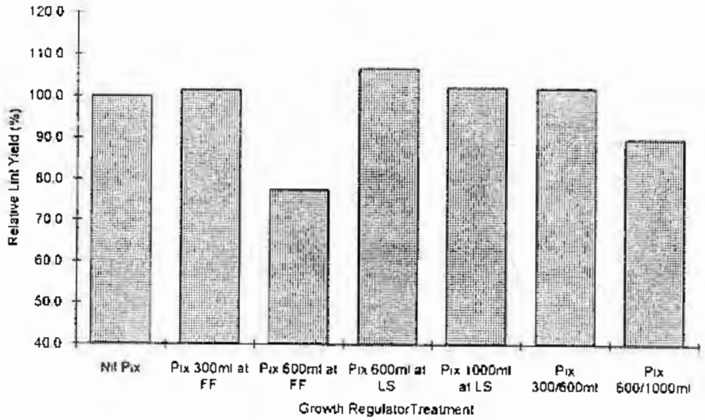
Site F: Emerald



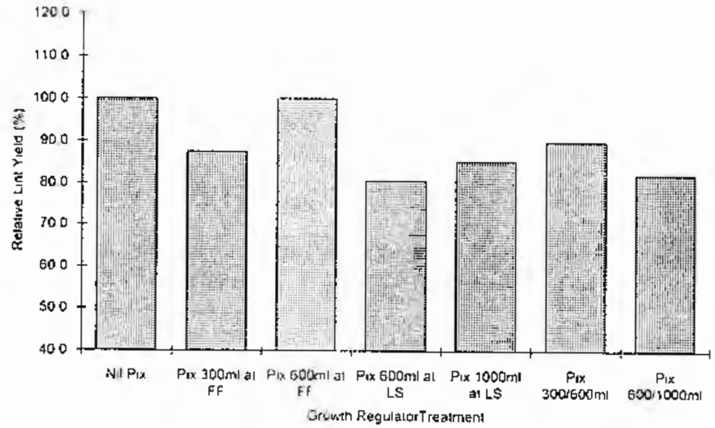
Site G: "Coolabah" Merah North (1995/96)



Site H: "Willawood" Merah North (1995/96)



Site I: "Kimberley" Warren (1994/95)



c. Effect of Pix Applications on Crop Maturity

With the aim of attempting to mature whatever fruit are set post damage within the season remaining following the hail strike, crop earliness is the factor of importance. Kerby (1985) found that an earliness advantage is only expressed as a yield increase where heat units are minimal. Hail damage immediately imposes a restriction on heat units available for growth and hence we would expect that application of pix would induce both a yield increase and an earliness advantage in most hail damage situations. Although where conditions are conducive to good growth following the hail strike and the season is not unusually short, any earliness advantage in applying Pix may be reduced as even the most delayed crop is able to mature its late set bolls.

As with lint yield responses to Pix, variability in the symptoms of hail damage within small areas of a crop has produced significant variation between the replicates of trials in statistical analysis of the data collated. Hence, although large differences were observed between maturity at some sites, the results were not statistically significant. Hence, conclusions drawn from these results can only be regarded as trends.

Table 2.4.3a presents a comparison of the differences in maturity between Pix application treatments at trial sites on the 1994/95 and 1995/96 seasons. This data is translated to maturity relative to the Nil Pix treatment in Table 2.4.3b. It should also be noted that the wet finish to both seasons prevented adequate sequential picks from being carried out at Sites B and H and so, treatment maturities could not be determined for these sites.

Small differences in maturity (eg. 0-20 GDDs) are not of commercial significance, as depending on the production area, the difference is only a matter of 0-3 days. But once maturity differences of 20-50 GDDs are measured, we are talking about differences in maturity of up to 10 days depending on production area which can be commercially important.

The differences in maturity measured at sites C, F, and F may become important from a commercial picking point of view (Table 2.4.3b). At Site C ("Arundel" Dalby), the most delayed treatments were where Pix was applied at Last Square Date, maturity was delayed compared to the Nil Pix treatment by 52.0 and 21.0 GDDs, following applications of 600 and 1000 ml/ha of Pix respectively. Note that 600 ml/ha Pix at Last Square was the highest yielding treatment. So, although gaining a larger yield advantage, the more economic application may have been the split application (300 / 600 ml/ha) as it delivered an earliness advantage as well as a yield response.

At Site E ("Abbey Green" Narrabri), where pix was applied early (First Flower) either as a single application or as part of a split application, maturity was advanced compared to other pix applications. Whereas the application at first flower induced earliness, maturity was further advanced by application of a second dose of Pix at Last Square. The trial was not able to go through to full maturity due to the need to carry out the commercial pick of the field. Late set bolls in treatments where vegetative growth was not pegged back by early Pix did not mature for picking and so any earliness advantage of applying Pix at First Flower was increased. Last Square applications of Pix had produced the greater yield advantage, but at the cost of earliness.

It is interesting to note that at Site F (Emerald) where insufficient water was available to give the crop the final irrigations it required, where Pix was applied at First Flower and vegetative growth had been pegged back at that stage, maturity of the treated areas was advanced. Where a second application of Pix was applied at Last Square Date to stop late vegetative growth, maturity was even further advanced. This suggests that in very short seasons or where the crop will be cut out early by restrictions on water etc., then Pix can play an important part in maximising earliness.

At both Sites A and I, the crops were left to mature fully and season conditions allowed maturation of late set bolls in all treatments and hence, any advantage in earliness from applying Pix was reduced and no differences are observed between maturity of treatments. Site D (Auscott Narrabri Field 22) displayed vigorous regrowth compared to Sites A and I, and was also allowed to mature completely and we find that any earliness advantage from applying Pix treatments is reduced.

Table 2.4.3a:

PIX TREATMENT MATURITY in Growing Day Degrees from Planting to 60% Open Bolls

	SITE						
	Wild Willows	Arundel	Auscott 22	Abbey Green	Emerald	Coolabah	Kimberley
	A	C	D	E	F	G	I
TREATMENT							
Nil Pix	2100	2033	1857	2528	2110	1922	1875
Pix 300 ml at FF	2092	2048	1857	2505	2092	1932	1875
Pix 600 ml at FF	2102	2038	1858	2510	2080	1945	1872
Pix 600 ml at LS	2095	2085	1857	2525	2115	1928	1872
Pix 1000 ml at LS	2097	2054	1860	2517	2112	1942	1885
Pix 300/600 ml	2100	2025	1855	2482	2077	1935	1875
Pix 600/1000 ml	2097	2048	1857	2498	2070	1929	1878

Table 2.4.3b:

RELATIVE MATURITY (Relative to Nil Pix Treatment) in Growing Day Degrees

	SITE						
	Wild Willows	Arundel	Auscott 22	Abbey Green	Emerald	Coolabah	Kimberley
	A	C	D	E	F	G	I
TREATMENT							
Nil Pix	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pix 300 ml at FF	-8.0	15.0	0.0	-23.0	-18.0	10.0	0.0
Pix 600 ml at FF	2.0	5.0	1.0	-18.0	-30.0	23.0	-3.0
Pix 600 ml at LS	-5.0	52.0	-0.5	-3.0	5.0	6.0	-3.0
Pix 1000 ml at LS	-3.0	21.0	3.0	-11.0	2.0	20.0	10.0
Pix 300/600 ml	0	-8	-2	-46	-33	13	0
Pix 600/1000 ml	-3	15	-1	-30	-40	7	3

d. Lint Quality

Lint quality tests for the 1994/95 season show no significant differences between lint quality characteristics between treatments and hence, no growth regulator treatment acted to improve lint quality. In comparing the effect of treatments on lint quality and differences between sites we need to keep in mind that different varieties were used at different trial sites.

From Tables 2.4.4a - 2.4.4e, it is found that fibre length for all sites and treatments lies in the medium to long range. Fibre strength is high at all sites except "Arundel" Dalby and "Abbey Green" Narrabri. The coloured cotton variety planted at "Arundel" Dalby and Sicala V1 planted at "Abbey Green" Narrabri, would be expected to have slightly lower fibre strength than the newer varieties planted at other sites. Uniformity is also low at "Arundel" Dalby, the variety may have an inherent lower uniformity but full quality data is not available on this variety.

A particular problem associated with hail damaged cotton and late planted cotton is low micronaire on which heavy discounts are imposed. In 1994/95, all sites except "Kimberley" Warren show micronaire values in the discount range and no growth regulator treatment is able to improve micronaire. At "Kimberley" Warren, micronaire values are higher and lie within the accepted range for marketing purposes. The higher micronaire values can be attributed to the fact that the proportion of bolls which survived the hail damage and were completely mature at picking contributed a large proportion of lint to the overall pick and hence, brought up the average micronaire value of a sample of lint.

In the 1995/96 season, maturity readings for lint samples were also available and these indicated that fibre maturity was not a problem at any of the three sites. Fibre lay in the 'very fine' category for fineness at all three sites. Although fibre elongation was low-average at each site, uniformity remained average-high, strength in the average-high range and fibre length in the medium-long range. So on the basis of these characters, lint quality was not a problem. But as expected, micronaire was low at both "Auscott Narrabri" and "Willawood" where the crops were regrown following damage and were delayed in maturity. At "Coolabah" Merah North, as regrowth was minimal few bolls set on regrowth contributed to the final yield. Any lint sample would have consisted mainly of bolls set prior to the hail damage and we find that micronaire values were within the acceptable range for marketing purposes.

Looking at the separate growth regulator treatments for 1995/96, although values differed significantly from each other in fibre strength at "Willawood" and "Coolabah" Merah North and with respect to fibre length at "Auscott Narrabri" and "Willawood", the increases in values where not sufficient to lift the lint sample for that treatment into a higher quality class and hence, were not of commercial value. But the split rate Pix treatments (300/600 ml per ha and 600/1000 ml per ha) acted to increase fibre length at "Auscott Narrabri" and "Willawood" (5% Level of significance). Fibre strength was increased for the split rates treatments at "Willawood", while at "Coolabah", Pix at 600 ml/ha and in the split rate of 300/600 ml per ha, increased fibre strength compared to other treatments.

Table 2.4.4a: "Wild Willows" Wee Waa 1994/95 Growth Regulator Trial Lint Quality Data

	Lint Quality Characteristic				
	Length (inches)	Uniformity (%)	Strength (Grams/tex)	Elongation (%)	Micronaire (Micrograms /inch)
TREATMENT					
Nil Pix	1.085	81.15	28.15	6.200	2.350
Pix 300ml at FF	1.128	83.08	30.82	5.950	2.525
Pix 600ml at FF	1.125	82.23	28.40	5.925	2.325
Pix 600ml at LF	1.118	81.90	28.68	5.950	2.375
Pix 1000ml at LF	1.118	82.85	30.15	6.275	2.425
Pix 300/600ml	1.108	81.90	27.88	6.350	2.325
Pix 600/1000ml	1.130	82.68	30.18	6.100	2.375

Differences between treatments are not significant.

Table 2.4.4b: "Arundel" Dalby 1994/95 Growth Regulator Trial Lint Quality Data

	Lint Quality Characteristic				
	Length (inches)	Uniformity (%)	Strength (Grams/tex)	Elongation (%)	Micronaire (Micrograms/ inch)
TREATMENT					
Nil Pix	1.033	78.25	23.35	5.975	2.875
Pix 300ml at FF	1.040	78.30	23.90	6.375	2.775
Pix 600ml at FF	1.015	77.90	23.28	5.875	2.775
Pix 600ml at LF	1.023	78.05	23.73	6.175	2.675
Pix 1000ml at LF	1.028	78.25	24.08	6.125	2.725
Pix 300/600ml	1.043	78.38	24.95	5.950	2.800
Pix 600/1000ml	1.038	78.70	24.38	6.225	2.700

Differences between treatments are not significant.

Table 2.4.4c: "Abbey Green" Narrabri 1994/95 Growth Regulator Trial Lint Quality Data

	Lint Quality Characteristic				
	Length (inches)	Uniformity (%)	Strength (Grams/tex)	Elongation (%)	Micronaire (Micrograms/ inch)
TREATMENT					
Nil Pix	1.053	81.73	28.15	6.338	2.325
Pix 300ml at FF	1.056	82.04	26.69	6.263	2.375
Pix 600ml at FF	1.084	82.31	29.01	6.000	2.363
Pix 600ml at LF	1.084	82.28	28.83	6.012	2.350
Pix 1000ml at LF	1.085	82.18	28.27	5.988	2.625
Pix 300/600ml	1.086	82.55	30.38	5.637	2.475
Pix 600/1000ml	1.071	82.24	28.61	6.150	2.388

Differences between treatments are not significant.

Table 2.4.4d: Emerald 1994/95 Growth Regulator Trial Lint Quality Data

	Lint Quality Characteristic				
	Length (inches)	Uniformity (%)	Strength (Grams/tex)	Elongation (%)	Micronaire (Micrograms/ inch)
TREATMENT					
Nil Pix	1.173	83.23	32.38	5.425	3.150
Pix 300ml at FF	1.170	83.55	33.53	5.275	3.000
Pix 600ml at FF	1.153	83.55	33.42	5.375	2.975
Pix 600ml at LF	1.148	83.30	32.73	5.250	3.025
Pix 1000ml at LF	1.168	83.88	32.35	5.150	3.150
Pix 300/600ml	1.153	83.30	32.58	5.175	3.125
Pix 600/1000ml	1.168	83.33	33.50	5.300	3.225

Differences between treatments are not significant.

Table 2.4.4e: "Kimberley" Warren 1994/95 Growth Regulator Trial Lint Quality Data

	Lint Quality Characteristic				
	Length (inches)	Uniformity (%)	Strength (Grams/tex)	Elongation (%)	Micronaire (Microgram s/inch)
TREATMENT					
Nil Pix	1.140	82.38	29.33	5.100	3.900
Pix 300ml at FF	1.155	82.70	29.08	5.125	3.975
Pix 600ml at FF	1.160	83.00	28.85	5.000	4.175
Pix 600ml at LF	1.143	83.08	30.03	5.225	3.725
Pix 1000ml at LF	1.138	82.15	29.30	5.025	3.750
Pix 300/600ml	1.160	82.68	28.58	4.925	4.025
Pix 600/1000ml	1.160	83.00	29.83	4.950	3.875

Differences between treatments are not significant

Table 2.4.4f: **"Auscott Narrabri" 1995/96 Growth Regulator Trial**
Lint Quality Data

	Lint Quality Characteristic							
	Maturity	2% Percent Mature Fibre	Fineness (millitex)	Length (inches)	Uniformity (%)	Strength (Grams/tex)	Elongation (%)	Micronaire (Micrograms/inch)
TREATMENT								
Nil Pix	0.888	79.26	114.67	1.168	83.80	32.53	6.100	2.983
Pix 300ml at FF	0.890	79.19	116.67	1.170	84.15	32.93	6.067	3.017
Pix 600ml at FF	0.880	78.52	113.67	1.162	84.03	32.82	6.167	2.967
Pix 600ml at LF	0.932	82.72	117.67	1.177	84.32	32.27	6.033	3.150
Pix 1000ml at LF	0.910	80.70	116.33	1.177	84.23	31.75	6.133	3.050
Pix 300/600ml	0.920	81.64	124.83 a	1.1867 a	84.80	33.25	6.150	3.250
Pix 600/1000ml	0.928	82.43	121.00 b	1.1967 b	84.92	33.05	5.983	3.200

NB: Treatments with subscripts of *a* and *b* are not significantly different from each other but are significantly different from treatments.

Table 2.4.4g: **"Coolabah" Merah North 1995/96 Growth Regulator Trial**
Lint Quality Data

	Lint Quality Characteristic							
	Maturity	2% Percent Mature Fibre	Fineness (millitex)	Length (inches)	Uniformity (%)	Strength (Grams/tex)	Elongation (%)	Micronaire (Micrograms/inch)
TREATMENT								
Nil Pix	1.083	93.50	130.67	1.198	85.48	30.93	5.933	3.800
Pix 300ml at FF	1.088	93.75	130.33	1.192	85.67	31.95	5.567	3.800
Pix 600ml at FF	1.062	92.04	127.33	1.195	85.40	30.50	5.617	3.650
Pix 600ml at LF	1.065	92.22	127.00	1.198	85.63	32.35 *a*	5.717	3.650
Pix 1000ml at LF	1.063	92.03	125.50	1.185	85.02	30.35	5.567	3.617
Pix 300/600ml	1.098	94.38	131.50	1.200	85.30	32.10 *b*	5.717	3.850
Pix 600/1000ml	1.083	93.33	129.50	1.192	85.30	30.83	5.617	3.767

NB: Treatments with subscripts of *a* and *b* are not significantly different from each other but are significantly different from treatments.

Table 2.4.4h: "Willawood" Merah North 1995/96 Growth Regulator Trial Lint Quality Data

	Lint Quality Characteristic							
	Maturity	2% Percent Mature Fibre	Fineness (millitex)	Length (inches)	Uniformity (%)	Strength (Grams/tex)	Elongation (%)	Micronaire (Micrograms/inch)
TREATMENT								
Nil Pix	0.9	77.97	101.67	1.063	81.93	27.72	6.250	2.650
Pix 300ml at FF	0.902	80.66	15.50	1.098	83.13	28.67	5.800	2.833
Pix 600ml at FF	0.868	77.78	105.50	1.068	82.33	28.82	5.667	2.733
Pix 600ml at LF	0.920	81.76	107.50	1.075	81.97	28.82	5.833	2.900
Pix 1000ml at LF	0.858	76.77	100.83	1.072	81.90	28.27	6.250	2.633
Pix 300/600ml	0.875	78.22	103.83	1.087	82.47	29.47 *a*	5.650	2.733
Pix 600/1000ml	0.893	79.82	105.50	1.110	83.35	30.48 *b*	5.583	2.800

NB: Treatments with subscripts of *a* and *b* are not significantly different from each other but are significantly different from treatments.

Conclusions:

In terms of vegetative plant response, a stronger response is measured when Pix is applied to cotton damaged at a younger growth stage and regrowing under good growing conditions.

The largest reductions in plant height (ie. vegetative vigour) were measured where Pix application treatments included an application at First Flower. Applications at Last Square Date reduced vegetative growth compared to no Pix, but more effective reductions were achieved where some Pix was applied at First Flower. Under poor to moderate conditions following damage, high rates of Pix would not normally be used and in these trials it was shown that such rates produced no additional effect on plant height.

With early hail damage and only moderate weather conditions following the hail strike, the largest yield recovery was measured where Pix was applied at Last Square Date, with 300 ml/ha Pix at First Flower increasing the response at some sites. Here, the strategy has been to let the crop to regrow largely at its own rate, then stopping late vegetative growth with the dose of Pix at Last Square.

But with good growing conditions following early hail damage, ie. optimal for growth, some pegging back of vegetative growth by First Flower application of Pix has been shown to be an advantage in terms of increased yield.

Under poor to moderate growing conditions, higher doses of Pix at First Flower (600 ml/ha) were detrimental to lint yield and no advantage was found in applying higher doses at Last Square.

With hail damage at late growth stages, no yield advantage was found in applying Pix.

With damage in the earlier growth stages, although Last Square applications of Pix produced the greater yield recovery, these same applications produced the most delayed cotton. If part of the recovered yield is compromised, a First Flower application of Pix at eg. 300 ml/ha (single or spilt application) will increase earliness and may be the more economic decision when taking into account discounts for low lint quality which may be imposed with late maturing cotton.

The higher rates of Pix, as single and split applications, were more advantageous where there was insufficient water supplies to allocate extra water to a hail damaged crop to allow it to regrow to its full potential. Higher rates decreased early vegetative growth to a greater extent and forced more rapid fruiting in the limited time available. Although had sufficient water been available, a greater yield recovery would have occurred with a less harsh growth regulator treatment. Similar situations occur where picking schedules for a management unit do not allow separate defoliation of the hail damaged section of the management unit and hence, the hail damaged cotton is not able to go through to full maturity.

With the current discounts for low micronaire cotton, lint quality is a factor of importance in growing both hail damaged and late cotton. If we aim to get the crops regrowing after hail and set maximum fruit numbers before last square date and then mature the fruit before first frost, then we are also aiming to increase the lint quality as we should be picking more mature lint. As the cotton is maturing under cooler conditions micronaire will be a problem, but if growth regulator strategies combined with other management strategies are able to bring the crop in as early as possible then micronaire problems will hopefully be reduced.

Further trialing of the strategies is required to collate more lint quality data as this series of trials failed to produce significant improvements in lint quality. Points to note would be that with late damage, micronaire is not as large a problem, as there is insufficient time to produce a replacement yield, the cotton remaining after the hail and set before the strike contributes the larger portion of the lint sample and hence, as long as these bolls are left to mature fully then the micronaire is not affected. As we attempt to regrow a crop following earlier damage, we are growing a late crop and micronaire will be reduced in the late set bolls maturing under cooler conditions. Where a compromise between recovering maximum yield and crop earliness has been suggested as a cost recovery strategy in using early and split applications of Pix, by accepting a slightly lower yield in turn for an earlier maturity you should also be reducing lint quality problems.

In all of the trials described in this section on growth regulator use, prior to the hail damage, growers had applied the optimum amount of nitrogen for their expected yield (pre-hail). No nitrogen was applied post damage in excess of the normal crop requirement, except in one situation which was suffering prolonged waterlogging. Hence, vegetative regrowth was not excessive due to excess nitrogen. But vegetative regrowth would have been reduced at least four of the sites due to less than ideal weather conditions following the hail damage. Vigorous regrowth was only measured at three sites. Hence, further trialing may be required in situations where nitrogen usage has been excessive and where weather conditions are conducive to extremely vigorous vegetative regrowth. Higher rates of Pix may be necessary under these growing conditions.

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2.4.3: Response of Hail Damaged Cotton to Applications of PGR-IV Cotton Growth Regulator

Introduction:

PGR-IV is a new crop growth regulator receiving attention in the United States and having potential for use in cotton production. Oosterhuis (1994) review the effects of PGR-IV on the growth and yield of cotton and this discussion is based on this review.

PGR-IV is a multi-entity plant growth regulator consisting mainly of 0.003% (w/v) gibberellic acid, 0.0028% (w/v) indolebutyric acid. It is reported to improve the growth and yield of cotton (Oosterhuis, 1995). Lint yield increases have been recorded in various studies with PGR-IV applied to cotton as an in-furrow treatment or as a foliar applied growth regulator (Hickey and Atkins, 1992 cited by Oosterhuis, 1994). Oosterhuis (1994) suggests that in the case of in-furrow treatments, yield enhancement is the result of increased root growth, nutrient uptake and seedling growth. But in respect to foliar treatments, yield enhancement is the result of increased boll retention and boll growth.

Vegetatively, PGR-IV produces a number of changes in cotton growth. Earlier emergence, increased seedling vigour and enhanced root development are attributed to in-furrow application of PGR-IV. Decreased plant height is recorded with foliar applications and although internode length is decreased, Oosterhuis (1994) associates the decreased plant height with the increased boll load or boll retention providing a stronger sink for assimilates than vegetative growth. Leaf area and leaf number are not recorded as affected by PGR-IV application. In respect to reproductive growth, reports vary as to the effects of PGR-IV. Increased square and boll numbers are recorded by Oosterhuis and Zhao (1994); Hickey and Atkins. 1992 and Wier *et al.* 1994; as cited by Oosterhuis (1994). Whereas, Robertson and Cothren (1993) cited by Oosterhuis (1994), reports increased yield due to increased boll weight not boll number. Increased boll retention, especially at primary and secondary fruiting positions, is widely reported.

PGR-IV is currently recommended to be applied in-furrow at a rate of 72 ml/ha. Whereas as a combined in-furrow / foliar treatment trials show that 72 ml/ha in-furrow, 150 ml/ha at pin head square and 300 ml/ha at first flower (Oosterhuis, 1995).

It is suggested that PGR-IV may be more appropriate than Pix for use in management of regrowth of hail damaged cotton. Pix acts to reduce vegetative growth, and hence by default increases reproductive development. PGR-IV by increasing boll retention directly, should make more efficient use of the reduced fruit set period available to a crop following hail damage. (Oosterhuis pers comm.). Application rates suggested as appropriate for testing the effect of PGR-IV on hail damaged cotton were 150 ml/ha at Pin Head Square, 300 ml/ha at First Flower and 300 ml/ha two weeks after First Flower.

Aims:

PGR-IV is a new cotton growth regulator for management of vegetative and reproductive growth in cotton and is currently being trailed in the United States. This trial is a preliminary comparison of the response of hail damaged cotton to PGR-IV and Pix growth regulators, evaluating the potential use of PGR-IV in the management of regrowth of hail damaged cotton.

Methods:

The response of hail damaged cotton to the application of the growth regulators PGR-IV and Pix® (Mepiquat Chloride) was measured in a trial located on "Auscott Narrabri" Field 22 in 1995/96.

The site was damaged by hail on 10th December, 1995 when the crop was at an average growth stage of R3.5 and hence, was squaring well. Damage was assessed at an average loss of 43%. The crop experienced approximately 70% defoliation, most plants were cut off at 6th - 7th node level, removing the major proportion of fruiting branches and squares. Stem bruising was evident on most plants.

Agronomic management for the trial area was carried out as per the whole field and is described in Appendix 2.2.

A hand held pressurised spray unit built for the application of growth regulators was used to apply treatments. The trials was designed as Randomised Complete Block Designs with 6 replications, with plots 4 rows (4m wide) by 10m in length. Fruit counts and plant height determinations were carried out over 1 m^2 sample areas. Lint yield and maturity of treatments were determined by sequential hand picking of 2 m^2 sample areas. Lint quality determinations were made using H. V. I. techniques at the Australian Cotton Research Institute, Narrabri.

Treatments imposed were as follows:

1. Nil Pix
2. Pix 300 ml/ha at First Flower on Regrowth
3. Pix 600 ml/ha at First Flower on Regrowth
4. Pix 600 ml/ha at Last Square Date
5. Pix 1000 ml/ha at Last Square Date
6. Pix 300 ml/ha at First Flower on Regrowth and 600 ml/ha at Last Square Date.
7. Pix 600 ml/ha at First Flower on Regrowth and 1000 ml/ha at Last Square Date.
8. PGR-IV at 150 ml/ha at PHS, 300 ml/ha at FF, 300 ml/ha at Mid flowering.

All growth regulator applications were made 7-10 days prior to the date nominated so that the compound was active in the plant by that date. Chemical was applied over the entire plot area providing treated buffer areas for the sample areas.

Results and Discussion:

A comparison of the Pix treatments is discussed separately in Section 2.4.2. These results and discussion will concentrate on a comparison of PGR-IV and Pix.

PGR-IV was found to reduce plant height compared to Nil Pix and Last Square Date applications of Pix, but failed to reduce plant height to the extent to which Pix applied at First Flower or in split applications was able to (5% Level of Significance) (Figure 2.4.5). PGR-IV is reported to have the capability of reducing plant height but growth regulators such as Pix which act directly on cell elongation processes affect plant height to a greater degree (Oosterhuis *et al.*, 1995).

Note that as previously described, due to the variability of hail damage and symptoms within small areas, statistical analysis of the data collated from the trial showed significant variation between replicates. Hence, although some large differences were observed between lint yields, the results were not statistically significant. Hence, conclusions drawn from these results can only be regarded as trends.

Yield responses to Pix are reported as being increased in seasons of reduced heat units, as increased earliness is induced by increased early fruit set (Kerby, 1985; York, 1983a and 1983b). Following hail damage at this site, regrowth was vigorous, rain during January did not affect development as good field drainage ensured no waterlogging. The crop was able to finish well and hence, any yield or earliness advantage of a growth regulator treatment would be masked.

The lint yield response to PGR-IV was equivalent to that for untreated cotton (Figure 2.4.6). Pix 300 ml/ha at First Flower pegged back vegetative growth sufficiently to produce a yield advantage of 8-10% over PGR-IV and the Nil Pix treatments.

No differences in maturity were measured (Table 2.4.5).

Figure 2.4.5: Plant Height Response in Hail Damaged Cotton to PGR-IV and Pix Growth Regulator Applications

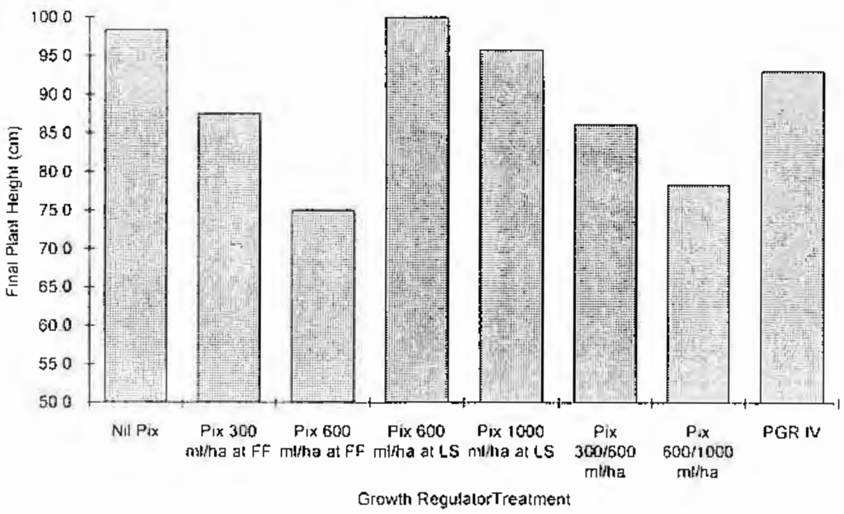


Figure 2.4.6: Lint Yield Response in Hail Damaged Cotton to PGR-IV and Pix Growth Regulator Applications

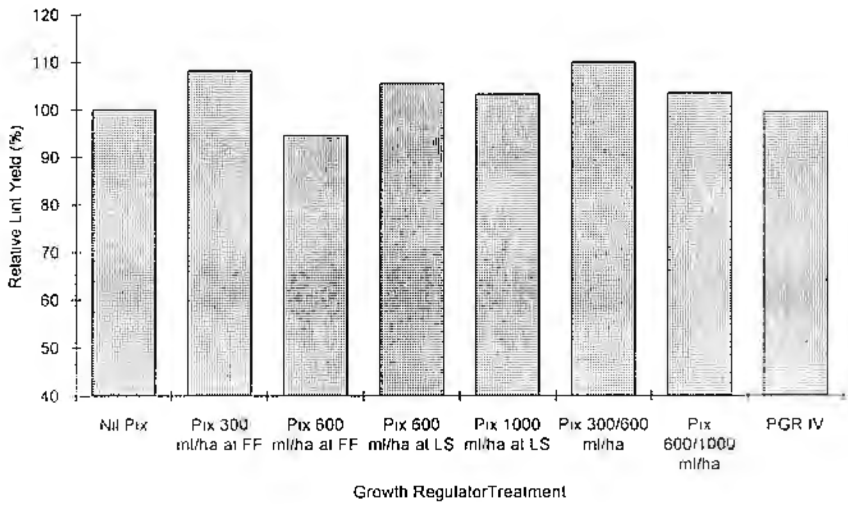


Table 2.4.5:

AUSCOTT NARRABRI (Field 22) - 1995/96 COTTON GROWTH REGULATOR TRIAL		
	MATURITY in Growing Day Degrees from Planting to 60% Open Bolls	**RELATIVE MATURITY** (Relative to Nil Pix Treatment) in Growing Day Degrees
TREATMENT		
Nil Pix	1857	0.0
Pix 300 ml at FF	1857	0.0
Pix 600 ml at FF	1858	1.0
Pix 600 ml at LS	1857	-0.5
Pix 1000 ml at LS	1860	3.0
Pix 300/600 ml	1855	-2
Pix 600/1000 ml	1857	-1
PGR-IV	1859	2.0

Fruit counts and final boll numbers do not indicate significant differences in boll retention.

Except for micronaire, the quality characteristics of the lint produced in the trial was good. The normal length and strength of fibre in Sicala V2 is 1.14 inches and 30 grams/tex, respectively. Hence, the values recorded in this trial were higher than the average for Sicala V2. Uniformity was average at a range of 83.8-84.92% and elongation was average at 5.98-6.15. ie. Fibre maturity, length, uniformity, strength and elongation were in desirable ranges for marketing purposes. Micronaire ranged from a treatment mean low of 2.97 to a high of 3.25 and this is below optimum and in the discount range. Differences in lint quality characters between treatments were only significant for fineness and strength (Table 2.4.6).

In regard to fineness, all values were in the very fine range of less than 155 millitex. Fibre fineness for the higher rate split Pix treatment was coarser, but only significantly different from the Nil Pix and 600 ml/ha Pix at FF treatment. Fibre length for the split rate Pix treatments was longer than for other treatments (5% Level of Significance), but all were classified in the 'long' range.

Following hail damage, fibre maturity and micronaire are the usual problem areas. In this trial, fibre maturity was not a problem but micronaire was obviously reduced. None of the growth regulator treatment acted to improve micronaire. PGR-IV did not act to improve or lower lint quality compared to Pix treatments.

Conclusions:

Under the conditions experienced in this trial, PGR-IV offered no advantage over Pix in the management of regrowth of hail damaged cotton.

References:

Oosterhuis, D. M. (1994)
"Effects of PGR-IV on the Growth and Yield of Cotton: A Review"
Proceedings of World Cotton Research Conference - 1,
Brisbane, Australia. Eds. Constable, G. A. and Forrester, N. W., Pages 29-39.

Oosterhuis, D. M.; Janes, L. D. and Bondada, B. R. (1995)
"Research on Plant Growth Regulators in Cotton - Summary of 1994 Results."
Proceedings of 1995 Beltwide Cotton Conferences. Cotton Research
Council, Memphis, TN.

Table 2.4.6: **Auscott Narrabri (Field 22) 1995/96 - Lint Quality Data**

	Quality Characteristic							
	Maturity	2% Percent Mature Fibre	Fineness (millitex)	Length (inches)	Uniformity (%)	Strength (Grams/tex)	Elongation (%)	Micronaire (Micrograms/inch)
TREATMENT								
Nil Pix	0.888	79.26	114.67	1.168	83.80	32.53	6.100	2.983
Pix 300ml at FF	0.890	79.19	116.67	1.170	84.15	32.93	6.067	3.017
Pix 600ml at FF	0.880	78.52	113.67	1.162	84.03	32.82	6.167	2.967
Pix 600ml at LF	0.932	82.72	117.67	1.177	84.32	32.27	6.033	3.150
Pix 1000ml at LF	0.910	80.70	116.33	1.177	84.23	31.75	6.133	3.050
Pix 300/600ml	0.920	81.64	124.83 *a*	1.1867 *a*	84.80	33.25	6.150	3.250
Pix 600/1000ml	0.928	82.43	121.00 *b*	1.1967 *b*	84.92	33.05	5.983	3.200
PGR-IV	0.887	79.10	117.83	1.175	84.38	32.97	6.133	3.033

NB: Treatments subscripted by *a* or *b* are significantly different from other treatments.

2.5: Response of Hail Damaged Cotton to Applications of Nitrogen and Pix®

Aims:

In examining the response of hail damaged cotton to applications of Pix as discussed in previous sections of this work, it has been suggested nitrogen levels in a crop also play a part in determining the rate of regrowth that can be achieved by a crop. These trials aimed to evaluate the combined use of nitrogen and Pix® (Mepiquat Chloride) in hail damaged cotton, with nitrogen used to encourage vegetative regrowth and followed by Pix to manage or control the regrowth.

Methods:

Four trials evaluating the response of hail damaged cotton to nitrogen and pix were carried out during the 1993/94 and 1994/95 cotton seasons. Trial sites being as described in Table 2.5.1.

Table 2.5.1: Response of Hail Damaged Cotton to Applications of Nitrogen and Pix® - Trial Sites 1993/94 and 1994/95.

		Trial Site	Date of Loss	Growth Stage at Date of Loss	Assessed Loss
A	1993/94	C.S.I.R.O. Leitch's Block (A.C.R.I.)	20/11/93	V5	Maximum Payout (70 - 80%)
B	1993/94	"Myall Vale" Wee Waa (Field 21)	20/11/93	R2	Maximum Payout (70-80%)
C	1993/94	Auscott Narrabri (Field 10)	21/1/94	R9.9	62.3% (Mechanically Simulated Damage)
D	1994/95	A. C. R. I. (Field B2)	13/12/95	R2.8	28.3% (Manually Simulated Damage)

Hail strikes in commercial cotton crops in the 1993/94 cotton season were few. Storms in late November provided trial sites in close proximity to the Australian Cotton Research Institute and two small scale trials were laid out. This cotton was, however, at a reasonably young stage and did not technically fall within the damage period that was required for testing of the nitrogen and pix management strategies. The opportunity was taken to collate data on early season damage and the effects of nitrogen and pix application to cotton damaged by hail at the V5 and R2 growth stages. The lack of hail during the rest of the growing season necessitated the simulation of hail at a backup site provided by Auscott Ltd. (Narrabri) in late January (R9.9 Growth Stage). The three trials have provided data on the response of cotton damaged by hail in early and late stages of development (ie. the extremes of the period required for testing) to side-dressed nitrogen and pix applications.

Trials for the 1993/94 season were designed as Randomised Complete Block Designs with 4 replications, with plots 4 rows (4m wide) by 15m in length, allowing for application of growth regulators by high-boy ground rig. These trials combined nitrogen and pix applications as follows:-

1. Nil Nitrogen, Nil Pix.
2. Nil Nitrogen, Pix 600 ml/ha at First Flower.
3. Nil Nitrogen, Pix 300 ml/ha at First flower and 600 ml/ha at Last Square Date.
4. Nil Pix, 50 units N as Urea (Side-dressed following Hail Damage).
5. 600 ml/ha Pix, 50 Units of N as Urea (Side-dressed following Hail Damage).

Damage was simulated at the Auscott Narrabri site using the hail simulation rig developed by Auscott Narrabri and this allowed for the inclusion of an undamaged control treatment.

In the 1994/95 cotton season, hail damage was simulated in a trial situated at the Australian Cotton Research Institute (Field B2), Narrabri. Damage was simulated manually when the crop was at an average growth stage of R2.8. Simulation was carried out by inflicting main stem cut-off at the midpoint of the main stem and removing approximately 90% of leaf material. Damage was assessed 14 days after the damage simulation and was assessed at an average loss of 28%.

The trial was designed as a R. C. B. D. with four replicates, plots were 4 metres (ie. 4 rows) wide and 15 metres in length, with treatments as follows:-

1. Undamaged
2. Nil Nitrogen, Nil Pix (ie. Untreated control)
3. Nil Nitrogen, 600 ml Pix at First Flower after Damage
4. Nil Nitrogen, 300 ml Pix at First Flower after Damage & 600 ml Pix at Last Square Date
5. 50 Units Nitrogen, Nil Pix.
6. 50 units Nitrogen, 600 ml Pix at First Flower after Damage
7. 50 units Nitrogen, 300 ml Pix at First Flower after Damage & 600 ml Pix at Last Square Date

In all four trials, nitrogen was applied as side-dressed urea 7-10 days after the natural or simulated hail damage. Urea was side-dressed by ground rig placing the urea into side of the hill at a depth of 15 cm.

Pix applications were made 7-10 days prior to First flower or Last Square so that the compound was active in the plant by that date. Chemical was applied over the entire plot area providing treated buffer areas for the sample areas. A hand held pressurised spray unit was built for the application of growth regulators in the A. C. R. I. trial in 1994/95.

Regrowth was monitored in weekly counts of squares and fruit set over 1 m^2 areas of crop. Lint yield and date to maturity were determined by sequential hand picking of 1 m^2 sample areas. Lint quality determinations were made using H. V. I. techniques at the Australian Cotton Research Institute, Narrabri.

Insect, water and agronomic management, other than trial treatments, was carried out by the co-operating grower and as required by the field or management unit as a whole. Agronomic data for each site is summarised in Appendix 2.2.

Results and Discussion:

Previous work has shown that growth stage at the time of damage has a significant effect on the degree of recovery of which a crop is capable following a hail strike (West, 1993). These trials cover crops which were at widely varying growth stages at the time of damage and hence, results for each will be presented and discussed separately.

Climate Conditions

Water allocations for the 1993/94 season were low after a dry winter during 1993 and no effective rain in water catchment areas. Effective rain during the cotton growing season did not eventuate till February 1994. Time between irrigations had been stretched to the maximum and most growers were short at 1-2 irrigations. Rain in February provided relief for crops and allowed Namoi valley crops to finish, although the effect of water stress showed in decreased yields. (Figure 2.5.1)

Temperatures and day degrees values for the season were very much along the lines of long term averages (Figures 2.5.2 and 2.5.3). Weather conditions in late November and December were characterised by periods of lower than average temperatures and in particular cool nights. This was not advantageous to vigorous regrowth following the hail damage on November 20th, 1993.

It should be noted that irrigations were stretched out at all trial sites due to the drought and low irrigation allocations for the season. Hail damage results in delayed maturity and a requirement for extra irrigations and so the imposition of a restricted water supply would affect the results of all trials. The Auscott Narrabri site would be more severely affected as the production of new squares on regrowth was occurring late in the season and at the time of significant moisture stress as water supplies ran out.

Climatic conditions for the 1994/95 were more optimum for growth of cotton and are summarised in Appendix 2.1. Water allocations for irrigation were still low and hence irrigations were stretched out as far as possible again for the 1994/95 season.

Figure 2.5.1: Average Rainfall Data - Myall Vale, 1993/94
Source: A. C. R. I. Narrabri.

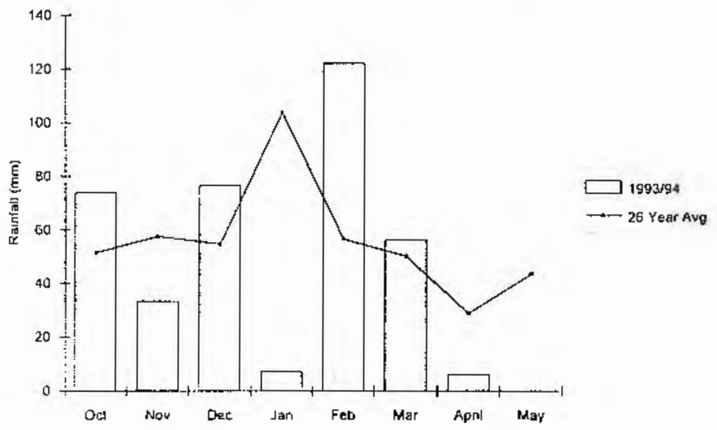


Figure 2.5.2: Average Maximum Daily Temperature (^{0}C) - Myall Vale, 1993/94
Source: A. C. R. I. Narrabri.

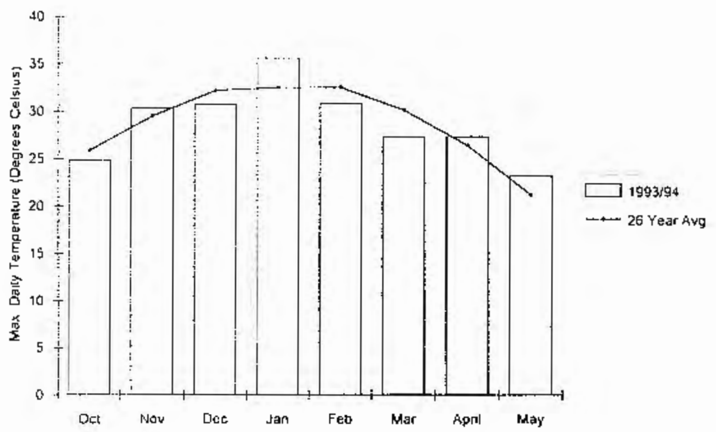
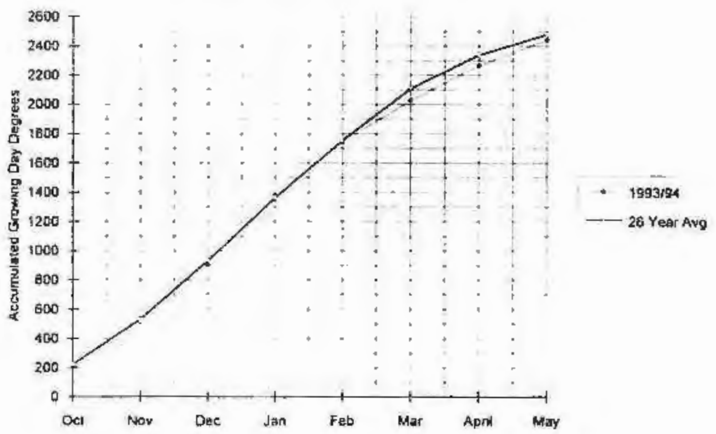


Figure 2.5.3: Accumulated Growing Day Degrees - Myall Vale, 1993/94
Source: A. C. R. I. Narrabri.



Results and Discussion (continued)

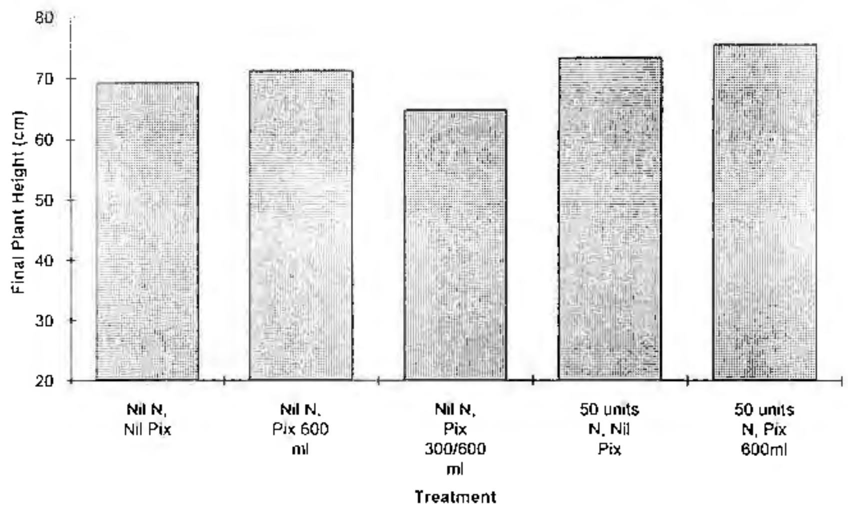
2.5.1: Trial Site A - C. S. I. R. O. "Leitch's" Block 1

Leitch's Block 1 represented the C. S. I. R. O. Cotton Unit's commercial scale insecticide strategy trial. The field trial was planted with cotton varieties as trial blocks with insecticide treatments overlaid. The field was damaged by hail on November 20th, 1993 when the crop was at the V5 growth stage. With damage being more substantial on the northern side of the field, one replicate was deleted from the insecticide trial and made available for a hail trial.

a. Vegetative Growth Response to Application of Pix and/or Nitrogen Following Hail Damage

Historically, crops on the Leitch's Block do not require large applications of pix or other growth regulators as growth does not tend to become rank. In combination with less than optimum growing conditions following the hail damage and lack of compensation for reduced plant stand, vegetative plant regrowth was not vigorous. Average final plant height ranged from 69-75 cm and in a commercial situation no Pix would have been applied to control vegetative regrowth. Differences in final plant height were not significant (Figure 2.5.4).

Figure 2.5.4: Plant Height Development Following Application of Pix and/or Nitrogen to Hail Damaged Cotton. - C.S.I.R.O. "Leitch's" 1993/94.



b. Fruit Development Following Application of Nitrogen and/or Pix to Hail Damaged Cotton

If we look at fruit development following damage, we see some significant differences in fruit numbers at some sampling dates. Square numbers for all treatments peak at approximately the same time after damage. In the early stages of regrowth, Nil Nitrogen with Spilt Pix (300/600 ml) has higher square numbers than the other treatment. (5% Level of Significance). But this difference does not carry through to later sampling dates (Figure 2.5.5).

Peak squaring for all treatments is approximately 1423 GDDs from planting (1131 GDDs post damage) and at peak squaring, treatment 4 (Nitrogen 50 units with no Pix) has significantly lower square numbers than the other treatments (5% Level of Significance). This carries through to boll numbers where treatments 4 and 5, where 50 units of nitrogen are applied with or without Pix, display a lower rate of production of bolls and a lower peak boll number compared to the other treatments as displayed (Figure 2.5.6) (Significant at 5% Level). Applying nitrogen has been detrimental to increase in fruiting.

c. Lint Yield Response of Hail Damaged Cotton to Application of Pix and/or Nitrogen

Boll size was very small compared to normal average size for Siokra L23 in undamaged cotton. Hence, any difference in boll numbers did not contribute a large quantity of lint to final yield.

The management strategies applied as treatments in this trial failed to produce a yield advantage on the hailed damage cotton. ie. There were no significant differences between applied treatments with respect to lint yield (Table 2.5.2). Analysis of the data shows large standard deviations indicative of the variation in plant density across the trial and variation between replicates. Looking at relative lint yield, all management treatments reduced lint yield (Figure 2.5.7).

Hail damage over the site of the hail trial was assessed as being at maximum payout levels. Not only was the plant stand reduced but plants sustained heavy bruising of stem tissue resulting in slow and low vigour of regrowth. The climatic conditions following damage were not advantageous to regrowth so overall the crop was stunted and slow to produce fruit. Boll number and boll size were reduced compared to that you would normally expect from Siokra L23. With this type of regrowth you would not apply pix in the commercial situation and hence, pix trial treatments were not expected to produce significant increase in lint yield and actually decreased yields in this trial. Application of nitrogen did not improve the response.

Figure 2.5.5: Square Development Patterns Following Application of Pix and/or Nitrogen to Hail Damaged Cotton. - C.S.I.R.O. "Leitch's" 1993/94

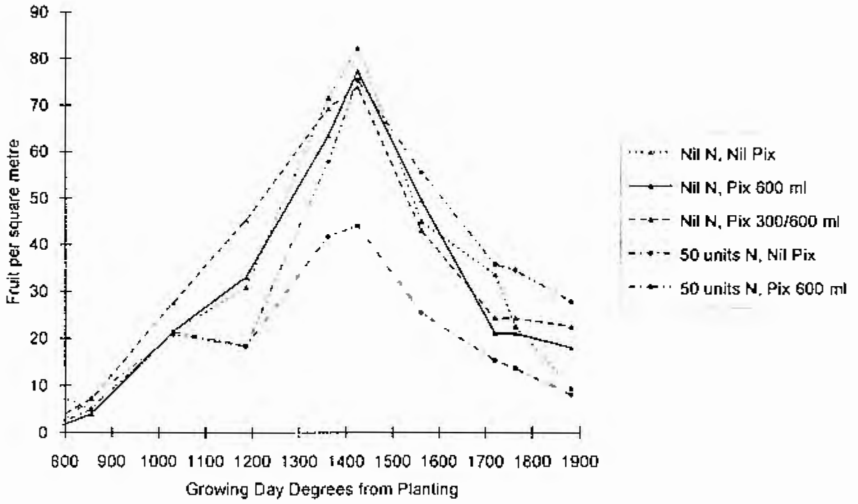


Figure 2.5.6: Boll Development Patterns Following Application of Pix and/or Nitrogen to Hail Damaged Cotton. - C.S.I.R.O. "Leitch's" 1993/94

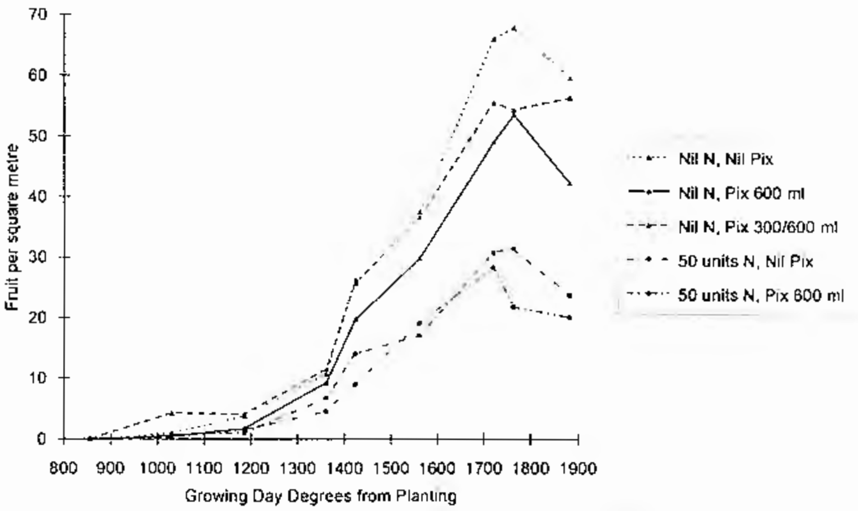
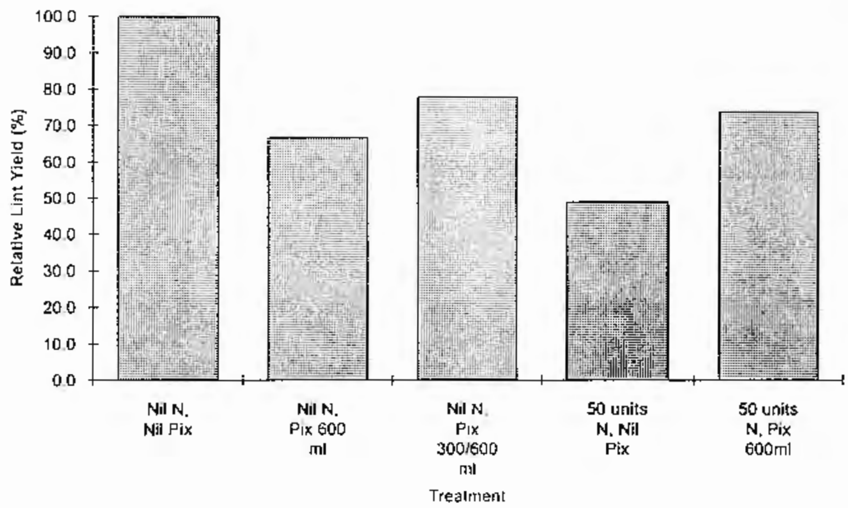


Table 2.5.2: Lint Yield Following Application of Pix and/or Nitrogen to Hail Damaged Cotton.
- C.S.I.R.O. "Leitch's" 1993/94

	LINT YIELD	
TREATMENT	kg/ha	ba/ha
Nil Nitrogen, Nil Pix	425.60	1.89
Nil Nitrogen, Pix 600ml	283.60	1.26
Nil Nitrogen, Pix 300/600 ml	330.80	1.47
50 Units N/ha, Nil Pix	164.00	0.73
50 Units N/ha, Pix 600 ml	312.80	1.39

NB: Differences not significant

Figure 2.5.7: Lint Yield Relative to Untreated Hail Damaged Cotton Following Application of Pix and/or Nitrogen
- C.S.I.R.O. "Leitch's" 1993/94



d. Effect of Application of Pix and/or Nitrogen on Maturity of Hail Damaged Cotton

Management treatments did not advance nor delay overall maturity compared to the controls plots with no Pix or Nitrogen. The small differences in time to 60% open presented in Table 2.5.3 are not significantly different.

Table 2.5.3: C.S.I.R.O "Leitch's" 1993/94 - Treatment Maturity

	MATURITY	
	Days to 60% Open from Planting	Growing Day Degrees to 60% Open From Planting
TREATMENT		
Nil Nitrogen, Nil Pix	189.6	2045
Nil Nitrogen, Pix 600ml	191.6	2060
Nil Nitrogen, Pix 300/600 ml	186.6	2024
50 Units N/ha, Nil Pix	184.7	2010
50 Units N/ha, Pix 600 ml	192.2	2064

NB: Differences Not Significant

e. Responses of Hail Damaged Cotton in terms of Lint Quality Following Application of Pix and/or Nitrogen

In terms of lint quality, no hail management treatment improved lint quality nor were any differences in lint quality measured between treatments. Micronaire was very low for all treatments. Fibre length and strength are reduced compared to the historical averages for the Siokra L23 variety of 1.14 inches and 30 grams/tex respectively (Table 2.5.4).

Table 2.5.4: C.S.I.R.O. "Leitch's" 1993/94 - Lint Quality

	QUALITY CHARACTERISTIC				
	Length (inches)	Uniformity (%)	Strength (Grams/tex)	Elongation (%)	Micronaire (Micrograms/inch)
TREATMENT					
Nil N, Nil Pix	1.07	79.93	28.18	6.23	2.45
Nil N, 600 ml Pix	1.09	81.18	29.52	6.3	2.38
Nil N, 300/600 Pix	1.09	79.93	28.0	6.48	2.48
50 units N, Nil Pix	1.09	80.17	28.23	5.97	2.40
50 units N, 600 ml Pix	1.08	81.08	28.98	6.63	2.48

NB: Treatments are not significantly different

Results and Discussion (continued)

2.5.2: Trial Site B: "Myall Vale" Wee Waa (Field 21)

"Myall Vale" Narrabri (Field 21) was severely damaged across part of the field by a hail storm on November 20th, 1993 when at the R2 growth stage. Had the damaged section of the field made up the larger percentage of the field, the grower would have replanted the field. The hail damage was assessed at maximum payout level, although the stand was not totally destroyed. A hail management trial was placed in the damaged section of the field. The trial was designed as a R.C.B.D. with four replicates but with problems in uniformly applying the urea, replicate four was dropped from the results.

a. Vegetative Growth Response to Application of Pix and/or Nitrogen Following Hail Damage

Stem tissue was severely bruised and scarred and so regrowth was slow to be initiated and of low vigour. The situation was exacerbated by the less than optimum growth conditions experienced in the six weeks following damage. Being on an alluvial loam soil and newly brought into cotton cultivation, vegetative growth at the site in previous years has been quite vigorous, and so in the case of this trial, the rate of vegetative regrowth has been modified by the hail damage and growing conditions. The application of nitrogen (50 units) along with Pix at 600 ml/ha reduced final plant height but this was not of any commercial significance (Level of Significance 5%). There was no statistical difference between final plant height for other treatments.

Statistical analysis shows that there is no significant difference in the number of squares on cotton in each of the management treatments through the season. Although there is a trend for Treatment Nos. 2 & 3 to reach their peak square number at a later date than the other three treatments. Differences in boll numbers are not significantly different. (Figures 2.5.8, 2.5.9). This is contradictory to the usual effect of pix applications which usually act to increase earliness of squaring as previously described.

b. Lint Yield Response of Hail Damaged Cotton to Application of Pix and/or Nitrogen

Replicate variability has produced large standard deviations. Hence, although differences in lint yield between treatments were large, treatment lint yields were not statistically significantly different (Table 2.5.5). Looking at the results as trends only, lint yields were reduced where no nitrogen was applied. Nitrogen should not have been limiting for this crop as 157 units of nitrogen was applied pre-plant and the crop was following a fallow.

Figure 2.5.8: Square Development Patterns Following Application of Pix and/or Nitrogen to Hail Damaged Cotton. "Myall Vale" Wee Waa (Field 21) - 1993/94

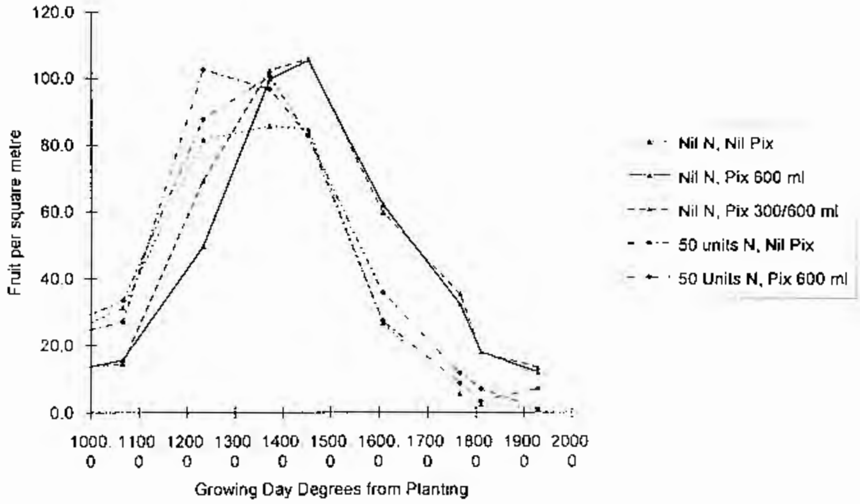


Figure 2.5.9: Boll Development Patterns Following Application of Pix and/or Nitrogen to Hail Damaged Cotton. "Myall Vale" Wee Waa (Field 21) - 1993/94

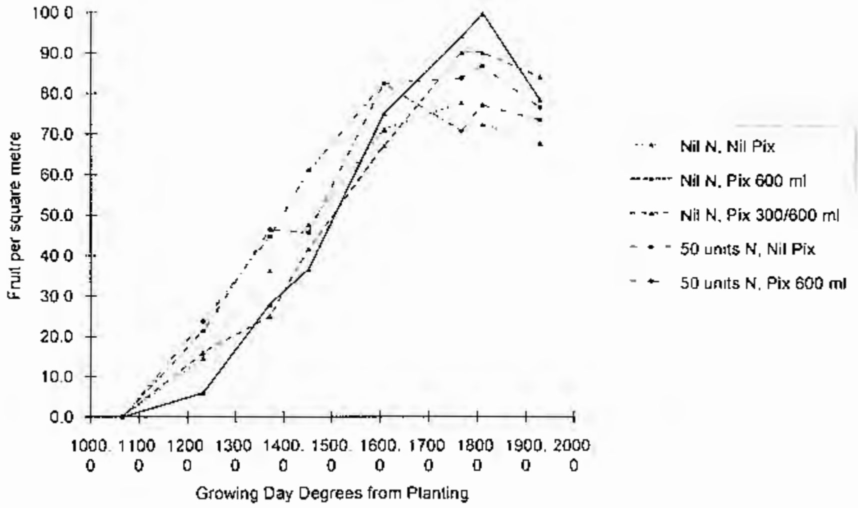


Table 2.5.5: Lint Yield Following Application of Pix and/or Nitrogen to Hail Damaged Cotton.
- "Myall Vale" Wee Waa (Field 21) 1993/94

	LINT YIELD	
TREATMENT	kg/ha	ba/ha
Nil Nitrogen, Nil Pix	1040.4	4.62
Nil Nitrogen, Pix 600ml	928.6	4.13
Nil Nitrogen, Pix 300/600 ml	893.7	3.97
50 Units N/ha, Nil Pix	1175.8	5.23
50 Units N/ha, Pix 600 ml	1163.8	5.17

NB: Differences not significant

c. Effect of Application of Pix and/or Nitrogen on Maturity of Hail Damaged Cotton

Differences in date to maturity (ie. Date to 60% open) were determined in sequential hand picks. Treatments which applied nitrogen with or without Pix were advanced in maturity compared to where pix was applied with no nitrogen.(Table 2.5.6).

At sequential pick 2, Nil nitrogen treatments with Pix applied at either 600 ml/ha or 300/600 ml/ha split were delayed compared to other treatments (5% Level of Significance). But by the time the crop opened to 50-70% open range around the date of sequential pick 3, the nil nitrogen/split Pix treatment had begun to open more rapidly and was no longer significantly less mature than treatment 5. At maturity. Treatment 2 (ie. Nil N/Pix 600 ml/ha) was delayed in maturity by 71 GDDs or 10 days compared to treatment 5 (50 units of Nitrogen plus Pix 600 ml/ha) (5% level of significance). Note that the Nil Nitrogen/Nil Pix treatment was of similar maturity to treatments 4 and 5. Availability of nitrogen has reduced recovery in terms of yield and maturity.

So from this, Pix treatment has not increased earliness in all treatments where Pix was applied compared to Nil Pix treatments. Where Pix was applied without added nitrogen, maturity was delayed.

Table 2.5.6: "Myall Vale' Wee Waa (Field 21) 1993/94 - Treatment Maturity

	MATURITY	
	Days to 60% Open from Planting	Growing Day Degrees to 60% Open From Planting
TREATMENT		
Nil Nitrogen, Nil Pix	195.9	2050
Nil Nitrogen, Pix 600ml	202.5	2097 ab
Nil Nitrogen, Pix 300/600 ml	201.3	2088 b
50 Units N/ha, Nil Pix	196.2	2052
50 Units N/ha, Pix 600 ml	192.5	2026

a- Treatment is significantly different from other treatments at Sequential pick 3 (Approx. 60% Open)
b- Treatments are significantly different from other treatments at Sequential pick 2.

d. **Responses of Hail Damaged Cotton in terms of Lint Quality Following Application of Pix and/or Nitrogen**

Micronaire readings for all treatments were well below the expected micronaire for the variety and was related to the hail damage and water stress. Fibre length and strength compared favourably with the historical data for the variety Sicala V1, which average 1.16 inches in length and 29.1 grams/tex in strength. The hail damaged cotton in this trial was both longer in fibre length and stronger than the historical averages (Table 2.5.7).

Fibre quality was not significantly different between treatments for any of the fibre characteristics measured. ie. management strategies did not improve or lower fibre quality.

Table 2.5.7: "Myall Vale" Wee Waa (Field 21) 1993/94 - Lint Quality

	QUALITY CHARACTERISTIC				
	Length (inches)	Uniformity (%)	Strength (Grams/tex)	Elongation (%)	Micronaire (Micrograms/inch)
TREATMENT					
Nil N, Nil Pix	1.21	84.93	33.07	6.4	2.57
Nil N, 600 ml Pix	1.19	83.83	31.17	6.1	2.57
Nil N, 300/600 Pix	1.20	84.80	32.93	6.2	2.80
50 units N, Nil Pix	1.21	84.67	32.80	6.1	2.70
50 units N, 600 ml Pix	1.22	85.13	31.93	6.0	2.73

NB: Treatments are not significantly different

Results and Discussion (continued)

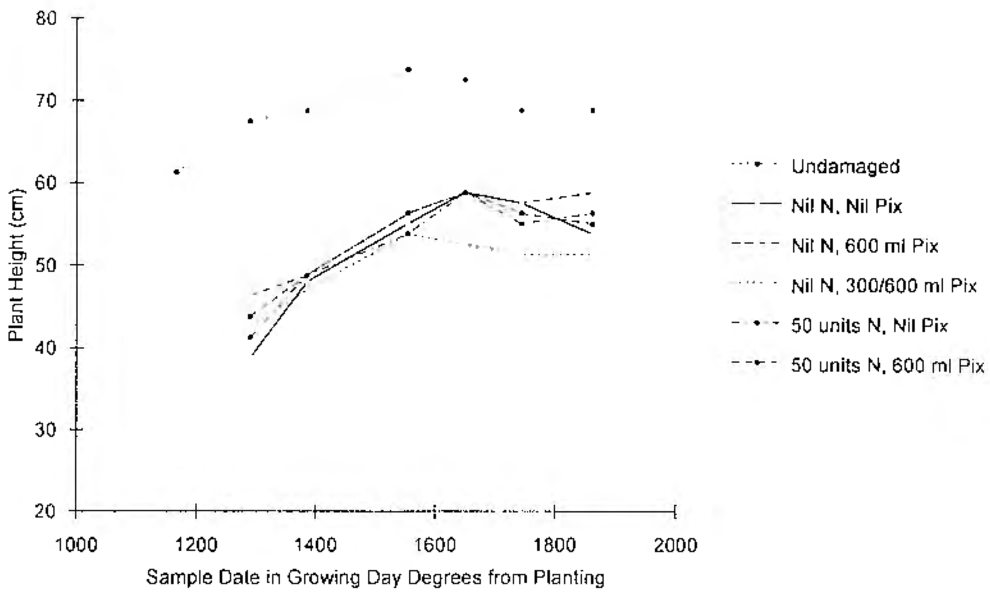
2.5.3: Site C - Auscott Narrabri (Field 10) 1993/94

Due to lack of hail events in the 1993/94 season, hail damage was simulated on Auscott Narrabri (Field 10) on a crop of Sicala V2 at the R9.9 growth stage.

Vegetative Plant Development and Fruit Development Following Application of Pix and/or Nitrogen to Simulated Hail Damaged Cotton

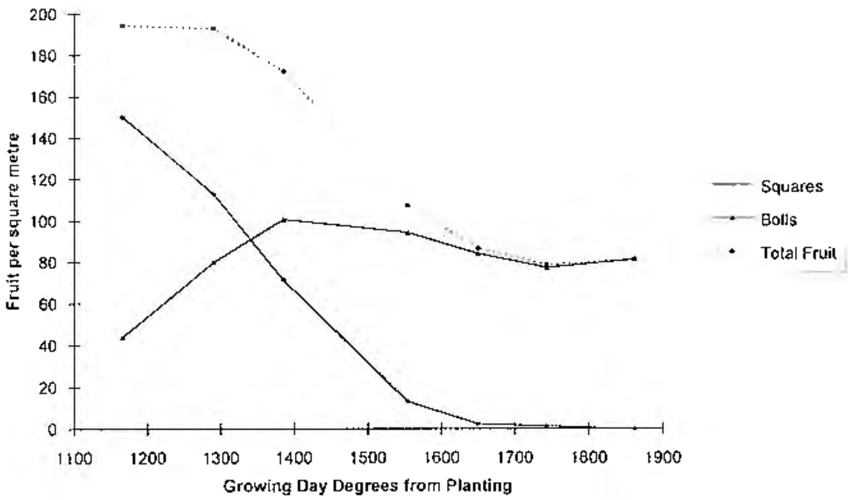
Following the simulated hail damage, due to the late growth stage at the time of damage and restrictions on recovery imposed by limited water supplies, vegetative regrowth in terms of increased plant height was reduced. Final plant height in simulated hail treatments remained reduced compared to undamaged cotton (Level of significance 5%) (Figure 2.5.10). Differences in final plant height between simulated hail treatments were not significant.

Figure 2.5.10: Plant Height Development Following Application of Pix and/or Nitrogen to Simulated Hail Damaged Cotton. - Auscott Narrabri (Field 10) 1993/94.



At the time of the hail damage simulation in the Auscott Narrabri trial at 1096 day degrees from planting, the crop was at the R9.9 stage of crop development. Hence, the crop was quite well advanced in its boll fill period with an average of 9.9 fruiting limbs present. Vegetative regrowth is minimal in such situations. Fruit counts 14 days after damage show that square production had already peaked in the undamaged crop whilst boll numbers increased till approximately 1385 day degrees from planting (Figure 2.5.11).

Figure 2.5.11: Fruit Development Patterns in Undamaged Cotton. Pix and Nitrogen Management Trial - Auscott Narrabri (Field 10) 1993/94.



Following the simulated hail damage, squaring was advanced by application of Pix at 600 ml/ha at first flower on regrowth whether with or without added nitrogen (Figure 2.5.12) and peak square numbers were also higher (5% Level of Significance). Both treatments also showed higher peak square numbers than the control (Nil N/Nil pix).

In Figure 2.5.13, early trends in boll numbers are not well defined and boll set has obviously been affected by water stress. There is no indication of an earlier start to boll set on regrowth. But where Pix was applied at first flower on regrowth final boll numbers are higher than other treatments (5% level of significance).

Figure 2.5.12: Square Development Patterns Following Application of Pix and/or Nitrogen to Simulated Hail Damaged Cotton - Auscott Narrabri (Field 10) 1993/94

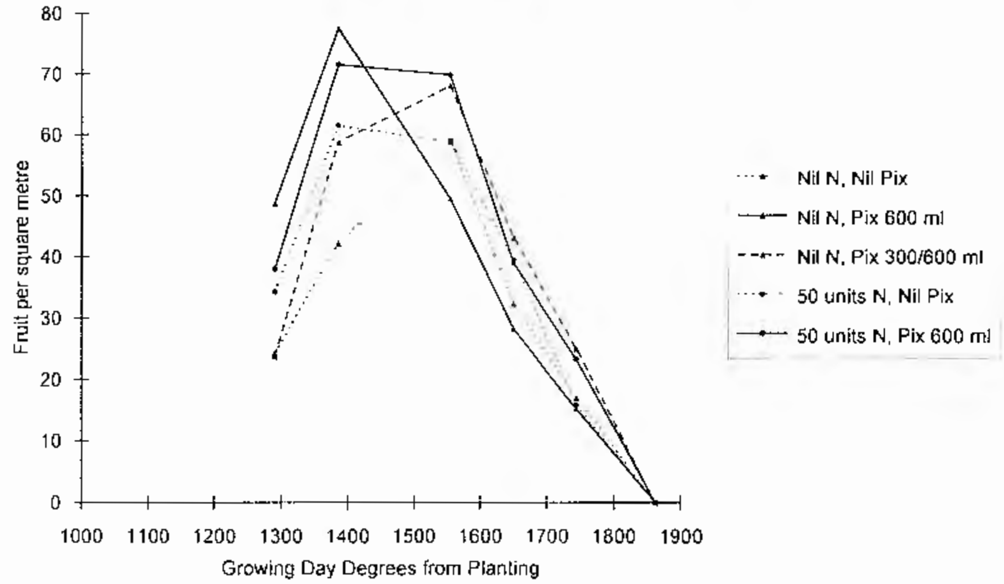
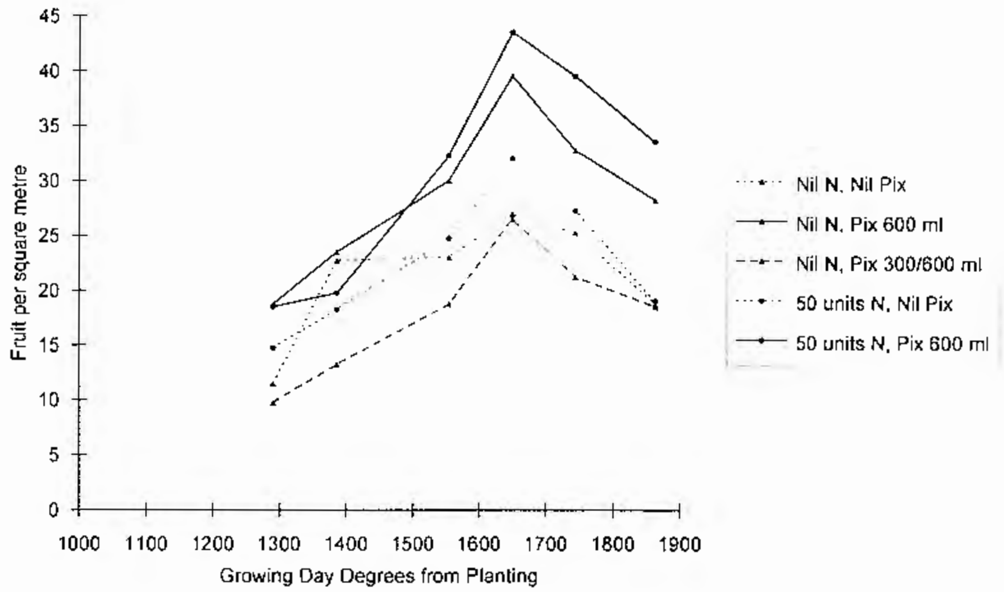


Figure 2.5.13: Boll Development Patterns Following Application of Pix and/or Nitrogen to Simulated Hail Damaged Cotton - Auscott Narrabri (Field 10) 1993/94



b. Lint Yield Response of Simulated Hail Damaged Cotton to Application of Pix and/or Nitrogen

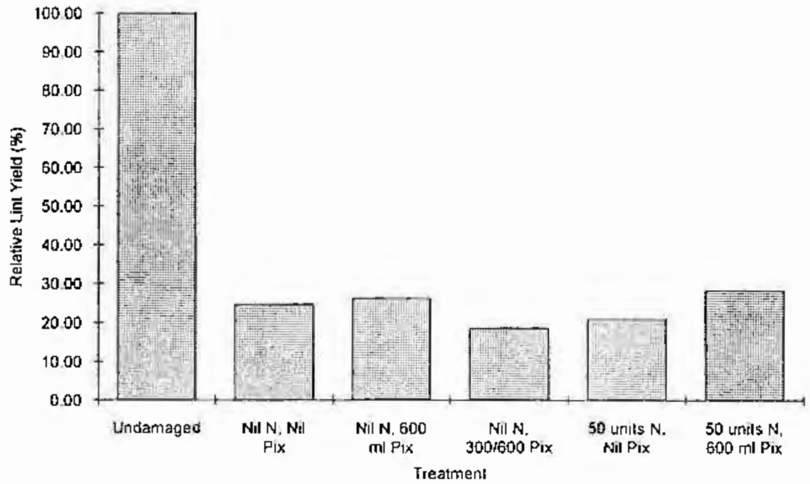
Analysis of overall final lint yield failed to show any significant differences between treatments imposed over damaged areas. The average lint yield of all damaged plots was 295 kg/ha (1.32 ba/ha) compared to the undamaged average yield of 1246 kg/ha (5.54 ba/ha) (Table 2.5.8, Figure 2.5.14). This represents a yield loss of 76% compared to the assessed loss 14 days after the damage simulation of 62%.

Water stress and late season mite infestation curtailed the regrowth after the hail simulation and the setting and maturation of bolls in the damaged plots. Hence, the small numbers of squares set following damage did not go through to become pickable bolls. Only bolls set prior to the hail simulation and left undamaged by the simulation would contribute to final yield.

Table 2.5.8: Lint Yield Following Application of Pix and/or Nitrogen to Simulated Hail Damaged Cotton. - Auscott Narrabri (Field 10) 1993/94

	LINT YIELD	
TREATMENT	kg/ha	ba/ha
Undamaged Control	1246.18	5.54
Nil Nitrogen, Nil Pix	307.13	1.37
Nil Nitrogen, Full Pix	326.38	1.45
Nil Nitrogen, Split Pix	231.13	1.03
50 Units N/ha, Nil Pix	260.35	1.16
50 Units N/ha, Full Pix	352.75	1.57

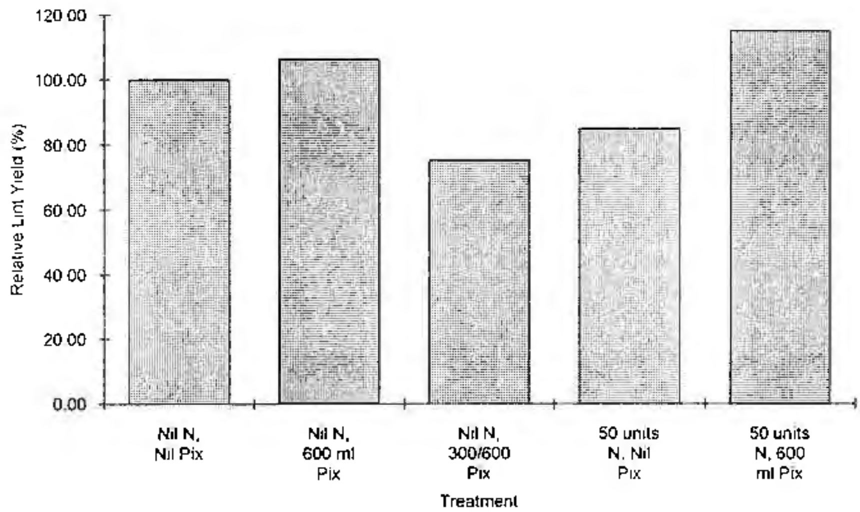
Figure 2.5.14: Lint Yield of Simulated Hail Damaged Cotton Relative to Undamaged Cotton Following Application of Pix and/or Nitrogen - Anscott Narrabri (Field 10) 1993/94



Of the management treatments imposed following the hail simulation, none produced a significant effect on yield. Although from Figure 2.5.15, which directly compares the management treatments, the lower yielding treatments were those where either no early Pix was applied or a low dose of 300 ml/ha was applied. These treatments were allowed to set squares at their own rate, whereas treatments where 600 ml/ha Pix was applied at first flower, vegetative growth was reduced and the crop was forced to set squares earlier. This has produced a slight yield advantage for treatments where 600 ml/ha was applied at first flower (Not statistically significant).

Boll size was not reduced by damage or affected by the management treatments.

Figure 2.5.15: Lint Yield Relative to Untreated Simulated Hail Damaged Cotton - Auscott Narrabri (Field 10) 1993/94



c. Effect of Application of Pix and/or Nitrogen on Maturity of Simulated Hail Damaged Cotton

The aim in using nitrogen and pix in these management strategies was to get the crop growing again after damage and then bring it to maturity before the end of the growing season. Using Date to 60% Open for each treatment as a measure of maturity, analysis has shown no significance between the treatments (Table 2.5.9). Regrowth was restricted by the lack of water to supply crop regrowth requirements but at such a late date of the simulated hail (ie. Growth Stage R9.9), regrowth is minimal and differences in treatment maturity would be expected to be minimal.

Responses of Simulated Hail Damaged Cotton in terms of Lint Quality Following Application of Pix and/or Nitrogen

Simulated hail damage and post hail management strategies employed in this trial did not affect lint quality in respect to fibre maturity, fibre strength, uniformity or micronaire. Differences between treatments for each of these quality parameters are not significant (Table 2.5.10).

Fibre length was found to be increased by hail damage compared to undamaged cotton (1% Level of Significance). But no differences in the affect of the management strategies was measurable. Cotton where hail was simulated also displayed a finer fibre than in the undamaged samples although fineness values are not significantly different in the analysis.

Usually you would expect to see a decrease in micronaire in hail damaged cotton as lint from immature bolls produced on regrowth lower the average micronaire of the lint sample. In this case, the regrowth did not produce pickable bolls and hence micronaire varied little from that of the undamaged samples. The micronaire of all treatments was lower than what would normally be expected at this site and with this variety. The low micronaire would most likely be due to the seasonal climatic conditions and water stress.

Table 2.5.9: **Auscott Narrabri (Field 10) 1993/94 - Treatment Maturity**

	MATURITY	
	Days to 60% Open from Planting	**Growing Day Degrees to 60% Open From Planting**
TREATMENT		
Undamaged Control	166.6	1868
Nil Nitrogen, Nil Pix	166.6	1868
Nil Nitrogen, Pix 600ml	166.9	1870
Nil Nitrogen, Pix 300/600 ml	167.7	1878
50 Units N/ha, Nil Pix	165.8	1860
50 Units N/ha, Pix 600 ml	166.0	1872

Table 2.5.10: Auscott Narrabri (Field 10) 1993/94 - Lint Quality

	QUALITY CHARACTERISTIC				
	Length (inches)	**Uniformity** (%)	**Strength** (Grams/tex)	**Elongation** (%)	**Micronaire** (Micrograms/inch)
TREATMENT					
Undamaged	1.123 *a*	82.28	30.18	5.48	3.000
Nil N, Nil Pix	1.173	83.70	31.85	5.73	2.900
Nil N, 600 ml Pix	1.180	84.15	31.10	5.65	2.925
Nil N, 300/600 Pix	1.178	83.00	31.58	5.70	2.475
50 units N, Nil Pix	1.185	84.18	31.43	5.43	2.725
50 units N, 600 ml Pix	1.185	83.73	31.65	5.70	2.825

NB: Values marked by *a* are significantly different from other treatments.

Results and Discussion (continued)

2.5.4: Site D - Australiau Cotton Research Institute (Field B2) 1994/95

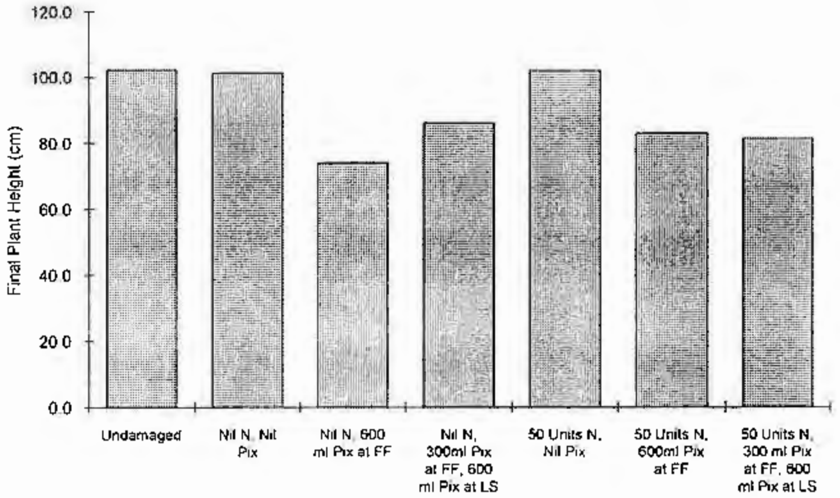
The three previously described trials combining nitrogen and pix treatments in managing regrowth in hail damaged cotton covered crops damaged in early growth stages (V3 and R1) and late growth stages (R9.9). With the possibility of a low incidence of hail again in the 1994/95 season, a hail trial using simulated damage was initiated to ensure that crops at growth stages intermediate between the previously tested growth stages could be trailed. Hence, hail damage was simulated at A. C. R. I. on a crop of Sicala V2 at the R2.8 growth stage. Simulated damage does not inflict the same "stress" factor as natural hail and regrowth is vigorous while weather conditions are conducive to growth and such conditions prevailed in 1994/95 (Appendix).

a. Vegetative Plant Development and Fruit Development Following Application of Pix and/or Nitrogen to Simulated Hail Damaged Cotton

Following simulated damage vegetative regrowth was rapid. Depending on the hail management treatment applied post damage, the plant compensated to produce plants either of equal height or reduced from that of undamaged cotton. Where no Pix was applied, with or without extra nitrogen, final plant height equalled that of the undamaged cotton (Figure 2.5.16). Pix applied at first flower at 600 ml/ha reduced final plant height to the greatest extent, while a split application of 300/600 ml/ha also reduced plant height but to a lesser extent (5% Level of Significance). The same rates of application of Pix also reduced plant height where extra nitrogen was added (5% Level of Significance). Regrowth in this trial was much more rapid than in the 1993/94 trials, but the moderate rates of 600 ml/ha Pix at first flower on regrowth or a split rate of 300 ml/ha at first flower followed by 600 ml/ha at Last Square adequately controlled vegetative growth even where excess nitrogen was applied.

Following simulated hail damage, peak squaring was delayed in damaged treatments by approximately 550 GDDs compared to undamaged cotton and reached similar levels (Level of Significance 5%). No differences were measured in either square numbers nor time to peak squaring between simulated damage treatments. Similarly no differences were measured in boll numbers between simulated hail treatments (Figures 2.5.17, 2.5.18). From this we can conclude that although delayed in development, the simulated hail treatments all compensated for the damage and produced similar final fruit numbers to the undamaged cotton, with no one treatment producing more fruit than another.

Figure 2.5.16: **Plant Height Development Following Application of Pix and/or Nitrogen to Simulated Hail Damaged Cotton. - A.C.R.I. (Field B2) 1994/95.**



Fignre 2.5.17: Square Development Patterns Following Application of Pix and/or Nitrogen to Simulated Hail Damaged Cotton - A.C.R.I. (Field B2) - 1994/95

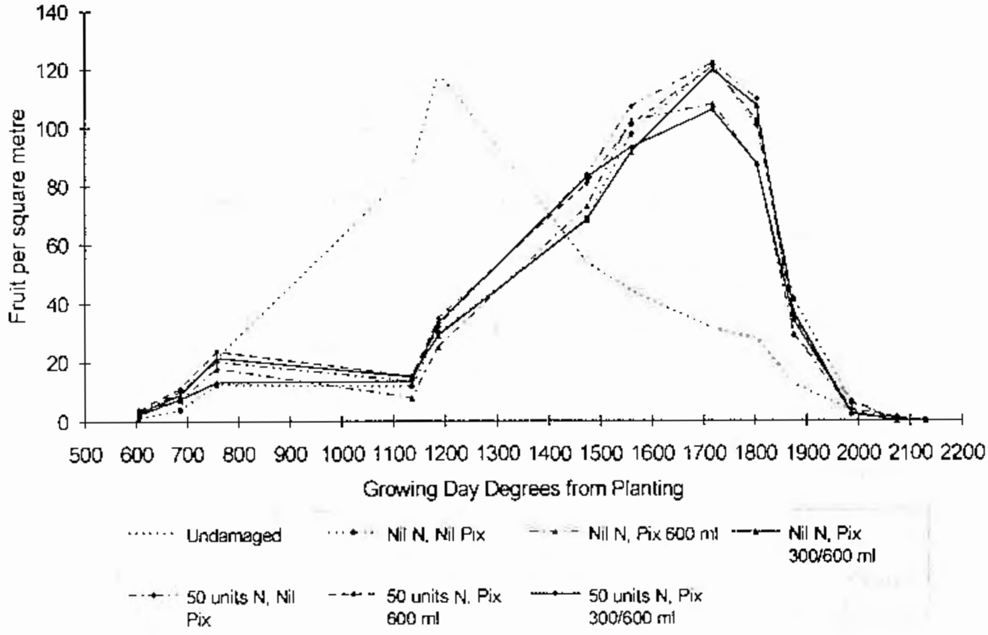
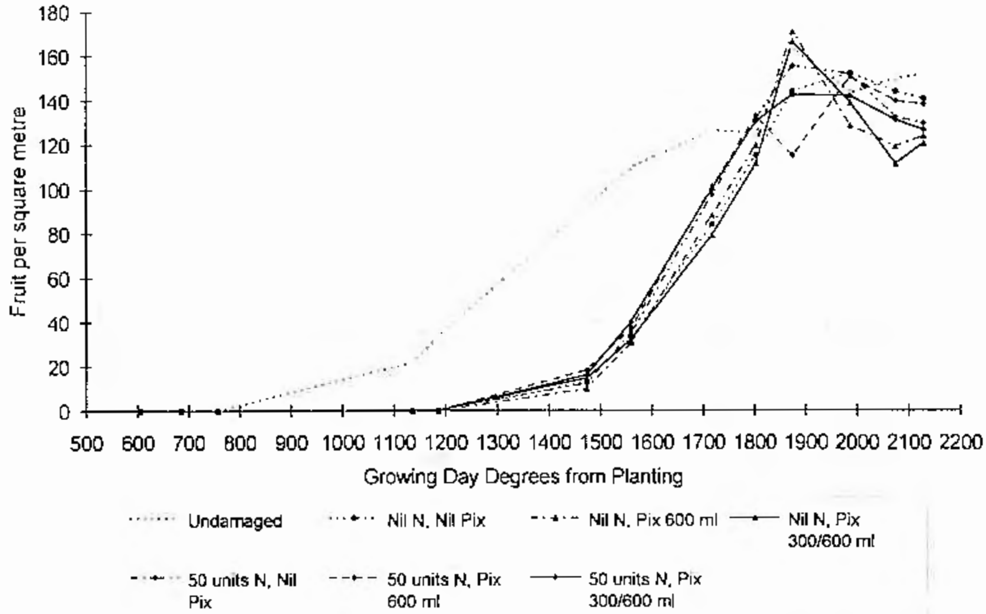


Figure 2.5.18: Boll Development Patterns Following Application of Pix and/or Nitrogen to Simulated Hail Damaged Cotton - A.C.R.I. (Field B2) - 1994/95



b. Lint Yield Response of Simulated Hail Damaged Cotton to Application of Pix and/or Nitrogen

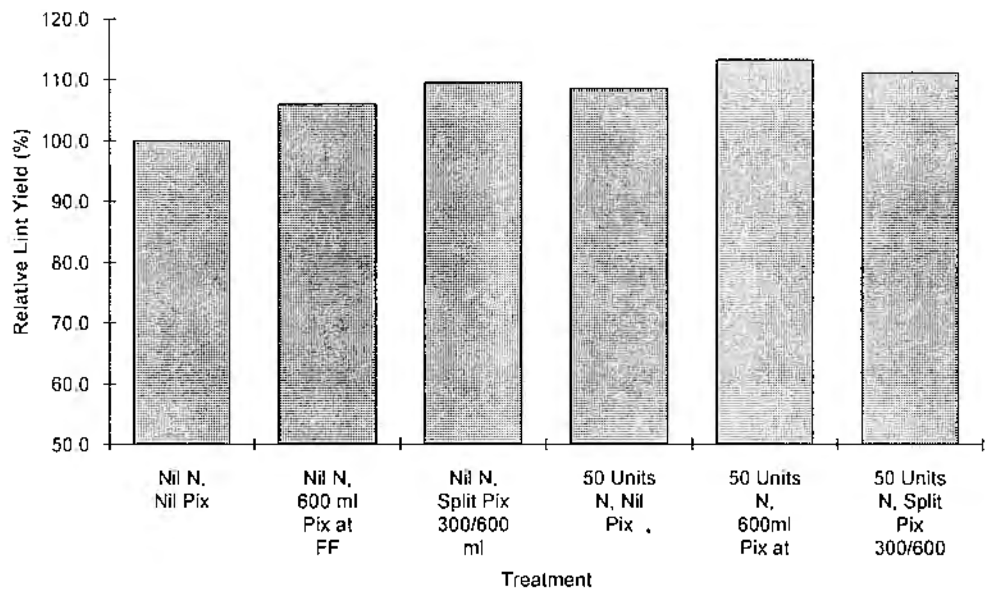
The undamaged cotton on average outyielded the cotton damaged by simulated hail by 44.6% (Table 2.5.11). But differences in lint yield between the separate treatments following simulated hail were not significant, even though the top yielding treatment (50 units N with 600 ml/ha Pix) showed a 13% yield advantage over the nil nitrogen/nil Pix treatment (Figure 3.21).

Table 2.5.11: Lint Yield Following Application of Pix and/or Nitrogen to Simulated Hail Damaged Cotton.
- A. C. R. I. (Field B2) 1994/95

	LINT YIELD	
TREATMENT	kg/ha	ba/ha
Undamaged	2654	11.80
Nil Nitrogen, Nil Pix	1739	7.73
Nil Nitrogen, Pix 600ml	1842	8.19
Nil Nitrogen, Pix 300/600 ml	1904	8.46
50 Units N/ha, Nil Pix	1885	8.38
50 Units N/ha, Pix 600 ml	1968	8.75
50 Units N.ha, Pix 300/600 ml	1931	8.58

NB: Differences not significant

Figure 2.5.19: Lint Yield Relative to Untreated Simulated Hail Damaged Cotton.
- Australian Cotton Research Institute (Field B2) 1994/95



c. Effect of Application of Pix and/or Nitrogen on Maturity of Simulated Hail Damaged Cotton

The management strategies employed in this trial did not have any significant effect on decreasing the delay in development caused by the hail damage. No difference in maturity was measured between damage treatments, while the undamaged cotton was mature 53-67 GDDs (14-16 days) before the damaged treatments (Table 2.5.12).

Table 2.5.12: A.C.R.I. (Field B2) 1994/95 - Treatment Maturity

	MATURITY	
	Days to 60% Open from Planting	Growing Day Degrees to 60% Open From Planting
TREATMENT		
Undamaged	182.2 *a*	2185 *a*
Nil Nitrogen, Nil Pix	198.0	2248
Nil Nitrogen, Pix 600ml	198.0	2249
Nil Nitrogen, Pix 300/600 ml	197.5	2245
50 Units N/ha, Nil Pix	198.2	2252
50 Units N/ha, Pix 600 ml	196.5	2238
50 Units N, Pix 300/600 ml	197.0	2242

NB: Treatments followed by *a* are significantly different from other treatments.

d. Lint Quality Responses to Hail Management Treatments

According to varietal records, Sicala V2 has an average fibre length of 1.14 inches, fibre strength of 30 grams/tex, length uniformity of 83% and a micronaire of 4.1. In this trial, fibre length was better than the average for both undamaged and simulated hail damaged cotton. Fibre uniformity was also marginally higher across all treatments. Fibre strength was improved on average and tended to be higher for treatments where Pix was applied at first flower at a rate of 600 ml/ha, but analysis showed this difference to be not significant. Micronaire was reduced compared to the historical average value in both undamaged and damaged cotton and all treatments fell within the discount range. This was probably due to the fact that water supplies were stretched out to the maximum possible through the season (Table 2.5.13). The undamaged cotton and Nil N/Nil pix treatments had, marginally higher micronaire than other treatments (5% Level of Significance).

Table 2.5.13: A.C.R.I. (Field B2) 1994/95 - Lint Quality

	QUALITY CHARACTERISTIC				
	Length (inches)	Uniformity (%)	Strength (Grams/tex)	Elongation (%)	Micronaire (Micrograms/inch)
TREATMENT					
Undamaged	1.22	84.88	31.23	5.33	3.48
Nil N, Nil Pix	1.19	84.20	30.35	5.75	3.33
Nil N, 600 ml Pix	1.19	84.80	34.10	5.95	2.70
Nil N, 300/600 Pix	1.21	85.18	31.70	5.58	2.70
50 units N, Nil Pix	1.21	85.10	32.08	5.98	2.70
50 units N, 600 ml Pix	1.19	83.68	33.18	5.70	2.65
50 Units N, Pix 300/600 ml	1.20	85.00	31.40	5.60	2.73

Conclusions:

Both the Myall Vale and Leitch's sites incurred damage at a time which correspond to the latest recommended replant date and seasonal conditions were not advantageous to rapid establishment of a new stand and so replanting was not an option. Damage was shown by assessment to be at maximum payout levels. At these sites, the severely damaged areas formed only a small part of the fields concerned and so growers management decisions were based on the less damaged and larger part of the fields.

The management strategies employed in the trials were designed around encouraging and controlling regrowth using nitrogen and then pix. Such strategies will only produce a response if climatic conditions have allowed regrowth in the first place. Both Leitch's and Myall Vale (Field 21) trials suffered due to the adverse conditions immediately following the damage and the severity of the damage meant new growth was slow and weak. When conditions later improved, the crop began to grow quite vigorously but due the limited growth season remaining the crop did not yield up to it's original potential. Climatic conditions and severity of damage have dictated that recovery in these trials was to be minimal and so any management strategy employed would have had minimal effect on increasing recovery.

In the case of Auscott Narrabri (Field 10) in 1993/94, regrowth is found to be minimal due to the late growth stage at the time of damage. Yield recovery was then further reduced by late mite infestation and restricted water supply. Under these conditions the growing season has been further and dramatically reduced. Management strategies which act to encourage the earliest and maximum squaring and fruit set rate have produced the largest yield recovery, although differences were minimal and not statistically significant.

With damage at an earlier date such as at the A.C.R.I. 1994/95 site, more time is available for compensatory growth and with optimal climatic conditions as experienced at this site, recovery was good. As late set and developing bolls in the most delayed of treatments have sufficient time to mature, any earliness and hence yield advantage of treatments incorporating Pix is reduced. All pix and nitrogen combinations improved yield recovery over the control where no nitrogen or pix was applied to damaged cotton, but yield increases were not large and were statistically not significant. The larger increases were produced where growth was encouraged by application of nitrogen but then managed with applications of Pix. In this situation a grower should weigh up the possible yield increase from the application of Pix and nitrogen against the actual returns from the small yield increase.

2.6: Case Studies on Mid-Season Hail Damage in Australian Cotton Crops (1993/4 - 1995/96)

2.6.1: Introduction:

Once past the last economically viable replant date, growers in all but the most severe hail damage situations, will choose to proceed with a damaged crop and attempt to maximise lint yield in the season remaining. Although the crops will regrow following the damage, the degree of recovery rapidly declines to zero at last square date.

Where hail damage covered the smaller part of a management unit, growers elected to manage the hail damaged area according to the management requirements of the undamaged part of the field or management unit. This also applied to crops where the hail damage occurred in an uneven pattern, inflicting damage for example across a tail or head ditch section of a field and making separate management strategies for damaged and undamaged areas impossible to implement. Crops were managed as per undamaged cotton where hail damage was considered light.

Where the hail damage covered the larger part of the crop management unit, changes in management were possible and necessary to maximise yield following the hail damage. Growers employed different strategies to regrow crops following the damage. Growers were either willing to risk that the growing season will be longer than the historical average and attempt to push out production past the usual crop cut out or last square dates for their area or in contrast, growers regrew the crops keeping in mind the average last flower dates for their area and attempted to achieve maximum yield recovery within this restricted growing season. Both scenarios rely on good weather conditions immediately following damage to allow rapid repair of damaged plant material and rapid regrowth.

2.6.2: Mid-Season Hail Damage in Dryland Cotton

Only a limited number of dryland crops incurred mid-season hail damage during the period covered by this work. Case studies were collated on those crops where damage covered a large enough portion of the crop or were sufficiently severe to require a change in crop management.

All growers attempted to regrow the crop, weather conditions played a part in their success in maturing the fruit set following the damage. For example in 1993/94, late rain on the Liverpool Plains allowed late regrowth but with mid-January hail damage, there was no time for the regrowth to reach maturity and heavy discounts were imposed on hail damaged cotton due to low micronaire. With hindsight, growers were of the opinion that high doses of Pix applied earlier in the regrowth period would have reduced the late vegetative regrowth and reduced the problem. In contrast, with a dry maturation period for regrowth on the Darling Downs in 1994/95, although crop development was delayed 2-3 weeks, lint matured and low micronaire was not a problem. Note that rain did eventually delayed picking of the crops once mature and colour discounts were imposed.

1995/96 provided some interesting comparisons between both dryland and irrigated crops and hail damaged and undamaged cotton crops. Wet weather conditions in late November, December and early January saw prolonged waterlogging in irrigated crops. Floods further impacted on production in the McIntyre valley. Dryland crops in many cases were on undulating and lighter country and were better drained through this period and suffered less waterlogging and responded more rapidly when warmer and drier weather arrived in January. Indeed at this time dryland crops were estimated to have a higher yield potential than some irrigated crops in the affected areas.

Hail strikes occurred in a number of areas occurred on 18/12/95. Dryland crops responded differently depending on the weather immediately following the damage. On the Darling Downs, rain continued and waterlogging prevented rapid regrowth. Moderate and drier conditions in early-mid January in the McIntyre and Namoi valleys produced good regrowth.

In deciding to proceed with the hail damaged crops, growers were accepting that insect control and other management would be continued and hence, full insecticide programs were implemented and hail damaged cotton required 1-2 extra insecticide sprays than undamaged cotton. These sprays were applied late in the growing season and were typically of a 'heavier' type eg. Talstar, Larvin, Parathion and/or curacron. Thresholds were not necessarily lowered but attention was paid to timely and accurate application of sprays.

Foliar sprays of nitrogen and in some cases iron were applied to boost nutrient supplies where wet weather conditions followed the hail damage and where growers were attempting to maximise the regrowth response within a reduced growing season.

Pix was applied by most of the dryland growers following the hail damage. Although growers were cautious in the timing of application and in the rates of Pix used as they were keeping in mind the potential hazard of applying Pix and then running into moisture or heat stress. Pix was applied, on average, four weeks after the hail damage as leaf area was replaced and squaring was re-initiated. Where growers used a single application of Pix, a rate of 400-600 ml/ha of Pix was used and was intended to stop late vegetative growth. Split applications were used where growers wanted to peg back vegetative regrowth in the early stages following damage without stopping growth and then apply second application to stop late vegetative growth or alternatively where late vegetative growth was anticipated due to late rain. Typical rates were 150 ml/ha for first applications and 500 ml/ha for second applications. The single application of Pix was successful in controlling vegetative growth where regrowth was not excessive. But on the Darling Downs rain periods continued following damage and control of vegetative regrowth was difficult and in hindsight, split applications of Pix may have been more successful along with closer monitoring of rates of growth early in the regrowth period. Defoliation was also difficult in the Darling Downs crops.

Defoliation was delayed up to 14 days compared to undamaged cotton but this did not pose problems where vegetative growth had been controlled. Moderate temperatures during autumn allowed lint to mature fully and severe depletions in micronaire were not recorded except on the Darling Downs as previously described.

2.6.3: Mid-Season Hail Damage in Irrigated Crops

As previously mentioned the success of the strategy for regrowing a crop following mid-season damage depends on good weather conditions following damage. This is clearly illustrated in irrigated cotton crops struck by hail during the mid-season period from 1993/94 to 1995/96. Hail strikes were few in the mid-season period which we were interested in covering.

Although drought conditions saw limited water available for irrigation purposes in 1993/94 and 1994/95. Other than the water situation, optimum conditions for regrowth occurred following hail damage. In the Macquarie valley, good yield recovery was achieved following moderate level damage. This was the only valley with adequate water supplies and hence, hail damaged crops were watered as required and with adequate nitrogen underneath, regrowth was rapid and vigorous. Although insect spray thresholds were not tightened across the board, it should be noted that crops were attractive to insects very soon after the damage and timely application of insecticides was important. In the documented cases, high doses of Pix were required (up to 1500 ml/ha in split applications were required to control vegetative regrowth. With moderate weather conditions in the late season even though delayed in development, crops recovered and matured and losses in yield and lint quality were minimised.

In a contrasting study in the same season, in the shorter growing season of the Liverpool Plains, regrowth did not mature and high discounts were imposed for low micronaire in a hail damaged crop. This crop had been resown following unsuccessful original establishment and hence was already late in development for the area. Not anticipating replanting or hail damage, sufficient nitrogen had been applied prior to planting for a full season yield potential. It proved to be very difficult to manage in respect to vegetative growth.

From the case studies collated in 1994/95 and 1995/96, it is obvious that growers made conscious decisions to promote the regrowth of their hail damaged crops. But once regrowth was initiated and the season progressed, growers either made conscious decisions in regard to how to manage the regrowth, or others allowed the weather conditions etc. to dictate the action they took.

In the Emerald area, part of the nitrogen requirement of crops is commonly applied post planting as side dressed or water run urea. Immediately following hail damage in 1994/95, growers applied 50-60 units of nitrogen in such a manner and watering their crops as soon as possible after the damage to reduce stress even though water was limited for irrigation for the season. Or where adequate nitrogen was present under the crop prior to damage, the damaged areas were given a boost by applying eg. 6 kg/ha nitrogen as foliar N. Traditionally, little Pix is used in the Emerald area. Some growers did consolidate fruit set with a low application of Pix (eg. 250 ml/ha) once regrowth was initiated. Although some good early regrowth was observed, crops did not compensate well due to the late stage of growth at the time of damage (for the production area) and due to inadequate water supplies available to water the crops to their full requirements. Growers did not or could not chase late bolls due to lack of water and the cost of late spraying.

In other production areas, heavy rain with hail storms and following rain saw prolonged waterlogging following mid-season hail. In these situations regrowth was not vigorous or rapid and growers attempted to promote regrowth with the application of foliar fertilisers. Foliar nitrogen was applied as eg. Easy N at rates of 10-20 units N to overcome nitrogen deficiencies induced by waterlogging and were applied as soon as sufficient leaf area was replaced to allow uptake of the fertiliser. Foliar fertiliser mixes such Ocean Fish, Triple 7 and Megamix were applied attempting to alleviate the stress imposed by the hail damage and waterlogging and to 'kick start' regrowth.

Once regrowth was initiated vegetative growth and fruit set was managed using growth regulators. In less waterlogged crops where regrowth wad been initiated at a moderate rate, split applications of Pix were applied early in the regrowth period between 4 and 6 weeks after damage with the aim of consolidating fruit set, then a second rate being applied to 'pull up' the crop and reduce the delay in maturity. This second application being applied anywhere between last square and last flower date for the crops studied. Typical Pix rates used in first applications were 300-350 ml/ha, and 350-500 ml/ha of Pix in second applications. (Second applications of Pix were not generally required in comparable undamaged crops).

But in the majority of cases covered in 1994/95 and 1995/96, early regrowth following damage was reduced due to the waterlogging no early applications of Pix was used. Crop development was delayed and to attempt to reduce crop lateness, Pix was used to 'pull up' the vegetative growth of the crops and hence, by default induce cut out. Pix was applied at varying times and rates depending on what the grower was trying to do with the crop.

The limited number of growers following a management strategy, indicated that they attempted to 'pull up' the crop by last flower date so as to allow the bolls set on regrowth to fully mature within the growing season remaining and hence, had applied Pix between last square and last flower dates. These growers were electing not to attempt to extend cut out and push the crop past the average climatic end to the season. In other crops, application dates for Pix were much delayed and applications were made too late to effectively reduce late vegetative growth. Application rates ranged from 600 ml/ha to 1300 ml/ha. Higher rates were used where growers nominated they were attempting to 'pull up' the crop.

No growth regulators were required in a limited number of crops which displayed no excessive vegetative growth due to the advanced physiological growth stage of the crop at the time of damage and the weather conditions which regulated the vegetative growth of the crop.

Note that in 1995/96 in the McIntyre valley, fruit set in all crops (hail damaged or not) did not begin until approximately mid-January when rain, floods and waterlogging eased. The general weather conditions for the season were the overriding factor posing problems for crop management rather than the hail. All crops were late and according to discussions with consultants were similarly managed.

On average, no extra irrigations above those applied to undamaged crops were required in the 1994/95 and 1995/96 case studies due to in season rain. But differences in management strategies now became obvious as increased production costs were now incurred by those growers who elected or were forced to push the crop extending cut out and now required to mature all late bolls set on regrowth. 1-2 late insecticides (mostly Larvin or curacron) were required to protect late set fruit. Clear and dry weather did enable good defoliation to be achieved in these crops but in 1994/95 the delay in defoliation of 2-6 weeks exposed the crops to late rain and picking was further delayed. Returns were heavily discounted for low micronaire and then colour discounts were imposed due to rain damage with total discounts in some cases totalling up to $220 per bale.

Where crops cut out at approximately the average last flower dates for the respective production areas due to either 1. the growth regulator strategy used, or 2. the lack of regrowth due to weather conditions or physiological growth stage of the crop at the time of damage or 3. due to the growers decision not to chase all late set bolls; although development may still have been delayed an average 2 weeks due to the hail damage but defoliation occurred under good conditions and few crops caught by the rain. Penalties for low micronaire were not as significant in these crops due to the lower proportion of bolls in a given sample being set on regrowth and maturing under deteriorating climatic conditions.

Climatic conditions following damage have played an important part in the successful management of the hail damaged crop but implementation of decisive management strategies has played a part in curbing production cost increases and reducing defoliation, picking and lint quality problems.

2.7: Discussion Points and Guidelines in Managing Mid-Season Hail Damage in Cotton

A few points should be kept in mind when regrowing a cotton crop following mid-season hail damage.

1. The hail damage has removed part or all of the yield set as bolls to the date of the hail strike.
2. There is a reduced season available to the grower over which to replace lost yield and a reduced overall crop yield potential.
3. Costs have been incurred in getting the crop to the stage of growth at which it was at the time of damage.
4. Costs will be now be incurred to regrow and mature the crop following the damage.
5. In regrowing a crop following hail damage, crop development is pushed into a later part of the growing season.
6. Growing late season crops involves problems with late watering, late insect control in a period of the season when insect control is difficult and expensive, late set bolls are maturing under cooler conditions and hence time to maturity is extended and lint quality problems are inherent, defoliation of late crops is difficult under the cooler conditions.

Case studies show that not all these points are taken into account when growers are regrowing a crop following mid-season damage. Growers are often overly optimistic as to how much quality cotton can be produced in the reduced growing season. Many growers attempt to regrow the same yield that they were expecting prior to the hail strike and incur a series of problems and extra costs. Water, nutrients and growth regulators are thrown at crops in attempts to get crops growing following hail damage and then if successful growers then need to pull up and mature the crop - a difficult proposition when climatic conditions override much of the management implemented and the strategies employed in attempting to manage a hail damaged crop

The suggested strategy is to attempt to replace a realistic proportion of the original yield potential and mature it within the growing season which remains available whilst containing input costs and hence reducing the overall financial loss.

According to case studies, the growers who have been more successful in replacing lost yield potential whilst containing increases in production costs have been those who have attempted to regrow the damaged crop within the average 'climatic limits' of their growing season without attempting to extend cut out dates, forsaking part of a potential yield recovery for more complete maturation of the fruit set and hence reducing the large discounts for low micronaire cotton and reducing the chances of adverse weather conditions affecting defoliation and picking.

Typically, management of the regrowth of damaged cotton in case studies involved watering only as the crop required, protection of all fruit initiated on regrowth with particular attention to early regrowth where some growers used tighter thresholds than normally used. Most crops studied had a full normal crop's requirement of nitrogen applied prior to the hail strike and no further nitrogen fertilisation was used. Foliar nitrogen and/or foliar mixes of micronutrients were widely used to boost regrowth following the stress of hail and especially under waterlogged conditions.

Where early regrowth occurred at a moderate to vigorous rate, pix was applied to reduce the rate of vegetative regrowth and encourage early fruit set on regrowth. But in a majority of the case studies collated, weather conditions immediately following damage were not conducive to rapid regrowth and pix was not applied within the first 4-6 weeks of regrowth. In these situations pix was used to reduce late vegetative growth and 'pull up' crops to encourage earlier maturation of fruit on regrowth. Large reductions in fibre micronaire due to immature bolls in the pick were only avoided where late application of pix was made between last square and last flower dates and the maturity of the crop was advanced sufficiently by the growth regulator treatment or where growers had made the decision not to attempt to chase late set bolls. Defoliation was easier where the vegetative growth and maturity of crops was pegged back by growth regulators or water usage strategies and hence were able to avoid some of the late season adverse weather conditions.

With the aim being to get the crop regrowing following hail damage and then maturing it in the remaining season available, nutrients and growth regulators can play an important part in managing a hail damaged crop. In this part of the study, a series of field trials concentrating on these two areas of management were carried out on hail damaged crops.

Nitrogen Fertilisation of Hail Damaged Cotton Crops

The nutritional status of a crop is of primary importance in determining the ability of a crop to recover from hail damage. The aim with nitrogen fertilisation should be to obtain a maximum yield while minimising the problems of rank growth and delayed maturity.

Following hail damage, growers have used a variety of fertiliser strategies with varying results. Crops have been left to regrow on the pre-existing nitrogen level, or nitrogen and other nutrients have been applied in small and large amounts to replace or boost nutrient levels in the crop. Resulting problems have included lack of regrowth due to less than optimum nutrient levels or excessive vegetative growth adding to the lateness and delayed maturity of hail damaged cotton.

Crop growth stage at the time of damage and the timing of the hail strike within the available growing season dictated the amount of regrowth that could be expected following the hail strikes. Mature cotton has a reduced requirement for nitrogen as regrowth following damage is minimal compared to younger cotton following hail damage. Crops at a less mature growth stage at the time of damage under optimum weather conditions will initiate vegetative regrowth quickly and hence will have a greater nitrogen requirement.

Petiole nitrate levels were monitored in a series of hail damaged cotton crops to identify deficiency or stress as regrowth occurred. At each of these sites, nitrogen applied prior to the hail strike was considered adequate for production of a normal cotton crop. Following the hail strike, petiole nitrate levels and the rate of decline of petiole nitrate indicate that nitrogen was not limiting for growth. Hence, further nitrogen fertilisation would not have increased yields. Only where prolonged waterlogging was imposed on young cotton attempting to regrow following damage, did nitrate levels decline at critical rates. Hence, monitoring the rate of decline of petiole nitrate in hail damaged cotton could be used to identify possible nitrogen deficiency.

As problems will arise in supplying nitrogen deficiency where weather conditions do not make application of nitrogen practical, it is suggested that as a rule larger quantities of nitrogen will probably only be required where insufficient for normal growth was applied prior to the hail strike or where conditions make the existing nitrogen inaccessible to the regrowing crop.

Extending this idea, with a crop damaged by hail prior to the application of its full nitrogen requirement, a suitable site was available to test the response of a hail damaged crop to varying rates of applied nitrogen fertiliser. Although uptake and utilisation of nitrogen and other nutrients was hampered by climatic conditions and crop regrowth and lint yield were reduced in the trial and prevented full conclusions being drawn as to the response of the crop to applied nitrogen, petiole sampling results indicated that nitrogen would have been a yield limiting factor for the nil nitrogen treatments under normal growing conditions. Application of sufficient nitrogen to bring levels up to the normal crop requirements brought petiole nitrate readings above critical levels. Addition of nitrogen in excess to a normal crop's requirement saw no further improvement in nitrogen uptake and it is suggested this application was excess to the requirements of the crop.

Foliar Fertilisation of Hail Damaged Cotton

Foliar fertiliser mixes are often applied to boost micronutrient levels in high yielding crops or to alleviating part of that stress imposed by waterlogging, hail damage etc. The foliar application of zinc and a micronutrient mix were compared as means of alleviating the stress imposed on cotton by hail damage in two trials. The trial data suggests that the foliar zinc assisted in increasing early canopy regrowth and initiation of the squaring and fruiting phases following the hail damage, with the areas not treated with zinc being delayed in development in comparison. But this is not suggesting that the application of zinc to any hail damaged crop will assist in the early recovery of the crop as these fields showed marginal zinc levels in tissue tests carried out immediately following the hail strike. It is suggested that the applied zinc and micronutrient mix alleviated the deficiency pre-existing in the field or a zinc deficiency induced by climatic conditions, contributing to earlier replacement of leaf area in zinc treated areas. Further work is needed to look at the effect of applied zinc and foliar micronutrient mixes on hail damaged cotton in fields where zinc is not expected to be a limiting factor to growth.

Use of Growth Regulators in Management of Regrowth of Hail Damaged Cotton

Control of the rate of vegetative growth by the use of growth regulators should be important in maximising the setting, retention and maturation of fruit following hail damage. In managing the growth of cotton following hail damage, we are attempting to prevent vegetative growth from becoming excessive so as to maximise early fruit set on the regrowth. Hail damaged cotton is delayed in development ie. late cotton and so, the second aim in managing the regrowth of hail damaged cotton, is to mature whatever fruit are set before the climatic end of the season.

In terms of reducing vegetative plant vigour, a stronger response to Pix was measured in cotton damaged at a younger growth stage and regrowing under good growing conditions. The largest reductions in plant height (ie. vegetative vigour) were measured where Pix application treatments were made early in the regrowth phase (First Flower on regrowth). By leaving Pix application to Last Square Date, vegetative growth was reduced compared to using no Pix, but Pix was more effective in reducing vegetative vigour when applied in a split rate with the first application at first flower and the second at Last Square or the single rate at First Flower previously described.

When we look at yield recovery, with early hail damage and only moderate weather conditions rather than optimum following the hail strike, the greatest yield recovery was measured where Pix was applied at Last Square Date, with added earlier application of 300 ml/ha Pix at First Flower increasing the response at some sites. Here, the strategy has been to let the crop to regrow largely at its own rate, then stopping late vegetative growth with the dose of Pix at Last Square. But with good growing conditions following early hail damage, ie. optimal for growth, some pegging back of vegetative growth by First Flower application of Pix has been shown to be an advantage in terms of increased yield.

With damage in the earlier growth stages, although Last Square applications of Pix produced the greater yield recovery. these same applications produced the most delayed cotton. If part of the recovered yield is compromised, a First Flower application of Pix at eg. 300 ml/ha (single or spilt application) will increase earliness and may be the more economic decision when taking into account discounts for low lint quality which may be imposed with late maturing cotton.

In a number of the trials conditions were not optimum for growth following damage and under these poor to moderate growing conditions, high rates of Pix would not normally be used commercially and in these trials it was shown that such rates produced no additional effect on plant height. The higher doses of Pix at First Flower (600 ml/ha) were detrimental to lint yield and no advantage was found in applying higher doses at Last Square. With hail damage at late growth stages, no yield advantage was found in applying Pix.

In situations where there was insufficient water supplies to allocate extra water to a hail damaged crop to allow it to regrow to its full potential, higher rates of Pix, as single and split applications, were more advantageous. Higher rates decreased early vegetative growth to a greater extent and forced more rapid fruiting in the limited time available. Although, had sufficient water been available, a greater yield recovery would have occurred with a less harsh growth regulator treatment. Similar situations occur where picking schedules for a management unit do not allow separate defoliation of the hail damaged section of the management unit and hence, the hail damaged cotton is not able to go through to full maturity.

With the current discounts for low micronaire cotton, lint quality is a factor of importance in growing both hail damaged and late cotton. If we aim to get the crops regrowing after hail and set maximum fruit numbers before last square date and then mature the fruit before first frost, then we are also aiming to increase the lint quality as we should be picking more mature lint. As the cotton is maturing under cooler conditions micronaire will be a problem, but if growth regulator strategies combined with other management strategies are able to bring the crop in as early as possible then micronaire problems will hopefully be reduced.

Further trialing of the strategies is required to collate more lint quality data as this series of trials failed to produce significant improvements in lint quality. Points to note would be that with late damage, micronaire is not as large a problem, as there is insufficient time to regrowth to contribute to yield, the cotton remaining after the hail and set before the strike contributes the larger portion of the lint sample and hence, as long as these bolls are left to mature fully then the micronaire is not affected. As we attempt to regrow a crop following earlier damage, we are growing a late crop and micronaire will be reduced in the late set bolls maturing under cooler conditions. Where a compromise between recovering maximum yield and crop earliness has been suggested as a cost recovery strategy in using early and split applications of Pix, by accepting a slightly lower yield in turn for an earlier maturity you should also be reducing lint quality problems.

In all of the trials described in this section on growth regulator use, prior to the hail damage, growers had applied the optimum amount of nitrogen for their expected yield (pre-hail). No nitrogen was applied post damage in excess of the normal crop requirement, except in one situation which was suffering prolonged waterlogging. Hence, vegetative regrowth was not excessive due to excess nitrogen. But vegetative regrowth would have been reduced at least four of the sites due to less than ideal weather conditions following the hail damage. Vigorous regrowth was only measured at three sites. Hence, further trialing may be required in situations where nitrogen usage has been excessive and where weather conditions are conducive to extremely vigorous vegetative regrowth. Higher rates of Pix may be necessary under these growing conditions.

PGR-IV is a new cotton growth regulator for management of vegetative and reproductive growth in cotton and was compared to Pix , to evaluate the potential use of PGR-IV in the management of regrowth of hail damaged cotton. PGR-IV is reported to have the capability of reducing plant height more than growth regulators such as Pix which act directly on cell elongation processes affect plant height to a greater degree. In this work, PGR-IV was found to reduce plant height compared to Nil Pix and Last Square Date applications of Pix, but failed to reduce plant height to the extent to which Pix applied at First Flower or in split applications. The lint yield response to PGR-IV was equivalent to that for untreated cotton. Pix 300 ml/ha at First Flower pegged back vegetative growth sufficiently to produce a yield advantage of 8-10% over PGR-IV and the Nil Pix treatments. Fruit counts and final boll numbers do not indicate significant differences in boll retention. PGR-IV did not act to improve or lower lint quality compared to Pix treatments. Under the conditions experienced in this trial, PGR-IV offered no advantage over Pix in the management of regrowth of hail damaged cotton.

Response of Hail Damaged Cotton to Applications of Nitrogen and Pix®

In examining the response of hail damaged cotton to applications of Pix as discussed in previous sections of this work, it has been suggested nitrogen levels in a crop also play a part in determining the rate of regrowth that can be achieved by a crop. Trials were designed to evaluate the combined use of nitrogen and Pix® (Mepiquat Chloride) in hail damaged cotton, with nitrogen used to encourage vegetative regrowth and followed by Pix to manage or control the regrowth. Such a management strategy will only produce a response if climatic conditions allow regrowth in the first place. Two trial sites suffered due to the adverse conditions immediately following the damage and the severity of the damage meant new growth was slow and weak and the combined nitrogen-pix strategies did not produce a yield response. Similarly, regrowth is found to be minimal with damage at late growth stages and minimal responses were measured to this type of strategy.

With damage at earlier dates, more time is available for compensatory growth and with optimal climatic conditions, recovery is good and late set and developing bolls in the most delayed of treatments have sufficient time to mature. Trial data showed that any earliness and hence, yield advantage of treatments incorporating Pix is reduced. All pix and nitrogen combinations improved yield recovery over the control treatments where no nitrogen or pix was applied to damaged cotton, but yield increases were not large and were statistically not significant. The larger increases were produced where growth was encouraged by application of nitrogen but then managed with applications of Pix. In this situation a grower should weigh up the possible yield increase from the application of Pix and nitrogen against the actual returns from the small yield increase.

Fertiliser and Growth Regulator Strategies for Hail Damaged Cotton

Following hail damage in the mid-season period, the suggested strategy is to attempt to replace a realistic proportion of the original yield potential and mature it within the growing season which remains available whilst containing input costs and hence reducing the overall financial loss. Hence, the aim would be to get the cotton crop regrowing following hail damage and maximise fruit set up to last flower date then maturing it before first frost. Nutrients and growth regulators play an important part in being able to implement such a management strategy for hail damaged cotton.

In regard to fertilisers and growth regulators the following points are of interest:-

1. Where adequate nitrogen for a normal crop's requirement of nitrogen has been applied prior to the hail damage, no indication of nitrogen deficiency has been measured in petiole nitrate monitoring of nitrogen levels in hail damaged cotton following a hail strike. This suggests that additional nitrogen is not required except under conditions where this nitrogen is made inaccessible to the crop such as in waterlogged situations.

2. The application of foliar nutrients is widely practised following hail damage as a means of boosting regrowth or preventing/overcoming micronutrient deficiency in the rapidly regrowing crops. Yield advantages in such applications are difficult to measure. But where a deficiency of a micronutrient pre-exists in a hail damaged crop or where climatic or soil conditions make the nutrient unavailable to the crop, foliar application of the nutrient was shown to increase the rate of early regrowth. Differences in yield responses were not measured.

3. Growth regulators such as Pix® (Mepiquat Chloride) have been found to be useful in managing vegetative regrowth following hail damage and in maximising fruit set on regrowth. Climatic conditions following the hail damage in these trials have not, in general, been such which have promoted extremely vigorous vegetative growth following the hail strike. Under these more moderate conditions, the recommended rates for use of the growth regulator have controlled vegetative growth and encouraged fruit set on regrowth. Under poor growing conditions, the higher recommended rates have been detrimental to regrowth and lint yield recovery.

4. Monitoring the rate of regrowth especially in the early period following damage is important in using a growth regulator such as Pix to manage regrowth following hail damage. Where weather conditions encourage moderate to vigorous early regrowth, an early application of Pix near first flower on regrowth has been found to be advantageous in pegging back vegetative growth and encouraging early fruit set. A later application at last square date provides extra control on vegetative growth where conditions have remained conducive to late growth. If weather or crop conditions are not conducive to good regrowth, by leaving the crop to regrow at its own pace and then pulling up the vegetative growth of the crop at last square date with the use of a growth regulator has been found to produce the greatest yield recovery. These same later applications produced the most delayed cotton. If part of the recovered yield is compromised, an early application of Pix (single or spilt application) will increase earliness and may be the more economic decision when taking into account discounts for low lint quality which may be imposed with late maturing cotton.

Chapter 3

Late Season Hail Damage

Where hail strikes occur late in the growing season there is no time remaining for the crop to regrow and in managing a crop post damage we are looking at rescuing what remains of the crop.

Every hail strike is different and the options or problems in managing a crop post damage are different in every case and this includes late season damage. During the period covered by this work, it was not until the final season that there were significant hail strikes in the later part of the season upon which to collate data. None of the sites were suitable for trials.

The severity of the late season strikes in irrigated crops necessitated quick management decisions to attempt to rescue cotton and in the dryland strikes, weather conditions post damage dictated crop response.

Case studies on each of the hail strikes were the best option for collating information on the management strategies employed by growers. Most of this discussion will centre on these case studies.

3.1 Effective Regrowth Following Late Hail Damage

At what point do we decide that no regrowth is possible following a hail strike? As in deciding on whether to replant or not following an early hail strike, heat units available are the key to the problem.

Square and boll maturation periods vary with temperature and are extended under cooler temperature regimes (Table 3.1). Under more optimum growing conditions with daily temperatures averaging 27 ^{0}C we would expect an average time for development for a square to flower to be approximately 20 days and the period from flower to open boll to be approximately 50 days. Dates of last effective flower, calculated based on date of first frost, were collated for use in the SIRATAC pest management package and are collated in Table 3.2. Past the last effective flower date, in the average season, a flower set as a boll will not be able to go through to full maturity without being hit by frost.

If the average square period is subtracted from the last effective flower date we can determine or estimate a last effective square date (Table 3.3). Following a hail strike if we are to regrowth the crop to any degree we require rapid initiation of squares following a hail strike and then rapid setting of squares within the squaring period remaining. Depending on the date of the hail strike, there may be little if any time remaining to set squares.

Immediately following a hail strike there is a period of 398-485 GDDs (Mean 448 GDDs) where no regrowth is measured as the plant is still in a stressed condition following the hail damage (West, 1996). This means a further decrease in time available for squaring following a hail strike. Subtracting a further period of 450 GDDs from the last effective square date would define an average date at which no fruit initiated on regrowth would be expected to mature in the average season (Table 3.3). Case studies show that when a hail strike occurs from this date on, in the average season no fruit set on regrowth contribute to yield. Of course, a grower may decide to take the risk that the season will be longer than the long term average and in the proportion of seasons which are longer than the average will see some fruit set on regrowth will mature.

Table 3.1: Day Degree Requirements for Square and Boll Development

	GDD	Days @ 22 ^{0}C	Days @ 27 ^{0}C
Initiation to 3mm	220	22	15
3mm to anthesis	300	30	20
Anthesis to maximum size	310	31	21
Maximum size to mature	365	37	24
Mature to fully open	75	8	5

Source: Hearn and Constable (1984).

Table 3.2: Effective Boll Setting Period as Set by Temperature

Region	First Flower *	Last Effective Flower*	Est. Last Effective Square
	(Start of Flowering 1st Oct. Planting)	(Limited by Frost)	(20 Days prior to Last Effective Flower)
Namoi	25-Dec	4-Mar	12-Feb
Gwydir	21-Dec	7-Mar	15-Feb
Macquarie	7-Jan	19-Feb	30-Jan
Lockyer	22-Dec	22-Mar	2-Mar
Darling Downs	25-Dec	6-Mar	14-Feb
St. George	10-Dec	15-Mar	23-Feb
Theodore	13-Dec	23-Mar	3-Mar
Biloela	13-Dec	23-Mar	3-Mar
Emerald	3-Dec	6-Apr	17-Mar
Mc Intyre	15-Dec	13-Mar	21-Feb
Bourke	10-Dec	15-Mar	23-Feb
Mungindi	10-Dec	15-Mar	23-Feb
Walgett	21-Dec	7-Mar	15-Feb
Boggabri	26-Dec	1-Mar	9-Feb
Breeza	7-Jan	19-Feb	30-Jan

* Source: SIRATAC Manual 1987.

Table 3.3: Estimated Date for Nil Effective Regrowth Following Hail Damage

Region	Last Effective Flower	Last Effective Square	Delay to Squaring Following Hail Damage	Estimated Date for Nil Effective Regrowth Following Damage
	(Limited by Frost)	(20 Days prior to Last Effective Flower)	Average 450 GDDs (or 30 Days @ 27^{0}C max . Temp.)	
Namoi	4-Mar	12-Feb	30 Days	12-Jan
Gwydir	7-Mar	15-Feb	30 Days	15-Jan
Macquarie	19-Feb	30-Jan	30 Days	30-Dec
Lockyer	22-Mar	2-Mar	30 Days	2-Feb
Darling Downs	6-Mar	14-Feb	30 Days	14-Jan
St. George	15-Mar	23-Feb	30 Days	24-Jan
Theodore	23-Mar	3-Mar	30 Days	3-Feb
Biloela	23-Mar	3-Mar	30 Days	3-Feb
Emerald	6-Apr	17-Mar	30 Days	17-Feb
Mc Intyre	13-Mar	21-Feb	30 Days	22-Jan
Bourke	15-Mar	23-Feb	30 Days	24-Jan
Mungindi	15-Mar	23-Feb	30 Days	24-Jan
Walgett	7-Mar	15-Feb	30 Days	15-Jan
Boggabri	1-Mar	9-Feb	30 Days	9-Jan
Breeza	19-Feb	30-Jan	30 Days	30-Dec

Using the dates generated by this exercise for estimates of dates for 'nil effective regrowth' following hail damage, 95 hail damage claims were recorded over the 1993/94 - 1995/96 cotton seasons in the Late Hail Damage category.

Crop damage claims lodged within the period covered crops ranging in development from late flowering to fully mature open crops and covered both dryland and irrigated crops. Management options implemented depended on whether crops were irrigated or dryland. Drought conditions in some valleys also limited the management options available for some irrigated crops.

Growth stage of the crop at the time of damage determines the physiological growth response that is possible following damage and also determines the management options a grower has available or may need to implement following late season damage.

All crops falling into this late season damage category were at or past cut out at the time of damage and limited growth would be expected following damage due to the physiological growth stage and due to the inadequate length of season remaining before first frost date.

Crops could be grouped as follows:-

1. Late Flowering ie. at or approaching cut-out/full boll load. (R12 Growth Stage)

2. R12+ Growth Stage with bolls ranging in maturity from small bolls in top crop to fully mature green bolls. Mature in hail loss assessment terms.

3. R12+ Growth Stage with boll load consisting mostly of mature green bolls. Mature in hail loss assessment terms.

4. R12+ Growth Stage with full boll load in various stages of boll opening. Mature in hail loss assessment terms.

Of the hail claims lodged, 27 claims were found to consist of light damage when assessed. These claims were below insurance policy excesses and were not proceeded with. A further 8 claims covered only minor sections of fields and hence did not cover a significant enough area of a crop to warrant a change in a crop management. Only four crops suffered damage significant enough to warrant abandonment of the crop and these will be discussed later.

Case studies were collated on the remaining crops where hail damage necessitated changes in management of the crop.

3.2 Late Season Hail Damage in Dryland Cotton Crops (1993/94 - 1995/96)

Crop damage was inflicted over a wide area of the Darling Downs from hail storms on February 13th, 1996. Crops had already been affected by heavy rain and some flooding during the early part of the season (November-December). Weather conditions had induced vigorous vegetative growth and combined with the heavy insect pressure which was experienced throughout the season resulted in poor lower canopy fruit set. The weather conditions made management of crop size and insect control difficult and expensive.

In the Dalby area, no rain was recorded following the hail strikes and dryland crops which were damaged by hail were cut-out by moisture stress. Hence, no vegetative or reproductive regrowth was recorded.

Most of the dryland crops in the Dalby area were at late flowering or cut-out at the time of damage (ie. category 1 or 2). Damage ranged from below assessable levels to moderately severe damage (eg. 50% assessed loss). The average crop (15-25%) suffered loss of the top crop including all late set fruit, some boll bruising and some defoliation. Little rain fell with the storm and with no follow up rain moisture stress became the main limiting factor in both hail damaged and undamaged crops. No regrowth occurred in hail damaged crops. The lack of rain was an advantage when looking at boll bruising as it ensured that boll bruising did not develop into boll rots. Crops were essentially left with relatively mature bolls to fill as smaller bolls in the top crop were removed.

Without hail, growers were required to protect the top crop from insects and wait for the crop to attain full maturity. With the lack of rain a percentage of the top crop did not mature in undamaged crops due to moisture stress. With hail damage and the top crop removed, an equivalent portion of the yield potential was lost due to hail damage. With little of the top crop left to mature in these cases insecticide sprays were saved. No other management could be employed in these situations.

Dryland crops further east in the Jondaryan-Pittsworth area suffered damage in the same storms. Again all crops were at late flowering or cut out at the time of damage with a good proportion of bolls yet to mature. Damage was assessed in the range of 40-100% loss. The storms were erratic and violent producing a range of damage severities across a farm. In the less severe cases, damage saw removal of a proportion of the top crop and boll bruising well down into the crop canopy.

Being dryland, growers were only left with the option of maturing what remained of the crops or in the more severe damage cases, abandoning the crop.

In the severe damage cases, growers either slashed the crop immediately or left the crop standing but abandoning management. These crops included damage ranging from 85-100%. Picking costs were determined to be in excess of possible returns from attempting to pick the remaining maximum yield of 15%, if the crop was able to mature the bolls or boll portions remaining. Growers elected to leave a crop standing where severely damaged areas formed part of a larger field. Where growers elected to pick through the severely damaged section, at picking, the returns from lint from these areas at a maximum managed to met picking costs and hence no advantage was gained by leaving the crop standing. Advantages may actually have been gained by slashing at the earlier date in advancing ground preparation programs .

Where cotton was less severely damaged, boll bruising was still extensive down into the canopy, but with crops only at or around cut out at the time of damage, the only option was to carry on and mature whatever remained of the crop.

Whilst little rain fell with the hail storm, in this more eastern area, an average of 50 mm of rain fell 14 days after the storm and induced a flush of new vegetative growth in these moderately damaged crops. The new vegetative growth was attractive to insects and with immature bolls at risk, growers were required to spray to protect fruit, with 1-2 sprays required to control *Heliothis* and/or aphid prior to picking. Hence, production costs were further increased for these crops with a reduced return due to hail.

One saving factor with these crops was the fact that besides the 50 mm of rain, conditions post damage were dry and not conducive to boll bruising developing into boll rots. A proportion of boll bruises counted as contributed to the overall yield loss in loss assessments, were actually able to open and were picked. Hence, this partial reduction in yield loss would have assisted in recouping productions costs outlaid in post damage insecticide costs.

Other late season dryland cotton hail strikes occurred in 1994/95, of the two case studies collated, in the first case, dry conditions following damage prevented regrowth in a crop damaged at cut-out. Spraying was continued only to mature immature fruit remaining following the strike. In the second case with damage at the R12+ growth stage, removing late fruit and inflicting light boll bruising, again the dry conditions prevented development of boll rot and reduced the significance of the hail damage.

Hence, in the dryland situation, management options following late season damage are few. Growers need to mature whatever fruit remain following the strike, or abandon the crop in severe damage cases. The costs of continuing with the damaged crop to mature immature or partly damage bolls is dictated by the weather and insect pressure.

3.3 Late Season Hail Damage in Irrigated Cotton Crops (1993/94 - 1995/96)

Under irrigation, there are a few more management options available for growers following a late season hail strike. Again the physiological growth stage dictates the degree of any regrowth response, either vegetative or reproductive. With late stage damage, where a proportion of the boll load remains following damage, the physiological response of the crop is to mature the boll load that remains before initiating regrowth. The presence of a boll load restricts or prevents a vegetative regrowth response. Where the major part of the boll load is mature and damage removes immature fruit, regrowth occurs. The availability of irrigation allows for maturation of the surviving boll load without moisture stress and provides moisture for regrowth. We have defined these hail strikes as occurring past a date at which in the average year regrowth can contribute to lint yield, hence any late vegetative regrowth can pose management problems.

Hail strikes recorded covered irrigated crops ranging in development from late flowering (cut-out) through to crop opening ie. categories 1 - 4 described previously. Numerous case studies show that where damage is inflicted at the late flowering stage around cut-out, although some regrowth occurs it does not contribute to overall lint yield, ie. regrowth was vegetative or if reproductive failed to mature to pickable bolls.

Only where the season proved to be longer than the historical average for an area did regrowth contribute to lint yield. Such conditions occurred in the Macquarie valley and Bourke area in 1994/95 where damage in the first week of January (late flowering growth stage) saw regrowth which contributed to final yield. The growing season had an unusually mild and late finish. On average water supplies for the area were limited, but in three case studies adequate water was available to water the crops late in the growing season and hence providing for the maturation of regrowth. In making the decision to regrow these crops the growers were taking on increased production costs as management included continuing the insect control program. The crops had received 4-7 insecticide sprays pre-damage and then received 5-6 sprays post damage and hence, overall received what would be considered a full spray program for a normal crop. Some degree of yield reduction would still be expected from the pre-damage yield potential ie. yield recovery from the damage even in a longer than average season could not be expected to be 100% and so the increased number of insecticides would have increased the production costs per bale. Defoliation and picking were delayed into late May and June and micronaire was reduced due to maturation of bolls under cooler temperature conditions hence decreasing returns.

In other hail damaged crops in the same area, where irrigation water was not available to water the regrowing crop to an optimum level, regrowth did not contribute to final yield. In these cases, damage was of a moderate - severe level but with part of the boll load remaining, regrowth was controlled and did not become excessively vegetative.

Where the growing season approximated the normal length in 1993/94 in the Macquarie valley and 1994/95 in the Namoi valley, regrowth past the last effective flower date did not contribute to lint yield. Vegetative regrowth was not excessive and where growers applied Pix as a preventative measure to stop any potential late vegetative growth or in trial strips, no difference was seen between treated and untreated areas.

Light damage at the late flowering stage (R12 growth stage) saw removal of late set small fruit and with the remaining fruit being relatively mature, regrowth was vegetative and was found to have the potential to cause late leaf growth and defoliation problems. Pix was used successfully by some growers to control the vegetative regrowth and in hindsight, other growers have indicated that they should have been more attentive to the rate of vegetative regrowth and used Pix to reduce late vegetative growth.

Growers in the Macquarie Valley experienced severe late hail damage in the 1995/96 season (28/2/96) when crops were at an advanced state of maturity (Categories 2, 3 and 4).

With damage at the R12+ growth stage, growers did not consider regrowing the crop. The management problem was how to mature the boll load which remained after the hail strike. Following the strikes, grower crop management aimed to do one of the following depending on stage of maturity (as described in categories 1-4):-

1. Fill last immature bolls then open up the crop
2. Attempted to open all green mature bolls then pick

or 3. Attempted to pick all open cotton ie. rescue the crop quickly.

In this situation a number of factors needed to be weighed up and risks determined. With a crops consisting of mature green bolls or in various stages of openness the key is opening the crop and picking as soon as possible. Of course, growers would prefer to pick as much cotton as possible of what remains of the crop following the damage by waiting for immature or unopen bolls to mature or open but weather remains the biggest problem. Adverse weather conditions following damage puts at risk all open cotton. Likewise any boll damage or bruising can quickly develop into boll rot and total loss of affected bolls if wet and/or humid weather follows the damage. Actual losses may then be much larger than that originally inflicted by the storm or the assessed loss.

Dry and warm weather conditions followed the late February hail strikes in the Macquarie valley. Where growers elected to attempt to fill remaining immature bolls in spite of damage and heavy bruising to mature bolls, they needed to apply final irrigations and control insects as in an undamaged crop and required full normal defoliations. With good weather conditions holding growers succeeded in maturing the late bolls. Although yields were depleted due to hail, low micronaire and other lint quality problems were only recorded in one case of late replant cotton where with hindsight the grower would not have waited for the last bolls which proved to be low micrónaire.

By electing to finish off immature bolls in the less open crops, growers incurred full production costs as crops required last irrigations, insect control and full normal defoliations and in some instances incurred loss of lint quality by waiting for the latest bolls.

In crops where the larger proportion of bolls were mature, growers in general, assessed the moisture status of the crops and the majority cancelled last irrigations allowing the bolls to open on the available moisture. Only where irrigations were due on or about the date of the hail strike did growers take the option of applying a final irrigation. Both crops falling into this category were yet to begin opening though having the majority of bolls mature. No further insect sprays were required in these crops. Defoliation programs were moved forward (ie. earlier) in all cases and with no leaf regrowth, defoliation using only one or two applications were possible. Hence, growers were able to contain production costs following the hail damage. Regrowth was only recorded in one study where defoliation was delayed to allow the very last bolls to mature and in this case a full defoliation program was necessary.

Where crops were in more advanced stages of boll opening and hence were within 7-10 days of defoliation, growers employed the strategy of drying out the fields following the damage and then defoliating as quickly as possible. Most brought defoliation forward and aimed for fast defoliations with a maximum of 1-2 applications. High rates of Prep® were the rule in defoliations. Insecticides were only required following damage to control aphid prior to defoliation in two case studies.

Contrary to any grower or consultant experience, the weather following these late hail strikes was warm and dry which has determined the success of the strategies used by the growers. Boll bruising was extensive in all crops and there was the potential for greatly increased losses if bruising developed into boll rot. With dry and clear conditions immediately following damage, growers elected to wait and finish crops. This could have been a disastrous decision had the weather turned instead of remaining abnormally warm and dry.

3.4: Discussion Points and Guidelines in Managing Late Season Hail Damage in Cotton

In surveys prior to initiating this work, major questions raised by growers in regard to damage in the later part of the season included:-

1. At what date in the growing season is regrowing the crop past being an option?
2. How do I decide whether to pull out immediately and rescue open or mature bolls or can I risk trying to mature the late and immature undamaged bolls?
3. What are the options for quick defoliation and picking?

Growers are very familiar with the use of the term 'last effective flower date', from which date onwards in the average season a flower set as a boll will not mature before the first frost. If regrowth following a hail strike is to contribute to lint yield then the crop needs to initiate new vegetative growth and then initiate squares to flower before the last flower date.

In hail damage simulation work, there was found to be an average delay of 450 GDDs recorded following a hail strike before the appearance of new squares on regrowth ie. up to 30 days. If this is added to the average period of 20 days required by a square to develop to a flower, then a hail strike occurring approximately 50 days prior to the last effective flower date will not produce regrowth which will contribute to lint yield.

Light to moderate hail damage with optimum weather conditions post damage may see earlier initiation of squares on regrowth and hence, push the last effective regrowth date back towards last square date. But some factors act to bring the last effective regrowth date forward further. The physiology of the cotton plant dictates that the fruit load of bolls acts as a stronger sink for assimilates than new vegetative growth, hence, where damage occurs at a mature growth stage and a portion of the boll load remains, the crop will mature this fruit before initiating new vegetative, this effectively delays the initiation of new squares brings forward the date for no effective regrowth.

Growers may argue exceptions to the last effective regrowth dates calculated in this work. In a year which is longer than the average growing season, effective regrowth can be achieved and case studies have been collated to support the fact. But in the average season this is not possible and in the three years of case studies covered in the work the last effective regrowth dates have been supported. The dates for each production area correspond approximately to the dates at which the average crop in a district is reaching cut out and therefore has the major proportion of its boll load set. Dryland and irrigated crops struck by hail on this date or later produced no effective regrowth to contribute to lint yield and hence these dates would be considered cut off dates for attempting to regrow crops.

The second question relates to the proportion of the boll load remaining after the hail damage that the grower aims to pick. Of course, the grower would aim to pick the maximum number of bolls whatever the stage of maturity the crop is at. With damage at or near cut -out a proportion of the bolls remaining would be immature and the mature bolls present may have avoided damage or suffered bruising. The proportion of mature bolls increases as the hail strike occurs at progressively later dates up to a fully mature and open crop. While a yield loss is incurred in not waiting for immature bolls to mature, risks are involved in chasing the immature bolls and costs involved in taking the crop through to maturity.

Following damage at this late stage, if regrowth is not going to contribute to lint yield, any vegetative growth that occurs can potentially make the crop attractive to insects and contribute to defoliation and picking problems. A major factor increasing losses following late season damage is adverse weather conditions whether rain or even high humidity which encourages development of any boll bruise into boll rot.

In the dryland situation, the initiation of regrowth occurs after a rainfall event therefore there is little control over vegetative regrowth. Accepting that a yield loss has been incurred in the hail strike. Then following the hail strike the crop will mature the remaining bolls on the remaining soil moisture reserves. As in an undamaged crop, if insufficient moisture is available part of the top crop will not mature and will be aborted or small pinched immature bolls will result. Production costs will still be incurred as in an undamaged crop to protect late fruit although the crop with less fresh foliage and young fruit is usually less attractive to insects.

Further rainfall events will provide moisture to mature more of the boll load in both hail damaged and undamaged crops. But the same rainfall events will initiate new vegetative growth in hail damaged cotton which will make the crops attractive to insects necessitating late application of insecticides. With sufficient time/optimum growth conditions, the vegetative growth may require controlling with growth regulators and the new leaf material will require full defoliation programs (2-3 applications) as opposed to where little regrowth is recorded and the canopy has been thinned by hail, a reduced program is often required. Hence overall production costs are increased by the rain events.

Lint yield has been reduced by the loss of fruit in the original hail strike. Yield losses attributed to hail are now only increased by loss of damaged bolls to boll rot or due to picking problems. Maturity of the crop is not delayed by late hail and in some instances where the top crop is removed by the hail, maturity is advanced.

On the other hand, lint quality will be affected by the number of immature bolls picked. Hence, if a growers chooses to chase late bolls following hail, time and conditions must allow bolls to fully mature if low micronaire problems are to be avoided. Low lint quality is therefore a belated loss due to hail. In dryland crops the same problem exists for undamaged crops where moisture is limiting causing abortion of the top crop.

Under irrigation, following hail damage in the late season, similar problems exist but growers also have the advantage of being able to water the crop to mature any immature bolls remaining. But in watering the crop, it predisposes the crop to the same vegetative regrowth as can occur with rain events in dryland cotton and hence the similar increased production costs per bale of cotton. To this can be added the costs of the irrigation. With a traditionally more vegetative crop than in the dryland situation, following hail, although defoliated to some degree, significant leaf material may remain and so with rain and/or high humidity is maintained within the canopy and the boll rot problem is made dramatically worse. Large numbers of bolls assessed as being partly lost to hail bruising now become totally unpickable.

Hence, the decision needs to be made as to what proportion of the immature boll load a grower wishes to chase to counteract possible increases in production costs, further lint yield losses due to boll rot and losses in lint quality.

Hail strikes in the later part of the growing season were few in occurrence until 1995/96. Hence, few opportunities arose to test a range of defoliation strategies. Defoliation is a difficult 'science' in most seasons with climatic conditions at the time of defoliation dictating the defoliation strategy and the chemicals used.

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Chapter 4

Fruiting Patterns of C. S. I. R. O. Varieties of Cotton

4.1: Introduction

In the process of identifying the response of Australian bred cotton varieties to damage by hail (CDL1C), it was found that little data was available documenting the fruiting patterns of current commercial C. S. I. R. O. varieties of cotton. The fruiting pattern and maturity type of a given variety were suggested as contributing to the crop's ability to replace lost yield in a given production area after hail damage. During the 1994/95 cotton season the fruiting patterns of current commercial and newly developed varieties of cotton were monitored in Cotton Seed Distributors Ltd. cotton variety trials. The fruit development patterns of varieties at three Namoi Valley trials was monitored for the 1994/95 cotton season with the aim of producing fruit development curves for each variety.

4.2: Trial Design and Methods

The three C. S. D. trial sites selected were located within 75 kilometres of the Australian Cotton Research Institute and were fully irrigated commercial crops. The sites represented three climatic zones of the Namoi Valley and were situated at Myall Vale, Merah North and Boggabri. With drought conditions prevailing again this season, the trials were placed on farms with the ability to irrigate to the full requirements of the crop. Trials are of a large scale mirroring the commercial situation and are designed as Randomised Complete Block Design with four replicates and varieties planted in strips according to planter width (ie. 8, 12 or 16 rows of metre width.). The crop agronomy for each site is summarised in Appendix 4.1.

Varieties trailed at each site are summarised in Table 4.1 and are selected as representing the varieties considered most suited to an area according to maturity type. They are compared at each site to the industry standard variety, Siokra 1-4.

Subject to weather conditions and irrigation schedules, weekly counts of fruit forms were carried out at each site. Counts were over $1m^2$ marked areas in each varietal strip in each replicate. The sampling period being from stand establishment through to last irrigation.

Fruit forms counted were classed as follows:-

Squares	-	Floral buds from 5 mm to yellow flower.
Small Green Bolls	-	Green bolls from pink flower up to 2 cm in diameter.
Large Green Bolls	-	Green bolls over 2 cm in diameter.
Open Bolls	-	Bolls with split locks to fully open.

In analyses and figures, the term "green bolls" is used which includes small and large green bolls or the term "bolls" which is total of small, green and open bolls. Data was analysed using the MINITAB Statistical package with analyses carried out at each sample date for differences in numbers of fruit forms present and differences in date of first square. Where "date of first square" is defined as the date at which 50% of the plants in the sample area bear a first square.

Table 4.1: **COTTON VARIETIES - Cotton Seed Distributors Ltd. Variety Trials (1994/95)**

		Togo Station Myall Vale	"Coolabah" Merah North	"Nandewar" Boggabri
VARIETY	MATURITY TYPE			
Siokra 1-4	Medium	*	*	*
DP 90	Medium - Late	*	*	
CS 50	Medium	*	*	
Sicala V2	Medium	*	*	*
Siokra V-15	Medium - Late	*	*	*
Siokra L23	Late	*	*	
CS 189+	Late	*	*	
CS 8S	Early	*		*
Siokra S324	Early			*
Exp 523	Early			*
Exp 613	Medium	*	*	*
Exp 97	Late		*	

4.3: Results

Fruiting patterns were developed by plotting fruit form numbers against accumulated heat units ie. Growing Day Degrees. The growth and development of cotton is directly related to temperature rather than chronological time ie. days from planting and hence accumulated heat units is the more accurate scale against which to measure the development of cotton.

Heat unit accumulation was determined from temperatures measured at the Australian Cotton Research Institute, Myall Vale according to the calculations used by Constable (1976), Constable and Shaw (1988). Growing Day Degree values for each day were calculated using the following formula:-

$$\text{Growing Day degrees (GDDs)} = \frac{(T_{max} - 12) + (T_{min} - 12)}{2}$$

Note that if a minimum of less than 12 ^{o}C occurs the value of $(T_{min} - 12)$ is zero.

The weather stations at the Merah North and Boggabri sites were found to be functioning unreliably. Heat unit accumulation for these sites was calculated from the Myall Vale data. Based on historical knowledge of climatic conditions, the assumption was made that heat units accumulated at Merah North at a more rapid rate than at Myall Vale. Heat units were summed over the growing season with the addition of one day degree per day to produce values for accumulated GDDs at Merah North. Similarly, at Boggabri, heat units were assumed to accumulate at a slower rate and were calculated by subtracting a day degree per day from the Myall Vale data. Weather data and accumulated heat units are presented in Appendix 4.2.

Fruit development patterns for cotton varieties at each site are presented graphically. Fruit count data is inherently variable. Sample areas were selected for uniformity to minimise variability. Fruiting pattern trends can be described from the graphs and statistically significant differences in fruit numbers are discussed.

Fruit development patterns for cotton varieties monitored at "Togo Station", Narrabri are presented in Figures 4.1(a) and (b). These are compared to those from "Coolabah" Merah North in Figures 4.2(a) and (b) and from "Nandewar" Boggabri in Figures 4.3(a) and (b).

4.3.1: Fruit Development at "Togo Station", Myall Vale (Site A)

At "Togo Station" there is very little difference between the number of squares borne by each variety. (Figure 4.1a). At 625 GDDs after planting, the short season variety CS8S has significantly higher square numbers but only when compared to Siokra L23 (5% Level of Significance). Siokra L23 is a later maturity variety and at this sample date had the lowest square numbers.

By 700 GDDs after planting, squaring has increased in CS189+ and now both CS8S and CS189+ have significantly higher square numbers than Siokra L23 (5% Level of Significance).

In the period between 800 and 1200 GDDs all varieties except DP90, Siokra L23 and Exp 613 reach peak square production. Peak square production is not reached by Siokra L23, DP90 and the experimental line 613 until just prior to 1200 GDDs after planting and at this point DP90 and Siokra L23 have higher square numbers than other lines due to the fact that square production in the other lines is now decreasing (10% Level of Significance). At this site, DP90 and Siokra L23 produced the highest peak in square numbers.

By approximately 800 GDDs after planting, boll setting has begun but no difference in boll numbers is distinguishable until approximately 1100 GDDs after planting. CS8S displays the earliest boll set pattern showing significantly higher boll numbers than other varieties and especially Siokra L23, at 1100 and 1200 GDDs (5% Level of Significance). In the period from approximately 1500 to 1700 GDDs, the rate of increase in boll numbers in CS8S, CS189+, Sicala V2 and Siokra V-15 declines. At the same time the rate of increase in boll numbers increases in the case of Siokra L23, DP90 and to a lesser extent Siokra 1-4.

Boll numbers in all varieties peaked at approximately 1800 GDDs after planting and at that time DP90 had the highest boll numbers, and Sicala V2 and Siokra V-15 the lowest. DP90 shed some smaller bolls in the following period so that the advantage of DP90 in respect to boll numbers was reduced. So that at the last sampling date DP90 and CS8S showed higher boll numbers than the standard. Sicala V2 and Siokra V-15 showed decreased boll numbers.

This trial was not taken through to full maturity but varieties CS8S followed by CS50 and Siokra 1-4 were the earliest to begin opening as presented in Table 4.5.

In investigating the fruiting patterns of varieties, boll numbers cannot be translated directly through to yield potential as boll size and seed size etc. affect the amount of lint present in a boll. Table 5 2 summarises the yield and quality characteristics of varieties at the "Togo Station" variety trial site in 1994/95. This is as determined by the commercial picking of the trial by Cotton Seed Distributors Ltd. and shows the variation in ranking of varieties compared to a ranking based on final boll numbers as presented in earlier graphs.

Table 4.2: Lint Yield and Lint Quality Characteristics of Cotton Varieties

Site:	"Togo Station" Myall Vale 1994/95							
	COTTON VARIETY							
	Siokra 1-4	DP90	Siokra L23	CS50	CS189+	CS8S	Sicala V2	Siokra V-15
Yield ba/ha	7.09	6.91	7.43	7.81	8.17	8.14	8.74	8.63
Yield ba/ac	2.87	2.79	3.01	3.16	3.31	3.29	3.54	3.49
Gin O/T	38.33	38.12	38.84	39.2	38.31	39.62	38.1	39.15
Colour	21-1	21-1	21-1	21-1	21-1	21-1	21-1	21-1
Staple	1.14	1.11	1.12	1.14	1.13	1.1	1.13	1.15
Micronaire	3.4	3.6	3.4	3.5	3.7	3.9	3.7	3.6
Gms/Tex	27.8	30.2	30.8	27.9	28.3	27.9	28.9	29.9
% of Siokra 1-4	100	97.39	104.77	110.11	115.2	114.77	123.21	121.6

Source: C.S.D. Variety Trial results 1994/95.

Figure 4.1a: **Square Development in Cotton Varieties**
Site: C.S.D. Variety Trial "Togo Station" Myall Vale 1994/95.

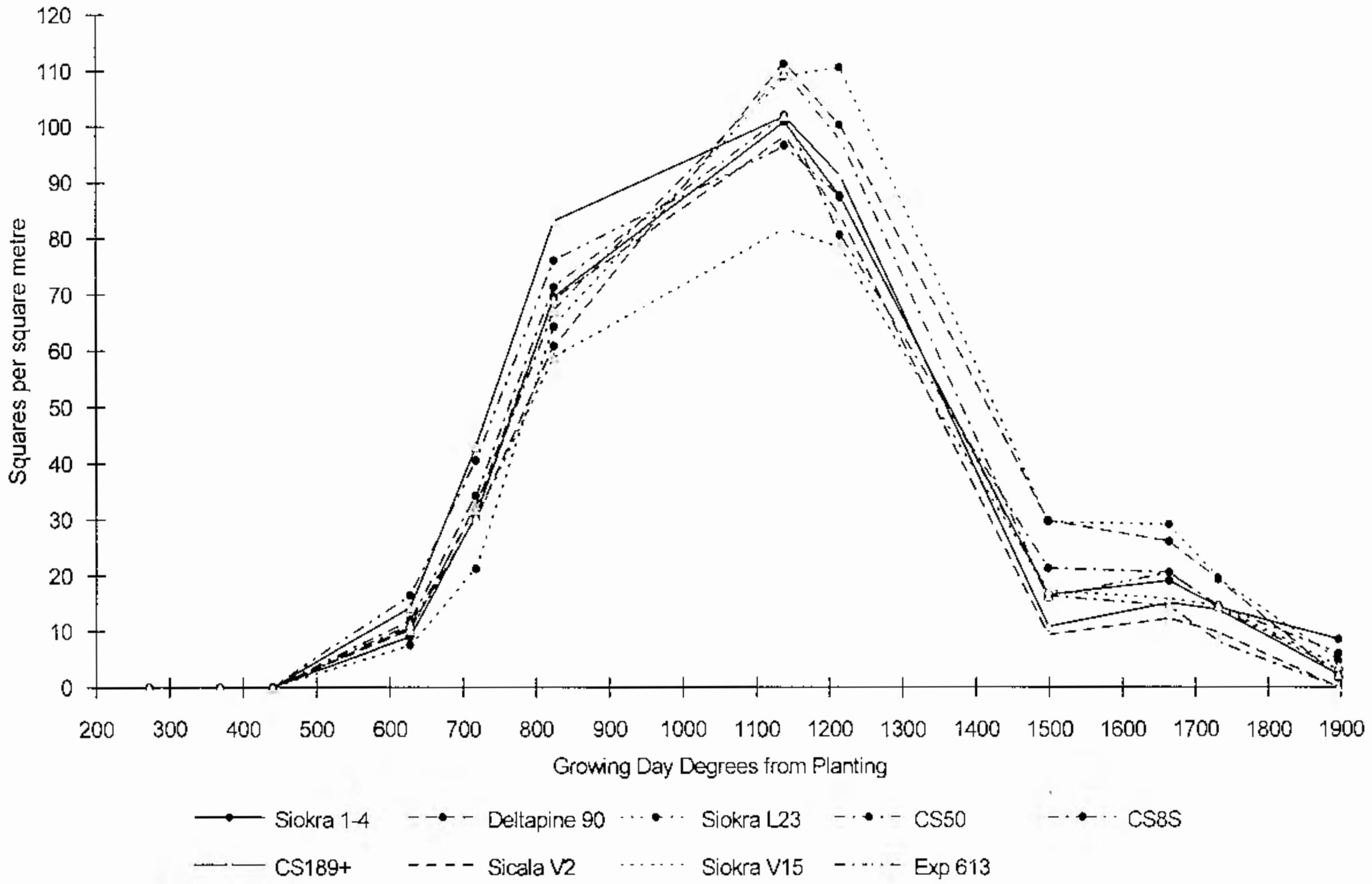
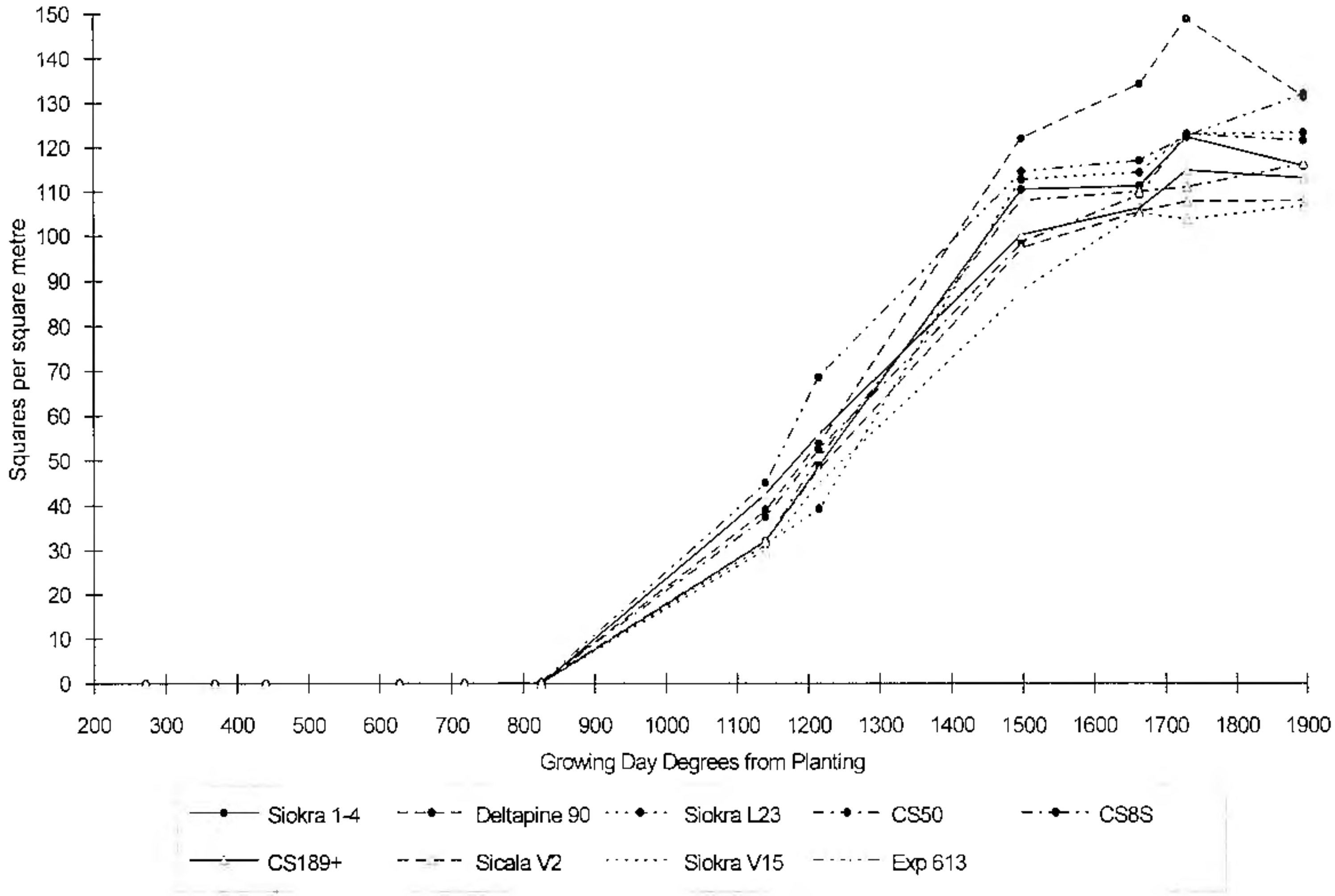


Figure 4.1b: **Boll Development in Cotton Varieties**
Site: C.S.D. Variety Trial "Togo Station" Myall Vale 1994/95.



4.3.2: Fruit Development at "Coolabah" Merah North (Site B)

"Coolabah" Merah North is an longer season area compared to Myall Vale. Theoretically, the later maturing varieties such Deltapine 90 (in the absence of Bacterial Blight infection), CS189+ and Siokra L23 would yield better. Siokra 1-4 has produced good yields in previous years so is not unsuited to the area.

In this trial fruit numbers would indicate that CS189+, along with DP90 and Siokra L23 would out yield Siokra 1-4 as they have higher boll numbers and potentially the highest yield. The new lines Exp 613 and Exp 97 also have higher final boll numbers than Siokra 1-4. But statistically speaking, only CS189+ had significantly higher boll numbers than the cotton varieties with the lowest boll numbers in final counts, Sicala V2 and Siokra V-15 (5% level of Significance). As boll and seed size and ginning turnout differ between cotton varieties, yield estimates should not be based on boll numbers. Actual lint yields are presented in Table 4.3 as determined in the commercial pick of the trial by C.S.D.

Table 4.3: Lint Yield and Lint Quality Characteristics of Cotton Varieties

Site:	"Coolabah" Merah North 1994/95							
	COTTON VARIETY							
	Siokra 1-4	DP90	Siokra L23	CS50	CS189+	Sicala V2	Siokra V-15	
Yield ba/ha	8.84	8.86	8.97	9.6	8.98	9.28	9.2	
Yield ba/ac	3.57	3.58	3.63	3.89	3.63	3.75	3.72	
Gin O/T	35.78	40.13	37.6	41.18	36.67	37.77	36.42	
Colour	21-1	11-2	21-1	21-1	21-1	21-1	21-1	
Staple	1.16	1.11	1.15	1.15	1.14	1.15	1.16	
Micronaire	3.7	4.2	4	4	4.1	4.1	3.8	
Gms/Tex	27.1	27	27.9	26.2	27.3	28.1	29.2	
% of Siokra 1-4	100	100.29	101.49	108.72	101.64	105.03	104.13	

Source: C.S.D. Variety Trial Results 1994/95.

Early square numbers are very similar between varieties (Figure 4.2a). All varieties except CS50, CS189+ and Exp 613 peak in square production prior to approximately 1000 GDDs after planting. These three varieties peak approximately 150-200 GDDs later. From approximately 1200 GDDs after planting, the rate of square production declines, CS50 and CS189+ continue squaring at a higher rate than other varieties up to approx. 1400 GDDs. Statistically at this point, Sicala V2 and Siokra V-15 showed lower square numbers than CS50 and CS189+ (10% Level of Significance).

Boll set had begun at Merah North by approximately 900 GDDs, but little difference is seen in boll numbers until the 1200 GDDs sampling date (Figure 4.2b). At this time CS189+, CS50 and Exp 97 show a decreased number of bolls set compared to other varieties. Between 1200 and 1400 GDDs, the rate of boll set by CS189+ and CS50 increases rapidly so that boll number between varieties are more similar by 1550 GDDs, although Sicala V2 and Siokra L23 have significantly lower boll numbers than CS189+ and CS50 (5% Level of Significance).

All varieties except CS50, CS189+ peak in bolls numbers approximately 1500 GDDs after planting. CS50 and CS189+ peak at approximately 1650 GDDs and reach the higher peak boll numbers (1% Level of Significance) along with Exp 613.

Boll shedding after cutout sees a reduction in boll numbers in all varieties through to maturity. Statistically speaking, Sicala V2 and Siokra V-15 show lower boll numbers than all varieties throughout development, but differences are only significant between these varieties and CS50 and CS189+ (1650 GDDs after Planting). At maturity (1850 GDDs), CS189+ has statistically (5% Level of Significance) greater boll numbers than Sicala V2.

Differences in maturity were not statistically significant. Although there is a 150 GDDs (8 Day) difference in time to maturity (Date of 60% open) between varieties. Siokra I-4 and DP90 being the earliest to maturity and Exp 97 the later maturing as described in Table 4.5.

Figure 4.2a: <u>Square Development in Cotton Varieties</u>
Site: C.S.D. Variety Trial "Coolabah" Merah North, 1994/95.

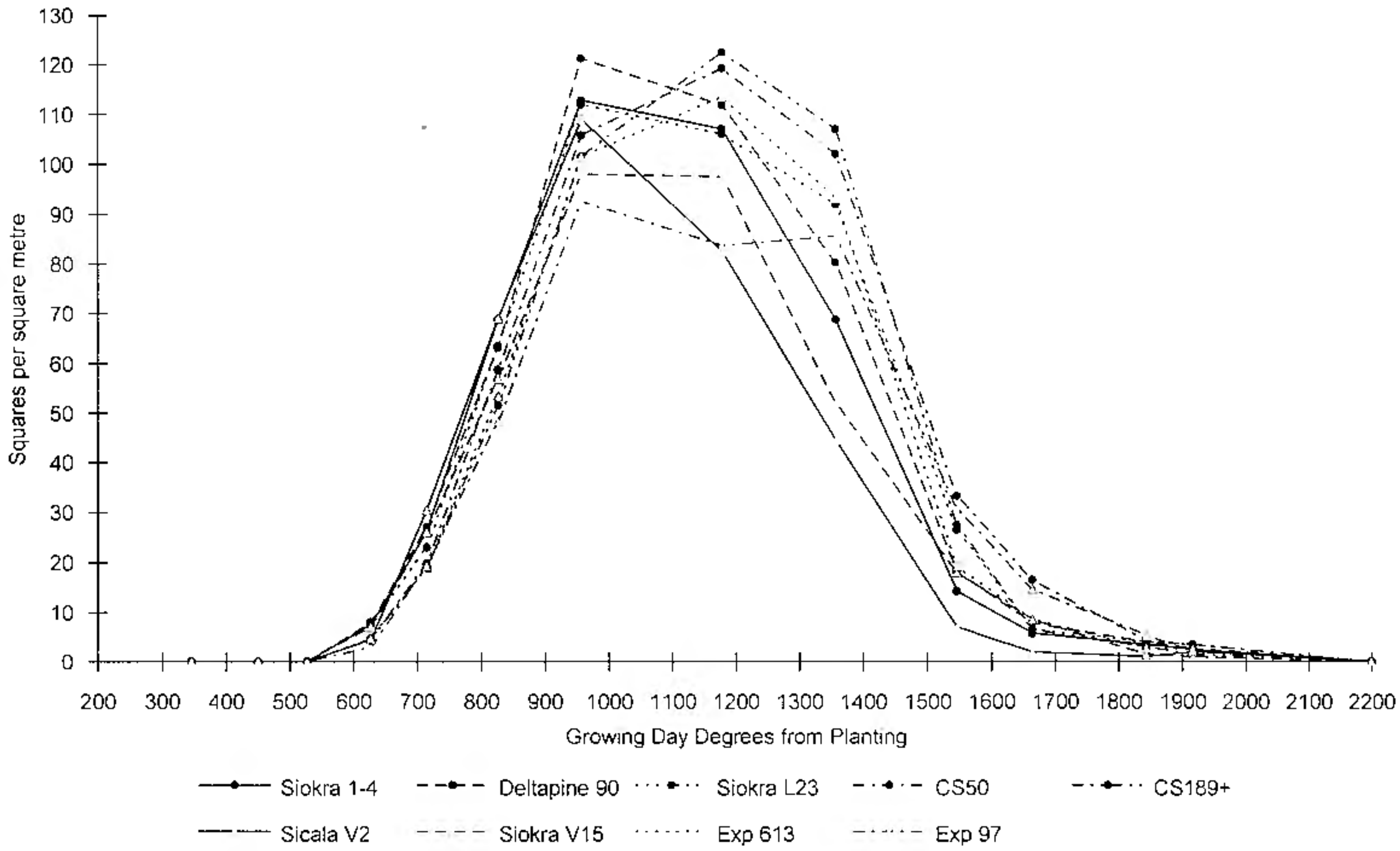
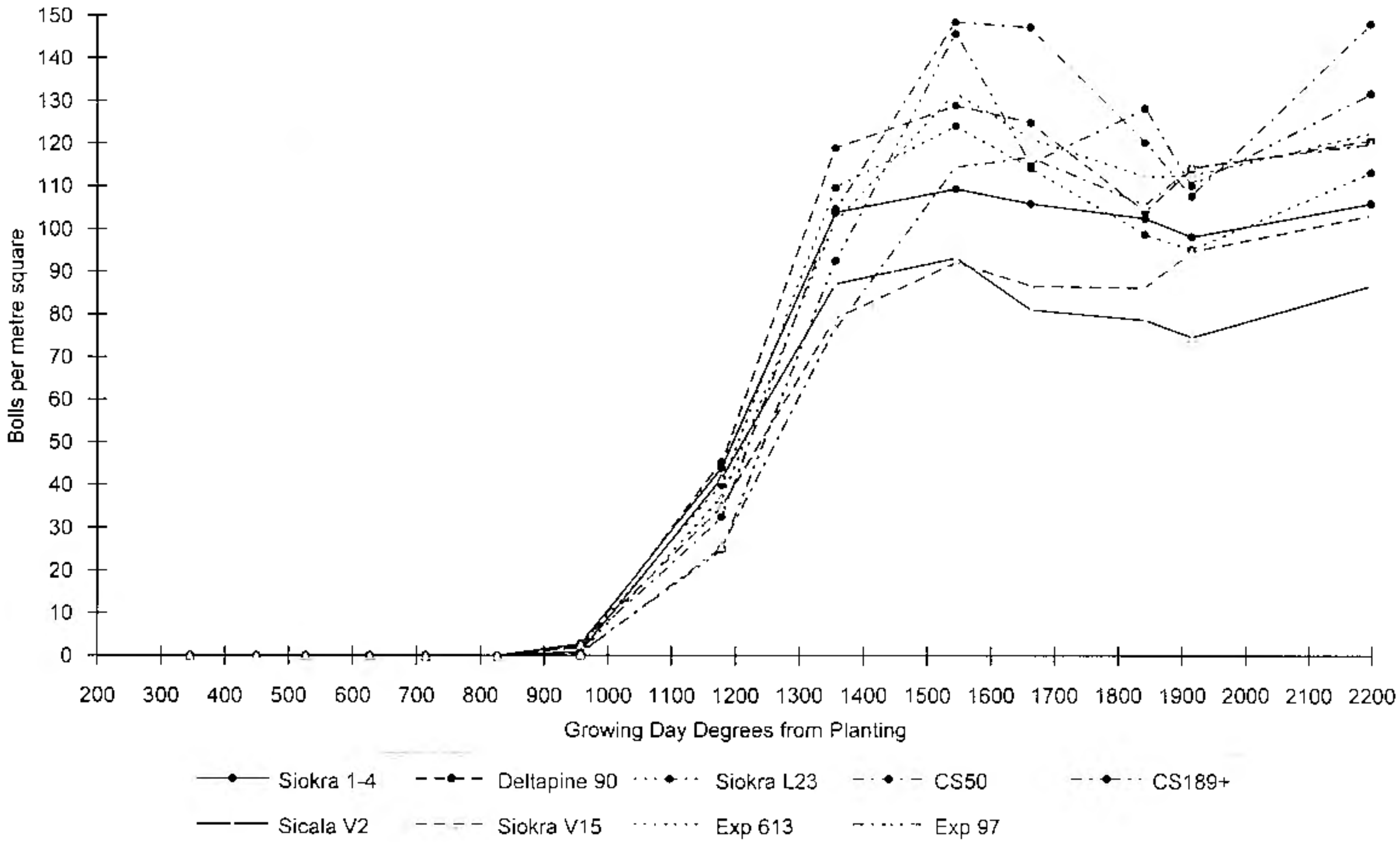


Figure 4.2b: **Boll Development in Cotton Varieties**
Site: C.S.D. Variety Trial "Coolabah" Merah North, 1994/95.



4.3.3: Fruit Development at "Nandewar" Boggabri (Site C).

The Boggabri area is considered one of the shorter season areas for cotton production in Australia. Growers historically have not had cotton varieties available of suitable maturity to give them flexibility in planting time and management. Siokra 1- 4 has proven to be a reliable yielding variety for the area but recent releases from the C.S.I.R.O. short season variety development program have the potential to out yield Siokra 1- 4 and mature earlier and hence give growers more flexibility in crop management.

Looking at the "Nandewar" Boggabri trial, although not statistically significant, early square numbers in CS8S are higher than other varieties but generally square numbers are similar between varieties up to 800 GDDs after planting. Square production increases in all varieties between 800 and 1000 GDDs, peaking between 1000 and 1200 GDDs after planting (Figure 4.3a).

Siokra 1-4, Siokra S324 and Exp 523 show the most rapid increases and during this period. Square numbers in Siokra 1- 4 are only surpassed by those in Exp 523. Siokra S324, Exp 613 and Exp 523 have statistically higher square numbers than the longer season varieties Sicala V2 and Siokra V-15 from 1000 to 1200 GDDs after planting (10% Level of Significance).

Boll set shows a similar pattern overall, with CS8S setting higher numbers of bolls at early dates and the variety continues to set higher boll numbers than other varieties well into the boll setting period. Sicala V2 and Siokra V-15 show significantly lower boll set early and significantly lower numbers than CS8S and Exp 523 as boll numbers peak between 1400 and 1600 GDDs after planting (5% Level of Significance).

In Figure 4.3b, boll set peaks in Siokra 1-4 and Exp 613 between 1400 and 1600 GDDs. Other varieties do not reach peak boll numbers until between 1600 and 1800 GDDs. Following the shedding of small bolls after cut out, Sicala V2 and Siokra V-15 show lower boll numbers than other varieties reflecting later boll setting and fewer set bolls overall in the reduced season length at Boggabri. CS8S and Exp 523 have significantly higher final boll numbers than these varieties (5% Level of Significance). The standard, Siokra 1-4 shows decreased potential yield compared to the newer varieties CS8S and Exp 523 if yield estimates are based on boll numbers, but as presented in Table 4.4, in commercial picking Siokra 1-4 outyields CS8S.

Although this trial was not followed through to maturity CS8S is the first variety to begin opening followed by Siokra 1- 4 and Siokra S324 as presented in Table 4.5.

Figure 4.3a: **Square Development in Cotton Varieties**
Site: C.S.D. Variety Trial "Nandewar" Boggabri, 1994/95.

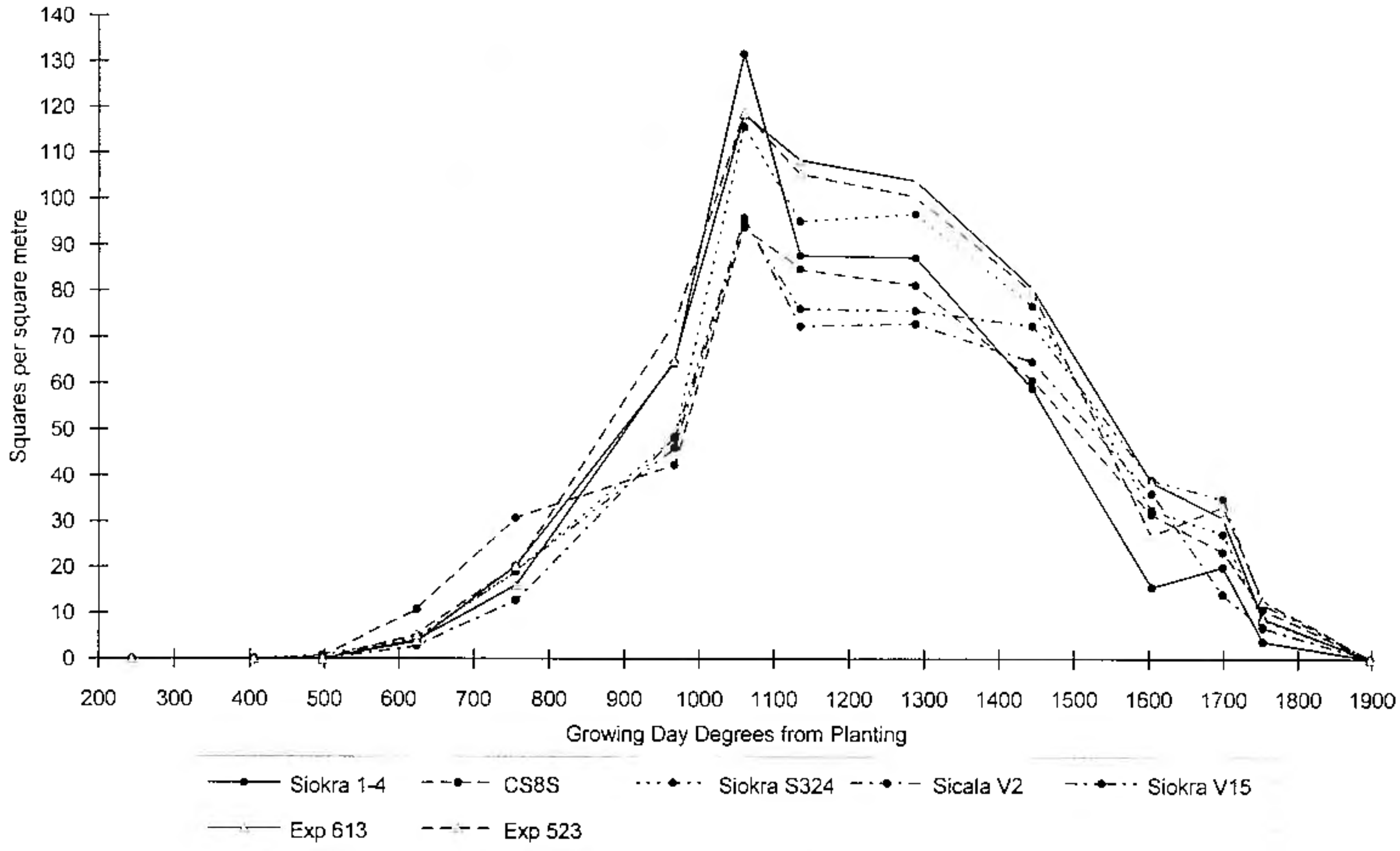


Figure 4.3b: Boll Development in Cotton Varieties
Site: C.S.D. Variety Trial " Nandewar" Boggabri, 1994/95.

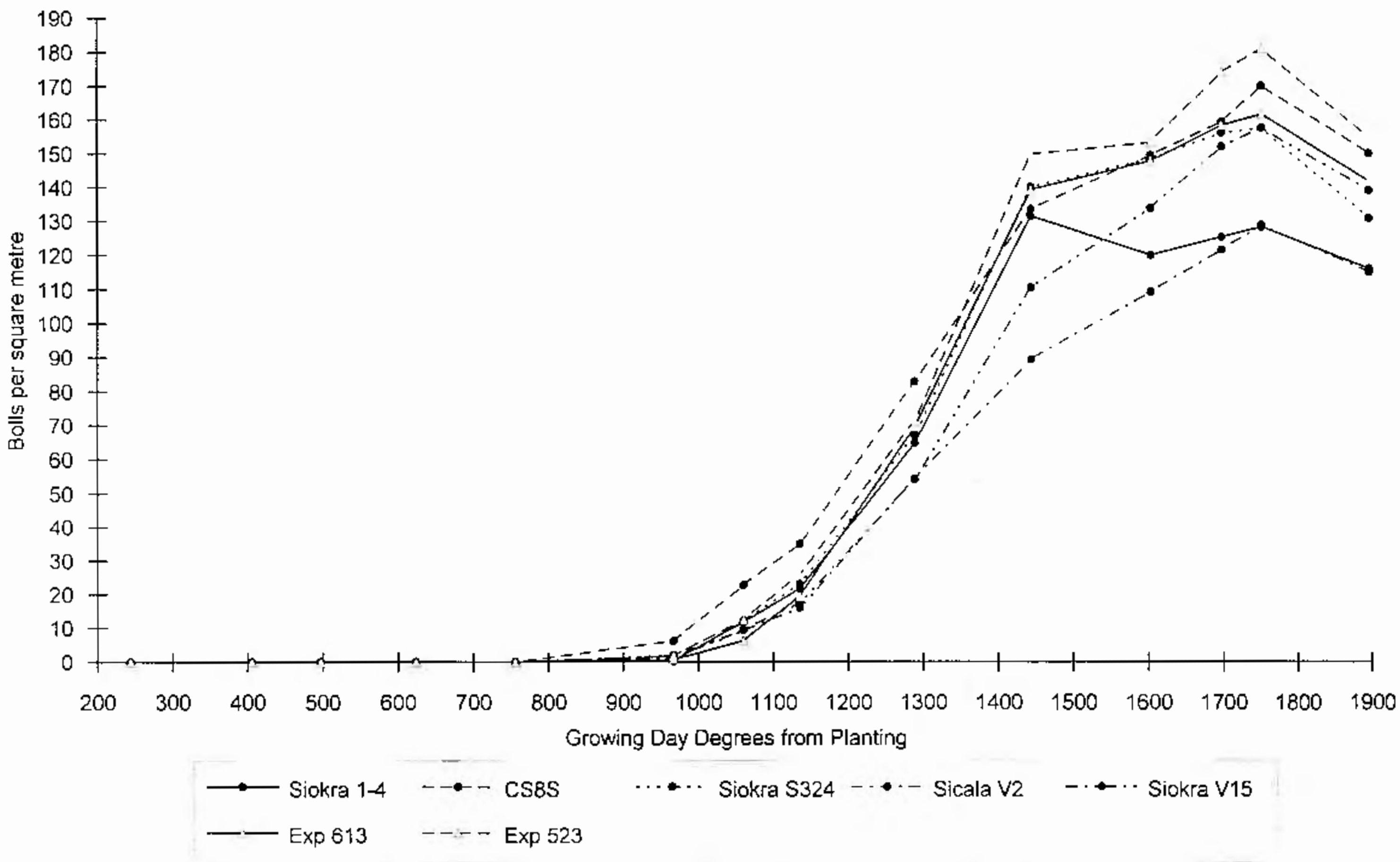


Table 4.4: Lint Yield and Lint Quality Characteristics of Cotton Varieties

Site:	"Nandewar" Boggabri 1994/95							
	COTTON VARIETY							
	Siokra 1-4	CS8S	Siokra S324	Sicala V2	Siokra V-15			
Yield ba/ha	7.65	7.37	7.28	7.56	7.96			
Yield ba/ac	3.09	2.98	2.94	3.06	3.22			
Gin O/T	36.79	36.52	37.56	37.01	36.74			
Colour	31-2	31-2	31-2	41-1	41-1			
Staple	1.14	1.09	1.1	1.11	1.13			
Micronaire	3.1	3.3	3.3	3.2	3.1			
Gms/Tex	26.2	27.8	25.6	28.1	27.9			
% of Siokra 1-4	100	96.37	95.1	98.98	104.08			

Source: C.S.D. Variety Trial Results 1994/95.

Table 4.5: Varietal Maturity in C.S.D. Variety Trials 1994/95

Site:	"Coolabah" Merah Nth		"Coolabah" Merah Nth		"Togo Station" Myall Vale		"Nandewar" Boggabri	
Variety	GDDs to 10% Open Bolls	Days to 10% Open Bolls	GDDs to 60% Open Bolls	Days to 60% Open Bolls	GDDs to 10% Open Bolls	Days to 10% Open Bolls	GDDs to 10% Open Bolls	Days to 10% Open Bolls
Siokra 1-4	1860	142.5	2050	161.0	1770	145.0	1820	164.5
DP90	1850	141.5	2055	162.0	1800	147.0		
CS50	1882	144.5	2077	165.0	1765	144.5		
Sic V2	1875	143.7	2052	161.5	1805	148.0	1870	169.0
Siokra V-15	1860	141.5	2060	162.5	1802	147.8	1860	168.5
Siokra L23	1885	145.0	2074	165.0	1902	152.0		
CS189+	1930	148.2	2090	167.0	1800	147.5		
CS8S					1742	143.0	1775	159.7
Siokra S324							1810	163.5
Exp 523							1880	170.0
Exp 613	1925	147.5	2078	165.5	1815	148.5	1880	170.0
Exp 97	1930	148.0	2200	169.0				

Discussion:

From the fruiting patterns depicted above for the three sites, we can broadly group the varieties by earliness to initiate fruit. But if a variety is to lend itself to recover more quickly from hail damage it should not only initiate fruit rapidly following damage but also square at a high rate to make maximum use of the season remaining.

The thermal time required to reach first square is loosely associated with maturity type. Although the trials were not taken through to full maturity, a comparison of degree of crop openness in the early stages of crop opening show larger differences in time to maturity than can be explained by the time required to reach 'First Square'.

Fruiting patterns of cotton varieties differ not only in terms of time to reach 'First Square' but also in terms of the rate of square production, boll period and hence time to maturity (Wells and Milroy, 1994). Each of these parameters depend to varying degrees on temperature conditions (Moraghan *et al.* 1968; Hesketh and Low, 1968).

The time required for a variety to develop to 'First Square' and 'First Flower' were determined for each variety at each site and the time period required for each variety to begin squaring at each location is summarised in Table 4.6(a) and (b).

Time to 'First Square' along with the squaring rate determine the rate at which fruit can be set. Squaring rates calculated between appearance of first square and first flower were determined for each variety at each site and are summarised in Table 4.6(c).

From this data we can get a more accurate picture of the fruiting pattern of varieties and determine if a particular variety may lend itself to recover more quickly from hail damage due to its inherent earliness to fruit or squaring rate as these characters would enable more rapid fruit set on regrowth in the reduced season available following a hail strike.

Varieties which are earlier to initiate squaring and/or have a higher squaring rate are shown to be earlier to maturity. The response in these trials is more defined in longer and shorter season areas than in moderate length growing areas. At the "Coolabah" Merah North site, Siokra 1-4, DP90 and Sicala V2 are in the earliest four varieties to reach first square and are only surpassed by CS189+ and the new line Exp 97 in high squaring rates. The combination of earliness to first square and high squaring rate in these three varieties have produced advanced maturity compared to other varieties at the date of 10% open bolls and at maturity (60% open bolls). Although this does not translate to higher lint yield at this site. The longer season varieties are only slightly later in reaching first square and have moderate squaring rates and also fruit over a longer period reaching a higher final lint yield.

At "Togo Station" Myall Vale, a moderate season length area, the response is less defined. CS189+, although having an earlier date to first square and a higher squaring rate once squaring is initiated, is not advanced in maturity due to the fact that there was an adequate length of good growing conditions for the variety to continue fruiting over a longer period and hence, boll maturation occurred over a longer period. After CS189+, CS8S and CS50 also have short periods to first square and high squaring rates and at this site, this translates to earlier maturity as the varieties do not tend to fruit over an extended period nor at the higher levels of CS189+.

"Nandewar" Boggabri is a short season climatic area. CS8S, Siokra 1-4 and Siokra S324 are well advanced in date to initial opening (10% open bolls). Where CS8S and Siokra S324 have conspicuously earlier dates to first square, Siokra 1-4 displays a high squaring rate than all other varieties and these characteristics combine to produce earlier maturity.

In terms of possible responses to hail damage or recovery from hail damage. It is obvious that varieties of longer season length displaying longer periods to initiation of squaring and lower squaring rates would be slower to initiate fruit following hail damage. This may not be a disadvantage in longer season areas but would be detrimental to recovery of yield potential in moderate and shorter season areas, or where management options available will not allow a variety to grow out to its full potential (eg. where water allocations are low). Where earlier and more rapid fruit set occurs following damage an increased yield response could be expected under such conditions.

The differences in date to first square and maturity measured in these trials is not large when looking at a commercial situation but when combined with agronomic management strategies increased fruiting rates and earliness to maturity may contribute to increased recovery within the reduced growing season following hail damage.

Table 4.6a: Appearance of First Square in Cotton Varieties

Site:	"Coolabah" Merah Nth 1994/95		"Togo Station" Myall Vale 1994/95		"Nandewar" Boggabri 1994/95	
Variety	GDDs from Planting	Days from Planting	GDDs from Planting	Days from Planting	GDDs from Planting	Days from Planting
Siokra 1-4	625	56.0	638	59.9	655	66.8
DP90	615	55.2	600	56.7		
CS50	635	56.7	612	57.7		
Sicala V2	650	57.6	645	60.5	715	70.5
Siokra V-15	655	58.4	625	58.7	630	65.5
Siokra L23	652	58.2	640	60.0		
CS189+	680	60.2	580	55.3		
CS8S			615	58.0	568	59.5
Siokra S324					590	60.0
Exp 523					625	65.0
Exp 613	658	58.5	595	56.5	635	65.7
Exp 97	677	60.0				

Table 4.6b: Appearance of First Flower in Cotton Varieties

Site:	"Coolabah" Merah Nth 1994/95		"Togo Station" Myall Vale 1994/95		"Nandewar" Boggabri 1994/95	
Variety	GDDs from Planting	Days from Planting	GDDs from Planting	Days from Planting	GDDs from Planting (Est.)	Days from Planting (Est.)
Siokra 1-4	1027	82.0	982	82.5	1061	93
DP90	1035	82.5	982	82.5		
CS50	1050	83.4	982	82.5		
Sicala V2	1055	83.6	980	82.2	1061	93
Siokra V-15	1002	80.7	982	82.5	1061	93
Siokra L23	1050	83.4	982	82.5		
CS189+	1062	84.2	982	82.5		
CS8S			975	82.0	957	85
Siokra S324					1061	93
Exp 523					1061	93
Exp 613	1058	83.8	982	82.5	1061	93
Exp 97	1065	84.3				

Table 4.6c: Squaring Rates in Cotton Varieties

Site:	"Coolabah" Merah Nth 1994/95	"Togo Station" Myall Vale 1994/95	"Nandewar" Boggabri 1994/95
Variety	Squares/GDD	Squares/GDD	Squares/GDD
Siokra 1-4	0.651	0.410	0.503
DP90	0.664	0.416	
CS50	0.572	0.428	
Sicala V2	0.644	0.410	0.365
Siokra V-15	0.568	0.354	0.376
Siokra L23	0.623	0.394	
CS189+	0.709	0.472	
CS8S		0.448	0.378
Siokra S324			0.334
Exp 523			0.497
Exp 613	0.541	0.428	0.465
Exp 97	0.661		

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Chapter 5

Crop Modelling and Yield Estimation following Hail Damage

Introduction:

There is currently much discussion in the cotton industry in regard to hail damage loss insurance. Current policies are seen to be inadequate in some respects in failing to cover the grower for the true cost of hail damage to a crop. Current loss assessment methods involve assessment of loss at the time of the damage. It has been suggested that a more equitable insurance scheme would involve end-of-season loss assessment where a grower could be reimbursed for any yield loss incurred and also the extra costs involved in bringing a hail damaged crop through to maturity. Such a scheme would require the application of 'good' agronomic management post hail to minimise yield loss for the scheme to be equitable.

Crop yield simulation models have been developed in the cotton industry which may assist in predicting the potential yield of a cotton crop prior to damage by hail. In the process of carrying out this work, a significant amount of data has been collated on the yield response of cotton to hail damage at various stages of crop growth. The aim of this exercise is to evaluate current yield models for their response to hail. The modification of such models to be sensitive to hail damage would enable more accurate damage assessment and yield prediction for loss adjustment purposes. The following report examines the OZCOT cotton yield simulation model, developed by the C.S.I.R.O. at the Australian Cotton Research Institute, and its potential for use in cotton hail loss adjustment.

Computer Simulation of Hail Damage

Report by A. B. Hearn

Introduction

The CRDC has funded a research project to study the management of hail damaged crops. Ms Karyl-Lee West executed the project in a series of experiments in which hail damage was mechanically simulated. A component of the project was to use a computer model of the cotton crop to simulate the crop's response to hail damage. The purpose of the simulation was to test the ability of a model to predict the yield loss. The simulated yield loss would then be compared with yield loss assessed by the methods used in the insurance industry. The methods currently used in the insurance industry were developed in the USA, and are not necessarily applicable to Australian conditions and Australian varieties. The study would indicate if computer simulation might be a better way of assessing hail damage than current methods.

Two of the experiments done were selected for the simulation study because more detailed data had been collected in these than in others. Ms West supplied details of the experimental treatments, and the data collected. This report describes the computer simulation of the damage done by hail to the cotton plant. and the concomitant effect on yield.

The Experiments

The experiments were done at the ACRI in the 1991-92 and 1992-93 seasons. They were identical and consisted of two levels of damage at four dates applied to two varieties. The varieties were DP90 and Siokra 1-4. The damage levels were nil and moderate. The moderate damage at the four dates in each season are described in Table 1 using the hail damage assessment methods used in the insurance industry.

TABLE 1: Damage treatments.

Stage	1991-92	1992-93	Cut off	Fruiting branch number/plant	Large bolls number/plant	Defoliation %
V3	1 Nov	15 Nov	C0 80%, CC 20%	-	-	100
V5	29 Nov	30 Nov	C0 50%, CC 40%, C1 10%	-	-	100
R8	17 Jan	14 Jan	C10 100%	2	1.5	30
R12	2 Mar	5 Feb	C13 100%	2	1.5	30

The symbols V3, R8 etc refer to the growth stage; V is the number of vegetative nodes at the time of damage, R is the number of reproductive nodes, or nodes bearing fruiting branches (or sympodia). Damage is assessed on the basis of four observations:

- the percentage of plants in each class defined by the node above which the mainstem is cut off - C0 = below cotyledonary nodes (plants therefore die), CC = cotyledonary nodes left; C1 = 1st mainstem node left, C2 = 2nd mainstem node left etc;
- the number of fruiting branches lost in addition to those lost on the portion of the mainstem cut off;
- the number of large bolls lost in addition to those lost on the portion of the mainstem cut off and the additional fruiting branches lost;
- defoliation - the percentage loss of the leaf area left after stem and branch loss.

The agronomic data needed for simulation are given in Table 2.

TABLE 2: Agronomic data.	1991-92	1992-93
Sowing date	9 October 1991	7 October 1992
Plant population - plants per sq m	DP90 = 9.0; Siokra = 9.2	DP90 = 10.8; Siokra = 10.1
Soil and fertiliser nitrogen - kg per ha	88 & 100	88 & 138
Irrigation dates - day of year	274, 295, 2, 13, 21, 52, 71	262, 356, 7, 15, 25, 39, 49, 77

The developmental data that had been collected during the season are estimates of LAI, and counts of squares, small and large green bolls and open bolls. Yield data consists of weight of lint in sequential picks, total lint and numbers of bolls picked. The boll size was estimated by dividing lint yield by numbers of bolls harvested and assuming a lint percentage of 40%.

The OZCOT model

The OZCOT model was developed at what is now the ACRI between 1981 and 1992, and successfully simulates the effects of sowing date, water supply, nitrogen supply, weather and region on development and yield. OZCOT does not explicitly model the branching structure of the plant. However the branching structure is implicit in the model, which uses the cumulative number of fruiting points produced as a measure of the size of the branching structure. The geometry of the branching architecture requires that the number of fruiting branches is a function of the square root of the cumulative number of fruiting points. As the plant develops not all of the fruiting branches continue to produce fruiting points. The proportion of fruiting branches actively producing new fruiting points decreases as the crop develops in response to internal stress in the plant resulting from competition for nutrients. OZCOT produces a cohort of new fruiting points and leaves every day as a function of the number of active fruiting branches.

Modifications to OZCOT

OZCOT was amended in order to simulate hail damage. Subroutine CINPUT1 was modified to read a new input file, HAIL.INP, which contains the details of the damage specified in Table 1. Subroutine PLTGRW calls a new subroutine, HAIL, which changes the appropriate state variables on the day the hail occurs. Subroutine ISTSQ was modified to take account of any delay to the first square event caused by hail damage. Minor modifications were made to OZCOT1 and INIT and a new common block created. OZCOT only executes hail damage if it detects that file HAIL.INP is present. These additions do not therefore prevent this new hail sensitive version OZCOT being used for crops without hail damage.

Subroutine HAIL estimates from the C and the V or R values (Table 1) how many mainstem nodes have been cut off. Separate procedures are then followed depending whether the damage is done in the vegetative (V) or reproductive (R) stage to damage the plant parts.

In the vegetative stage the delay to the first square event is estimated from the number of nodes lost, giving each a value of 42 day degrees, plus the time needed for vegetative branches to start growing from the surviving axillary buds. Victor Sadras (pers. comm.) has observed that the delay in producing vegetative branches is 78 day degrees for DP90 and 58 day degrees for Siokra. The estimate of delay is passed to subroutine ISTSQ. The area of each cohort of leaves is then reduced by subroutine HAIL according to the percentage in Table 1.

In the reproductive stage, even though some fruiting sites remain on the plant after hail damage, it is assumed that they are on inactive branches, or are on branches that become inactive as a result of hail damage. Consequently the number of active fruiting sites is reset to zero for estimating production of new fruiting points. OZCOT uses a similar procedure when water stress stops production of fruiting points.

Next the number of existing daily cohorts of fruiting points and leaves affected by cut off of the mainstem is estimated. The fraction of existing cohorts affected is the fraction of the reproductive nodes (mainstem nodes bearing sympodia) that have been cut off. Not all of each cohort is lost when the mainstem is cut off, because part of a cohort is on the fruiting branches borne below the node where the mainstem was cut off. It is assumed that all of the most recent cohort is lost and none of the last cohort produced before the oldest node cut off. Therefore the fraction of each cohort lost decreases linearly from 100% for the most recent down to nil for the last cohort before the cut off. Next, the fraction of fruit and leaves lost from the remaining fruiting branches is estimated as a function of the fraction of branches lost below the mainstem cut off point (the number of branches lost in Table 1 divided by the number of branches, that is reproductive nodes, below the cut off point). The number of large bolls (as defined for hail damage assessment) lost is then distributed uniformly among the cohorts of medium and large bolls (as defined in OZCOT). Likewise the percentage loss of the leaf area left after stem and branch loss has been taken into account is distributed uniformly among the remaining cohorts of leaves.

Finally the loss of nitrogen is estimated as proportional to the loss of leaf area.

Simulation

Control Treatments

The first step was to run OZCOT for the control treatments in order to check that the simulated yield levels were satisfactory. Based on knowledge of the experimental site, it was assumed soil conditions (slope, drainage) and fertility (nitrogen expressed as initial soil N and potential boll weight) were above average. This was accounted for with a waterlogging threshold of water content/capacity > 0.92 instead of the default 0.87, soil nitrogen 88 kg per ha instead of 44, and a factor of 1.5 instead of 1.3 to estimate the potential boll size from the standard boll size. Standard boll size is the value used by breeders and agronomists to characterise a variety, based on the average of trials over a large number of sites and seasons. The results of the runs for the control treatments in Table 3 and Figure 1 show that OZCOT simulated the yield levels of the controls reasonably well.

Hail Damage Treatments

Most interest focuses on yield. In presenting the results, yield will be addressed first. Two other aspects will then be examined: first, how well the procedures in subroutine HAIL simulated the actual damage in terms of loss of plant parts; and second, how well OZCOT simulated subsequent crop growth and development in response to that damage. The latter are important in analysing any failure of the model to simulate effect on yield.

Yields & yield components

Table 3 shows the observed and simulated yields and yield components for all treatments. Yields are also show graphically in Figure 1. OZCOT did not predict the yield of hail damaged crops as well as that of intact crops. Simulation of the effect of damage on yield was variable, with some treatments reasonable, while other treatments were not. The description "reasonable" is a subjective and relative term used in the context of experience of the limitations of simulation. "Reasonable" may not be acceptable for all purposes. The issue here is whether it is acceptable for hail assessment, which will be addressed later.

The following treatments were reasonable: V5 in 1991-92, and V3 and R12 in 1992-93. Poor results were obtained with the treatments V3, R8 and R12 in 1991-92 with under-estimation of yield, and R8 in 1992-93 with over-estimation of yield. Treatment V3 in 1991-92 actually increased yield, while OZCOT predicted a 25% decrease. The worst result was R8 in 1992-93 when OZCOT over-estimated yield by a factor of 3. The correlation coefficient between observed and simulated yields was 0.53 ($n=20$, $p<0.05$), and the predicted yields were biased, because low yields over-estimated.

OZCOT predicted the numbers of harvested bolls better than it predicted yield. The overestimate of the yield of R8 in 1992-93 was associated with overestimating the number of harvested bolls rather than boll size. The underestimate of yield in V5, R8 and R12 in 1991-92 are all the result of underestimating the number of harvested bolls.

OZCOT failed to predict the extent of increase in boll size in treatments V5, R8 and R12 in 1991-92. This increase in boll size is a very interesting compensatory response that needs further study. OZCOT did predict on in increase in boll size in R8 and R12 , but not the degree observed. Potential boll size appears to be much larger than assumed in OZCOT.

The correlation coefficients between observed and simulated values are 0.79 and 0.69 ($n=20$, $p<0.001$) for boll numbers and boll size respectively, and are appreciably greater than that for yield. These suggest there is potential for improvement if better boll number and boll size prediction could be made simultaneously.

Because the results of simulating the effect of hail damage on yield are patchy, it might be concluded that the results are not good enough for hail damage assessment. However OZCOT's simulation was marginally better than the insurance industry's damage assessment method (or the insurance industry's damage assessment method was worse!). The damage had been assessed by the insurance industry's method. This assessment, expressed as a percentage loss of yield, is shown in Table 4 together with the observed yield loss and the simulated yield loss for comparison. The correlation coefficients between the observed loss and the simulated and assessed losses are 0.29 and 0.05 ($n=16$) respectively. Simulation was better than the assessment, that is closer to the actual yield loss, in 11 cases, worse in 2, and neither better nor worse in the remaining 3 cases.

Loss of plant parts

Simulation by OZCOT of the actual mechanical damage done to the plants, as opposed to the effect on subsequent development, was evaluated by comparing measured LAI and counts of squares and bolls before and after damage with the simulated values. The comparison of observed and simulated values in Table 5 shows how well the procedures in the new subroutine HAIL simulated the loss of plant parts caused by hail. The evaluation is limited because on some occasions an interval of up to 24 days elapsed between damage and the next count or measurement of LAI. A further limitation was that in the vegetative stage LAI was very small, and there were no squares or bolls (or very few in V5 in 1991-92). In general given the limitations, the actual loss of plant parts was well simulated.

Observed and simulated reductions in LAI, and in numbers of squares and bolls, were similar for all treatments with the notable exception of treatment R8 in 1992-93. In this treatment OZCOT underestimated the number of bolls before damage by a factor of 3, and overestimated the number after damage, also by a factor of 3, because OZCOT was late in setting bolls compared with the actual crop. It is noteworthy that OZCOT was least successful in predicting the yield of this treatment.

LAI development

In most cases the simulation of LAI development was excellent. Figure 2 shows the Siokra treatments in 1991-92 as examples. OZCOT simulated LAI development well in the control and in the damage treatments both before and after damage. Treatment V3 was least satisfactory. The decline in simulated LAI at the end of the season in the control was the effect of defoliation. On the damage treatments simulated defoliation occurred later and is not shown because maturity was delayed. An index was constructed to show how well the simulated pattern of LAI development matched the observed pattern. The values of the index for each treatment are given in Table 6. Of the 15 treatments not shown in Figure 2, 8 were as good or better than those in Figure 2, and one (V3 DP90 in 1992-93) was appreciably worse.

TABLE 6: Index of success for simulation of LAI; 0.0 = poor, 1.0 = good.

Treatment	1991-92		1992-93	
	DP90	Siokra 1-4	DP90	Siokra 1-4
Control	0.81	0.89	0.83	0.84
V3	0.60	0.69	0.42	0.63
V5	0.58	0.90	0.76	0.72
R8	0.62	0.72	0.86	0.62
R12	0.95	0.80	0.95	0.57

Fruiting curves

The simulation of the fruiting pattern was not as accurate as simulation of the pattern of LAI development, and was much more variable. Figure 3 shows the square and green boll curves for the Siokra treatments in 1991-92, the same treatments that were used to illustrate simulation of LAI in Figure 2. Treatment V5 is particularly poor; the others were satisfactory. It can be seen in Figure 3 that OZCOT responded to hail damage in treatments V3 and V5 with delayed square production when compared with the control. The delay was consistent with the observed delay in V3 (2 weeks), whereas in V5 the simulated delay was 25 days but the observed delay was 40 days. This failure to predict the length of the delay in V5 is the reason for the poor simulation of fruiting. In the following year the delay to squaring in treatment V5 was less and was accurately predicted by OZCOT. OZCOT is not sensitive to whatever factor caused the different response to V5 damage in 1991-92 compared with 1992-93.

Table 7 gives the index of the relative success of OZCOT in simulating fruiting for all treatments. Of the 15 treatments not shown in Figure 3, 8 were similar to or worse than treatment V5, and 7 were similar to the other treatments. Treatment R8 in 1992-93 was particularly poor; this was the treatment in which yield was least well predicted.

TABLE 7: Index of success for simulation of fruiting; 0.0 = poor, 1.0 = good.				
	1991-91		1992-93	
	DP90	Siokra 1-4	DP90	Siokra 1-4
Control	0.35	0.41	0.11	0.01
V3	0.34	0.34	0.42	0.07
V5	0.09	0.15	0.18	0.48
R8	0.16	0.37	0.00	0.00
R12	0.39	0.47	0.34	0.24

Data on boll opening are not shown, but OZCOT did not predict it well. The simulated onset of boll opening was later, and the subsequent rate of opening slower, than the observed, whether assessed by numbers of open bolls or sequential picks. Consequently OZCOT indicated that the hail damage treatments would cause a greater delay in maturity than actually occurred.

Improving OZCOT's prediction of response to hail damage.

Comparison treatment by treatment of the yield data in Tables 3 and 4 with Table 6 (success in simulating LAI development) and Table 7 (success in simulating the pattern of square and boll production) shows that failure to predict yield loss was not associated with failure to simulate LAI development or the course of fruit production. It was expected that where the response of LAI development and fruiting curves to hail damage was well simulated that yield response would also be well simulated, and vice versa. It was not so, and there was no correlation between simulating fruiting dynamics well and predicting yield well, with the notable exception of treatment R8 in 1992-93.

The lack of correlation between success in simulating the course of development after hail damage and in predicting yield was disappointing. We are left without an explanation of why OZCOT simulated the yield response poorly in some treatments and without any guide to improving the prediction.

One option is to count fruit numbers immediately after hail occurs and use these as additional input into the model. A start could be made with data from the current experiments but the time that elapsed between the damage and the count is too long in some cases. Another option is to determine the potential boll size more precisely. A further option is to model the dynamics of the branching structure of the plant explicitly rather than implicitly as currently.

CERCOT is the next generation of model which has been developed from OZCOT with a more robust soil water and soil nitrogen and plant nitrogen components. CERCOT should simulate the loss of nitrogen from the plant resulting from hail damage more accurately. CERCOT is also more likely to be able to detect anomalous soil nitrogen and water conditions. Both loss of nitrogen from the plant and anomalous conditions might have contributed to OZCOT's failure to predict yield loss more accurately on some occasions, in R8 in 1992-93 for example, though there is no evidence that this is the case.

Conclusions

OZCOT did not simulate hail damaged crops as well as it simulated intact crops. However the model has the potential to predict the yield loss caused by hail damage more accurately, or at least less inaccurately, than the method currently used by the insurance industry. There are a number of options that could be explored in future work to improve the ability of OZCOT to predict the yield loss caused by hail damage.

This has been a preliminary study of computer simulation of hail damage to cotton. It has been very worthwhile, and has pushed OZCOT to the limit and tested it in a new way. The way is open for a more detailed study to explore the options suggested for improving OZCOT's performance. The experimental data used in this study could be augmented by using the other experiments done by Ms West in this project.

Hail damage causes severe damage to the branching structure of the plant. OZCOT might do better if the branching structure were explicitly modelled. We lack data to do this on some aspects of the dynamics of the branching structure of the cotton plant. There is a community of interest in this topic involving several groups: the virtual modelling at CTPM, the insurance industry, Victor Sadras at ACRI studying response to terminal damage by pests, and Steve Milroy, Mike Bange and myself at ACRI developing OZCOT/CERCOT. Two questions arise from this community of interest:

- should OZCOT and its successor CERCOT model the dynamics of the branching structure explicitly rather than implicitly as currently, and how could the virtual plant algorithms (the L_system) be used without using the 3-D virtual graphics with its large computer power demands?
- should a joint research project be proposed and funded to study the dynamics of the branching structure by the interested parties?

TABLE 3: Observed and simulated yields and yield components.

Year	Variety	Treatment	Bolls/m		Lint kg/ha		Sc/boll g	
			Actual	Simulated	Actual	Simulated	Estimated	Simulated
1991-92	DP90	Control	123.9	110.4	2125	2216	4.29	5.14
		V3	125.3	89.4	2571	1884	5.13	5.40
		V5	61.3	84.5	1968	1658	8.03	5.03
		R8	68.3	51.6	2142	1259	7.84	6.26
		R12	67.0	48.9	1928	1147	7.19	6.02
	Siokra 1-4	Control	120.0	117.9	2118	2310	4.41	4.66
		V3	117.0	95.1	2575	1900	5.50	4.76
		V5	68.3	84.3	1978	1819	7.24	5.14
		R8	71.8	53.3	2076	1367	7.23	6.10
		R12	71.0	53.9	1845	1270	6.50	5.61
1992-93	DP90	Control	121.1	120.1	2430	2147	5.02	4.58
		V3	138.8	122.6	2105	2199	3.79	4.60
		V5	124.5	108.8	1938	1570	3.89	3.70
		R8	34.0	81.8	440	1331	3.24	4.17
		R12	70.0	65.9	1359	1283	4.85	4.99
	Siokra 1-4	Control	125.7	128.1	2552	2252	5.08	4.18
		V3	137.8	135.2	2552	2299	4.63	4.05
		V5	129.5	112.7	2123	1693	4.10	3.58
		R8	33.3	77.5	421	1557	3.16	4.79
		R12	73.0	66.7	1365	1574	4.67	5.62
Correlation coefficient			0.79		0.53		0.69	

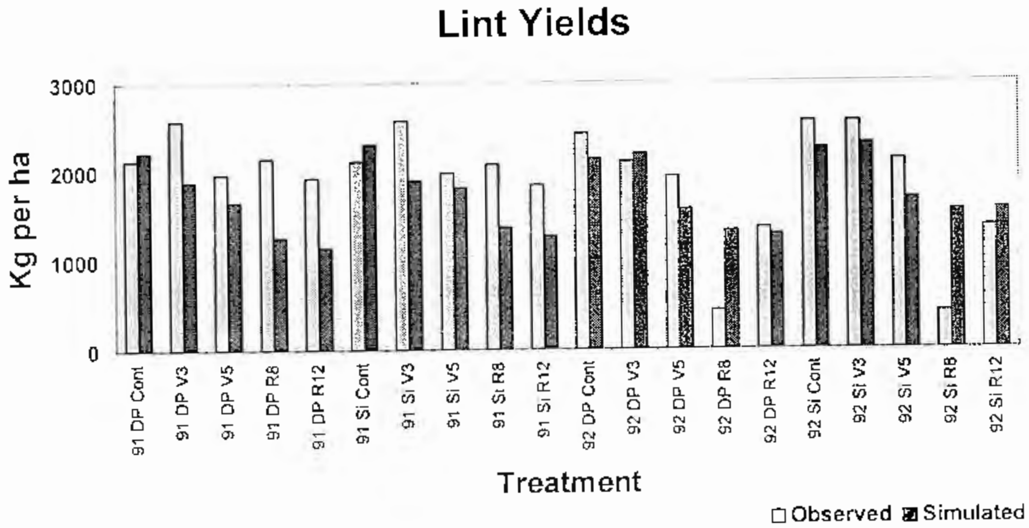
TABLE 4: Percentage yield loss .

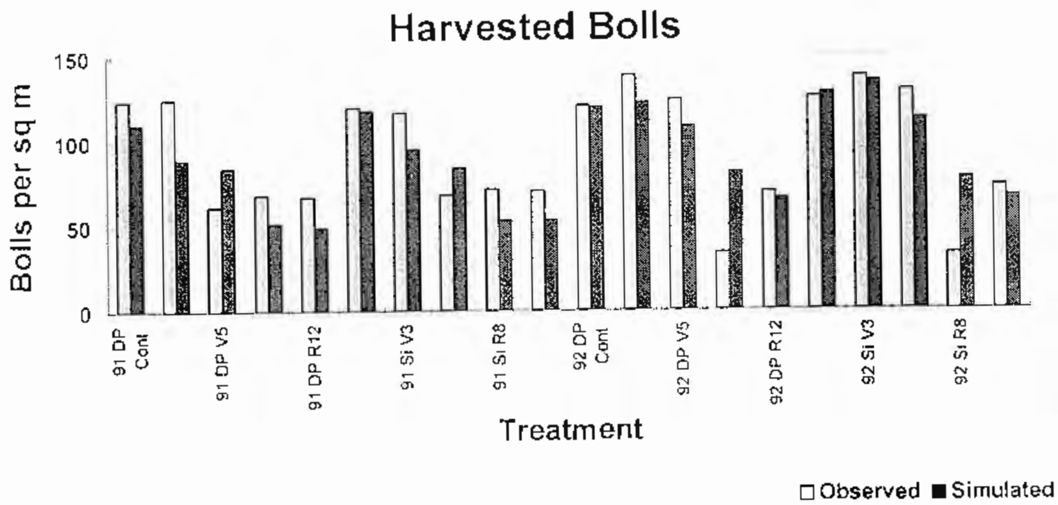
Year	Variety	Treatment	Actual	Simulated	Assessed
1991-92	DP90	V3	-21.0	15.0	59.9
		V5	7.4	25.2	57.8
		R8	-0.8	43.2	46.0
		R12	9.3	48.2	71.6
	Siokra 1-4	V3	-21.5	18.5	59.9
		V5	6.6	22.2	57.8
		R8	2.0	42.6	46.0
		R12	12.8	46.9	71.6
1992-93	DP90	V3	13.4	-2.4	70.7
		V5	20.2	26.9	45.4
		R8	81.9	38.0	59.1
		R12	44.1	40.2	64.1
	Siokra 1-4	V3	0.0	-2.1	70.7
		V5	16.8	24.8	45.4
		R8	83.5	30.9	59.1
		R12	46.5	30.1	64.1
Correlation with observed				0.29	0.05

TABLE 5: Observed and simulated squares, bolls and LAI before and after hail damage.

Year	Variety	Treatment		Squares		Bolls		LAI	
				before	after	before	after	before	after
1991-92	DP90	V3	Observed	-	-	-	-	0.02	0.00
			Simulated	-	-	-	-	0.02	0.00
		V5	Observed	5	0	-	-	0.06	0.04
			Simulated	9	0	-	-	0.08	0.00
		R8	Observed	141	26	20	35	3.21	1.17
			Simulated	129	36	38	32	2.55	1.15
		R12	Observed	-	-	105	103	2.76	1.24
			Simulated	-	-	27	28	3.21	1.44
	Siokra 1-4	V3	Observed	-	-	-	-	0.02	0.00
			Simulated	-	-	-	-	0.02	0.00
		V5	Observed	12	0	-	-	0.06	0.02
			Simulated	10	0	-	-	0.08	0.00
		R8	Observed	152	19	37	35	2.16	0.89
			Simulated	154	27	44	38	1.92	0.88
		R12	Observed	-	-	118	18	2.47	1.26
			Simulated	-	-	117	30	2.54	1.15
1992-93	DP90	V3	Observed	-	-	-	-	0.02	0.00
			Simulated	-	-	-	-	0.03	0.00
		V5	Observed	-	-	-	-	0.14	0.00
			Simulated	-	-	-	-	0.12	0.00
		R8	Observed	153	36	36	13	2.48	0.88
			Simulated	122	32	14	38	2.29	1.52
		R12	Observed	55	0	114	35	3.67	1.90
			Simulated	94	29	91	50	3.70	0.18
	Siokra 1-4	V3	Observed	-	-	-	-	0.02	0.00
			Simulated	-	-	-	-	0.03	0.00
		V5	Observed	-	-	-	-	0.15	0.00
			Simulated	-	-	-	-	0.12	0.00
		R8	Observed	201	43	51	12	1.41	1.00
			Simulated	130	32	15	41	1.70	1.07
		R12	Observed	65	4	173	38	4.35	2.46
			Simulated	110	30	102	54	2.63	1.27

Figure 1: Observed and simulated yields and yield components.





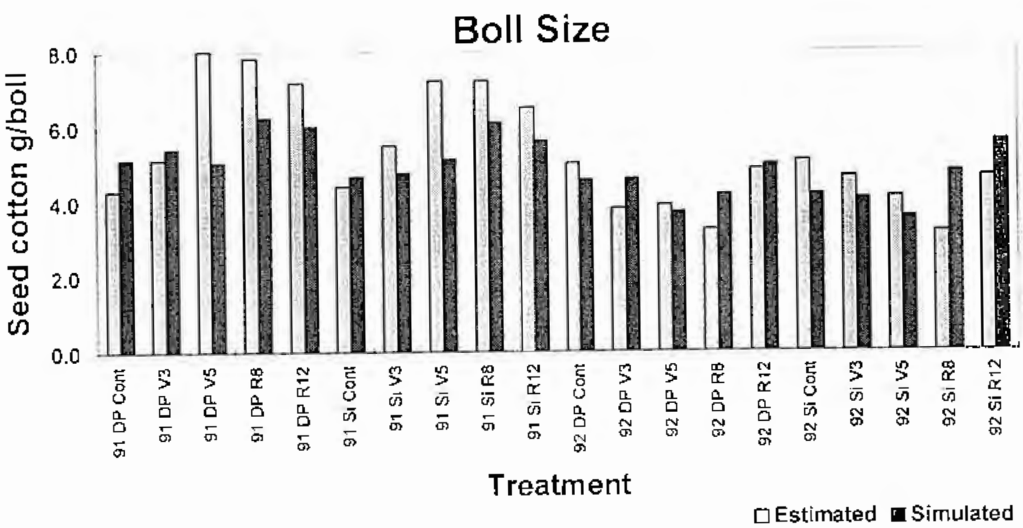


Figure 2: Observed and simulated LAI for Siokra 1-4 in 1991-92.

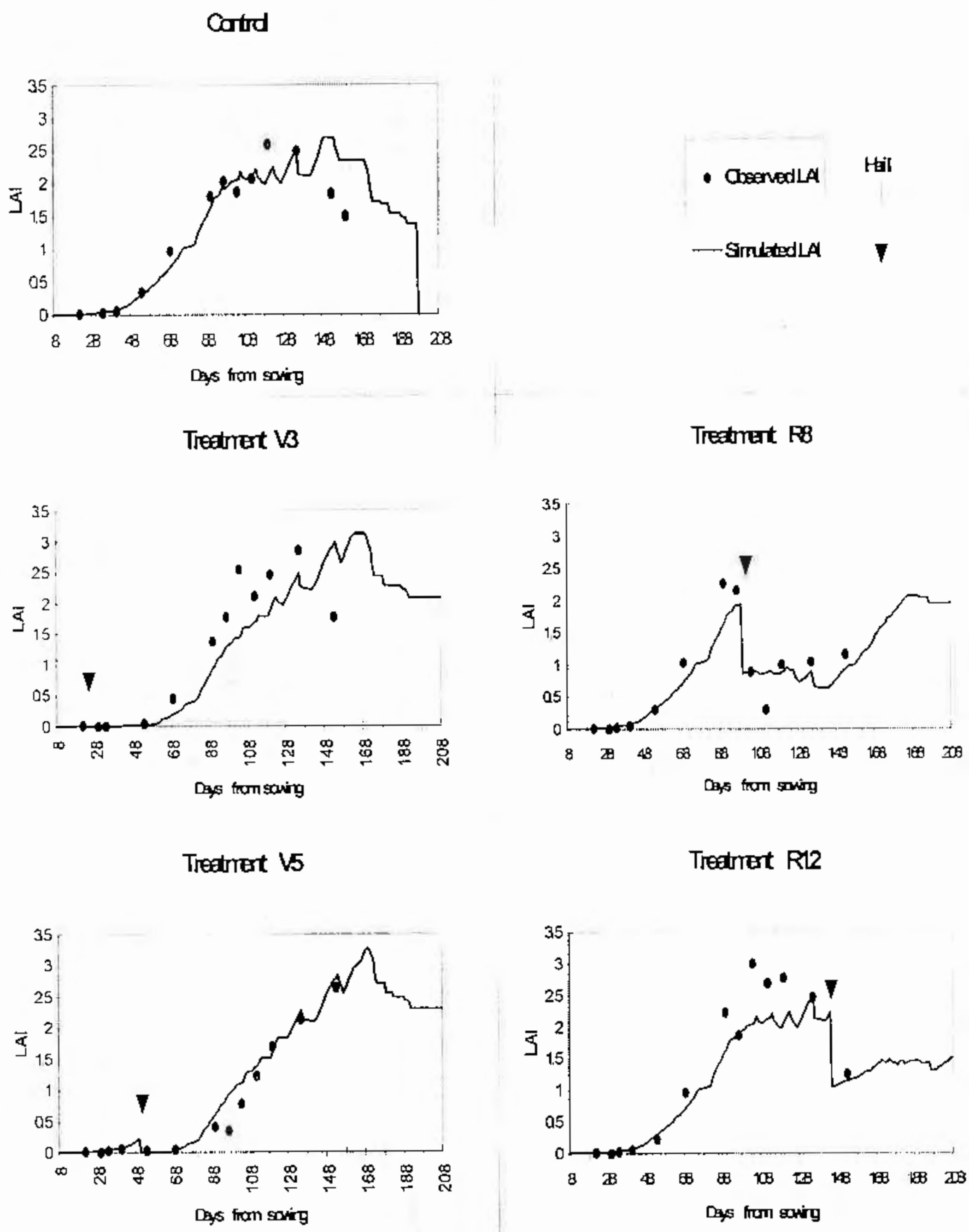
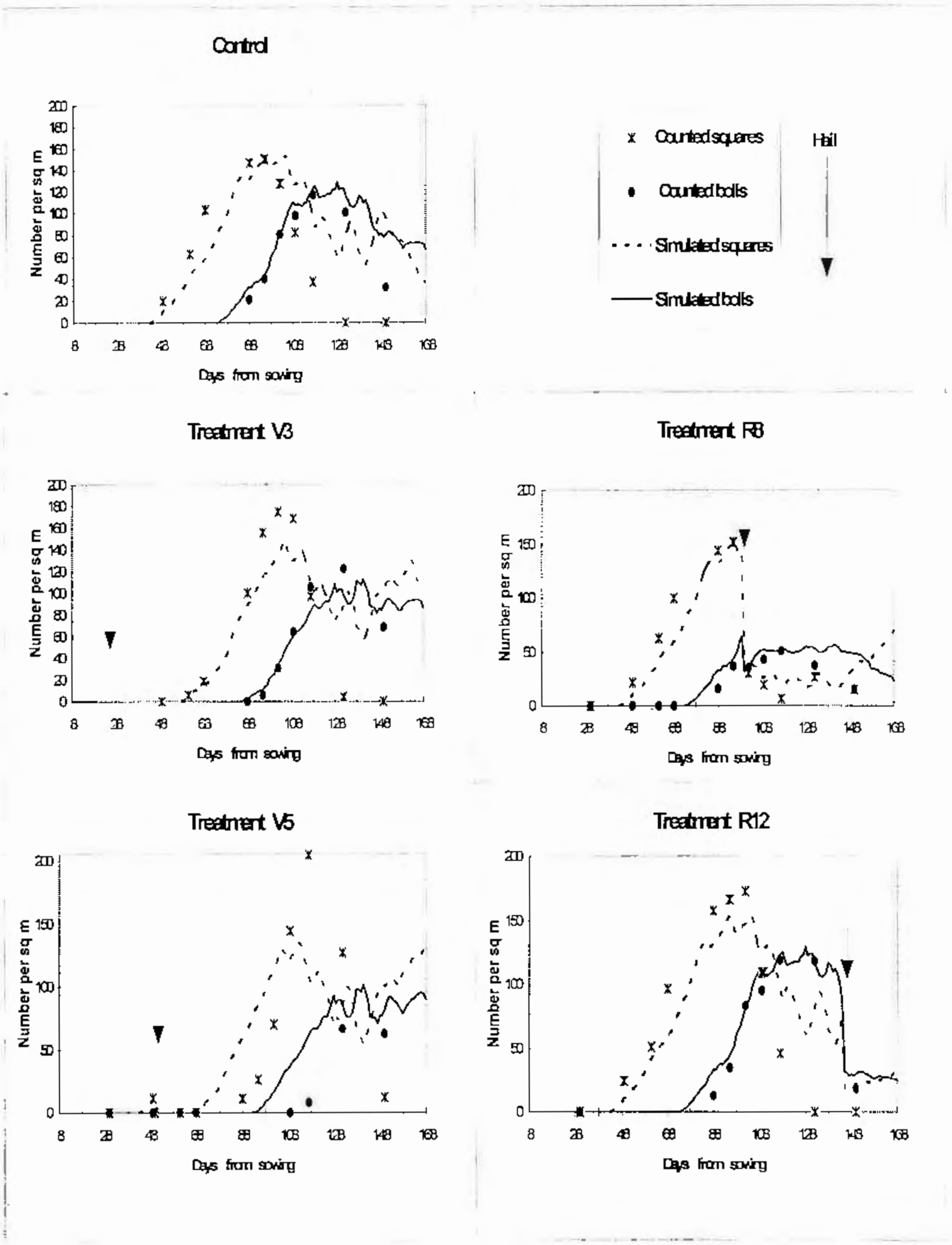


Figure 3: **Observed and simulated fruiting for Siokra 1-4 in 1991-92.**



Chapter 6:

Guidelines for Managing Hail Damaged Cotton

6.1: Introduction

Australian cotton production areas are prone to significant damage by hail storms and hail damage can be an important source of economic loss to growers. Hail insurance schemes over the last decade have only reimbursed production costs to growers for costs incurred up to the time of the hail strike. Only in recent years have insurers begun to look at yield based policies where growers can insure a given crop yield or policies where growers can insure against a loss of profit. With the expense of insurance, all growers are not insured. Where growers are insured, insurance payouts following damage do not cover the full cost of the hail damage to the grower. In most cases, growers need to attempt to regrow the crop to attempt to recoup losses.

The aim of this work has been to identify optimum management strategies for hail damage and develop guidelines for overcoming management problems and hence assist in maximising crop returns following hail damage.

Where early season hail damage is incurred, management problems centre around what would be considered a viable plant population to carry on with and what would be considered a last date for replanting following hail damage. Whereas following damage later in the growing season where the grower is attempting to regrow the crop from the existing plant stand, grower questions relate to optimum water, insect, nutrient and growth regulator strategies for hail damaged cotton. With late season damage, the critical question is when is it too late to try and regrow a crop following damage and when faced with not being able to economically regrow the crop, how to rescue what remains following the damage.

The amount of regrowth which can be expected from a cotton crop following a hail strike depends on a combination of factors:-

1. Severity of the damage.
2. Growth Stage of the crop at the time of damage
3. Length of the growing season remaining.
4. Resources available.
5. Weather conditions following damage.

The severity of the hail damage may in itself dictate that a crop would be abandoned. But uneconomic levels of yield recovery would also be expected where the crop was damaged at more advanced physiological growth stages or if damaged at a date in the growing season where insufficient time remained for initiation and maturation of regrowth. It is also inadvisable to regrow a crop following damage where the cost of producing the regrowth cotton outstrips the expected return. Besides financial resources, the availability of other crop inputs such as irrigation water or rain events can dictate whether a grower continues with a crop.

Overriding all these factors is the weather conditions following damage. The rate of growth and development of cotton is dictated by climatic conditions. Therefore, the recovery of the cotton crop following hail damaged is controlled predominantly by the weather conditions. Any crop management option employed by growers to encourage or manage regrowth can only work within the restrictions imposed by the weather conditions. Only where temperatures etc. are conducive to growth will crop recovery be at a rate where the manipulation of nutrient levels, growth regulator use, insect and water strategies will be effective. Where conditions are overcast, wet conditions or low temperatures occur, regrowth is reduced or does not occur and manipulation of these areas of crop management will not improve recovery.

Decisions to be made in regard to the management of hail damaged cotton crops change through the season and relate to the stage of crop development at the time of damage and the proportion of the growing season remaining after the damage. For the purposes of crop management decisions following hail damage, it is useful to divide the growth of the crop into three development phases:-

1. Planting Period (ie. early season)
2. Growth and Development Period (ie. mid-season)
3. Maturation Period (ie. late season)

The planting period covers the period from first planting date through to a last economic replanting date with management decisions in relation to hail damaged cotton covering replanting options.

During the growth and development phase management questions relate to regrowing the crop after hail damage and cover the period from the last economic replant date through to the last square or flower date.

The maturation period covers the period from the last square date through to harvest and covering decisions in regard to the economics of continuing with a crop, or rescuing what remains after the hail damage within economic constraints.

We are therefore referring to management options/decisions relating to early, mid or late season hail damage. This breakdown of the crop development is used in this study. Not only do management options change with the date of the hail strike but they also differ depending on the severity of damage and the area damaged and importantly, the location of the crop or production area. In an attempt to cover as many of the variable effects of hail damage on management as possible, trials were carried out in all cotton production areas.

With such a wide range of management options employed by growers following hail damage and the variable success of these strategies, an important part of this program was to collate case studies on the management of all hail strikes recorded over the period covered by this work from all Australian cotton production areas. With a limited response from growers, consultants and insurance companies, conclusions drawn from case studies are based on a limited number of responses.

Trials were carried out in all cotton production areas where hail damage was recorded over the period. The success of these trials was related strongly to the weather conditions following the hail strikes and hence the vigour of regrowth.

6.2: Managing Early Season Hail Damage in Cotton

In general, from case studies, hail damage to cotton in the **early vegetative growth stages** does not pose difficult management problems nor increase production costs beyond that of the cost of replanting. The delay in crop development of a damaged stand where a grower continues with the existing stand is similar to that time required to re-establish the crop should the grower choose to replant. This is provided that the weather conditions allow replanting at an early date and within the normal planting period for the production area.

Hail damage in the later part of the cotton planting window when established cotton is in the **later vegetative growth stages** poses more significant management problems. Delays in crop development of the damaged crop due to hail are significant, as are yield depletions with delayed replanting date.

Late vegetative stage damage causes a number of management problems:-

1. **Crop development delays up to four weeks are recorded whether growers are regrowing a hail damaged stand or have replanted following hail damage.** (This does not include delays in defoliation or picking which are incurred should the delayed crop be exposed to late rain etc.)

2. **Crop production costs are increased by the delayed development.**

   In general, case studies show that late vegetative stage damaged crops replanted or regrown from damage require:-
   - 1-2 extra irrigations. Water usage may be low immediately following the damage as the crop recovers from the hail damage. But once growth recovers and development continues water usage returns to that of a normal crop. As development is now delayed, late irrigations are required if the damaged crop is to mature fully.
   - Extra insecticides and applied later in the season when insect resistance levels are higher and hence 'heavier' and more expensive sprays are required. The number of extra insecticide sprays is dependent on insect pressure in an area.
   - With a larger proportion of the boll load developing later in the season and under cooler conditions, low lint quality and in particular low micronaire is an inherent problem in hail damaged cotton. Low micronaire lint is heavily discounted in the marketplace.
   - Late defoliation under cooler conditions is usually more difficult and more expensive as multiple application of defoliants is required.
   - Late development exposes the crop to late rain and frosts which potentially increase defoliation and picking costs and make picking less efficient. Downgrading of lint quality may occur due to rain damage and frosts, growers returns are reduced with price discounts especially in respect to lint colour and leaf trash.

3. **Most policies are do not to cover the increased production costs inherent in regrowing a hail damaged and therefore late developing cotton crop.**

   Insurance payments for early season hail damage assume reasonable levels of crop recovery or assume that close to the original yield potential is achievable following replanting.

All growers of irrigated cotton replanted following mid-November hail damage found similar problems as crops yielded poorly and were expensive to grow and hence, were marginally economic if they produced a profit at all. The general recommendation from growers was to manage the damaged crops to minimise the delay in development and minimise production cost increases. It should be noted that in these case studies, the tendency of many producers was to maximise inputs into these crops and attempt to regrow the original potential yield. But in hindsight, the same producers stated they would not do the same again as the significant delay in development increased production costs dramatically and crops quickly become uneconomic.

Dryland producers are even more reliant on weather conditions and were also more willing to wait to see what the weather will do in respect to providing rain for replanting or recovery from damage. Case study growers recommend making clear decisions immediately following hail damage, in regard to continuing with a reduced stand or not. They found that by putting off replanting decisions or playing around with badly damaged cotton trying to encourage growth did not work but saw high input costs accumulate and delayed development exposed the crops to late rain and frosts and the associated picking problems. If replanting to other crops was not an option, there were strong recommendations to continue with reduced stands rather than waiting for further late rain events for replanting.

Some growers elected to replant to shorter season varieties following late vegetative stage or early squaring stage hail damage. Growers did not find a maturity advantage. It is suggested that the short season varieties currently available were not of sufficiently short maturity to compensate for the loss of growth season. Cotton varieties currently being developed in the short season breeding programs may provide better opportunities for replacing yield potential when replanting following hail damage.

In summary, points to remember in regard to early season damage:-

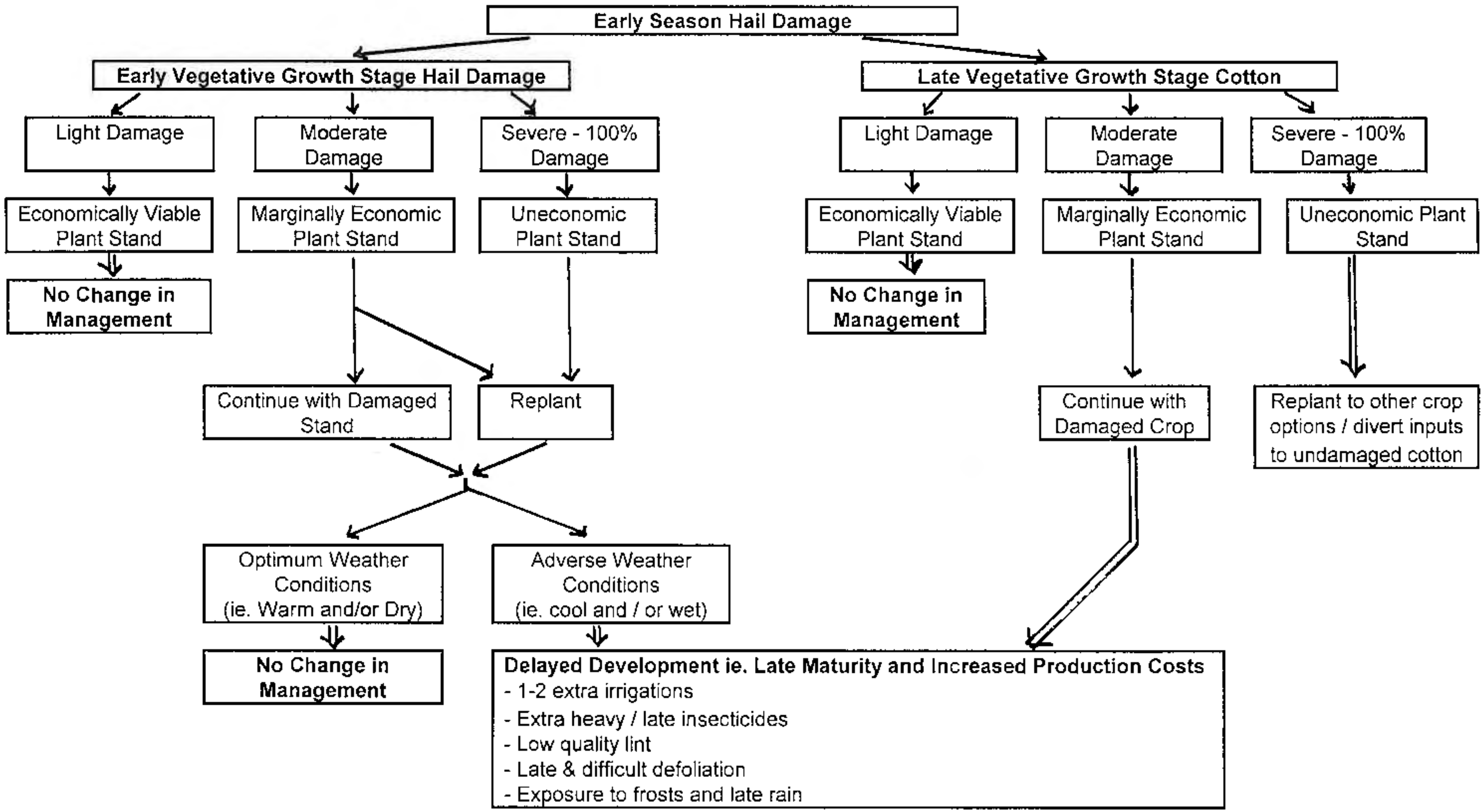
- **An economically viable plant population is required and guidelines are agronomically proven in respect to optimum plant populations.**

- **If the viable plant stand is low then a grower needs to weigh up the yield depletion from carrying on with the reduced stand and hail damage and compare this to the potential yield depletion from replanting at a much delayed date.**

- **Delayed development is a feature of both carrying on with a hail damaged crop and replanting. The extra costs and risks associated with growing late crops are high and not necessarily covered by hail insurance.**

- **Both yield depletions and increased production costs should be examined in determining the full cost associated with early season hail and compared to other cropping options and/or transferring resources to undamaged cotton.**

Figure 6.1: OPTIONS FOLLOWING EARLY SEASON HAIL DAMAGE (PRIOR TO LAST ECONOMIC PLANTING DATE)



6.3: Managing Mid-Season Hail Damage in Cotton

Points to be kept in mind when regrowing a cotton crop following mid-season hail damage:-

1. **The hail damage has removed part or all of the yield set up to the date of the hail strike.**
2. **There is a reduced season available to the grower over which to replace lost yield and a reduced overall crop yield potential.**
3. **Costs have been incurred in getting the crop to the stage of growth at which it was at the time of damage.**
4. **Further and increased costs will be now be incurred to regrow and mature the crop following the damage.**
5. **In regrowing a crop following hail damage, crop development is pushed into a later part of the growing season.**
6. **Growing late season crops involves problems with late watering, late insect control in a period of the season when insect control is difficult and expensive, late set bolls are maturing under cooler conditions and hence time to maturity is extended and lint quality problems are inherent, defoliation of late crops is difficult under the cooler conditions.**

Case studies show that not all these points are taken into account when growers are regrowing a crop following mid-season damage. Growers are often overly optimistic as to how much quality cotton can be produced in the reduced growing season. Many growers attempt to regrow the same yield that they were expecting prior to the hail strike and incur a series of problems and extra costs. Water, nutrients and growth regulators are thrown at crops in attempts to get crops growing following hail damage and then if successful, growers then need to pull up and mature the crop - a difficult proposition when climatic conditions override much of the management implemented and the strategies employed in attempting to manage a hail damaged crop

According to case studies, the growers who have been more successful in replacing lost yield potential whilst containing increases in production costs, are those who have attempted to regrow the damaged crop within the average 'climatic limits' of their growing season without attempting to extend crop cut out dates. They are therefore forsaking part of the potential yield recovery but attaining more complete maturation of the fruit set on regrowth and hence reducing the discounts for low micronaire cotton. This also reduces the chances of adverse weather conditions affecting defoliation and picking.

Typical management in these situations involved watering only as the crop water usage indicated and protection of all fruit initiated on regrowth with particular attention to early regrowth to encourage early fruit set on regrowth. The successful growers applied no further nitrogen fertiliser except where normal crop requirements were yet to be applied when the hail damage occurred. Hence, did not promote excessive vegetative growth by watering too early or applying excessive quantities of nitrogen. Foliar nitrogen and/or foliar mixes of micronutrients were applied to boost regrowth following the stress of hail damage but in particular where waterlogging was a problem. The use of growth regulators was also considered important in managing the regrowth of the crop canopy, although weather conditions dictated the rate and timing of their application.

The suggested strategy is to attempt to replace a realistic proportion of the original yield potential and mature it within the growing season remaining whilst containing input costs and hence reducing the overall financial loss.

With damage in the mid-season, the aim should be to get the crop regrowing following hail damage and then maturing fruit set on the regrowth, and to this end, nutrients and growth regulators play an important part in managing a cotton crop damaged by hail in the mid-season. In this study, field trials concentrating on these two areas of management were carried out on hail damaged crops in the various Australian cotton production areas which experienced hail over the period covered by the work.

NITROGEN FERTILISATION OF HAIL DAMAGED COTTON CROPS

The nutritional status of a crop is of primary importance in determining the ability of a crop to recover from hail damage. The aim with nitrogen fertilisation should be to obtain a maximum yield while minimising the problems of rank growth and delayed maturity.

Nitrogen application programs implemented by growers following hail damage have produced vegetative regrowth ranging from poor to excessive depending on the amount applied post damage and the amount applied pre-damage. Excessive nitrogen encourages vegetative growth and therefore delayed crop maturity. Inadequate nitrogen would not allow sufficient regrowth to occur. So the question is how to determine the nitrogen requirement of a hail damaged crop.

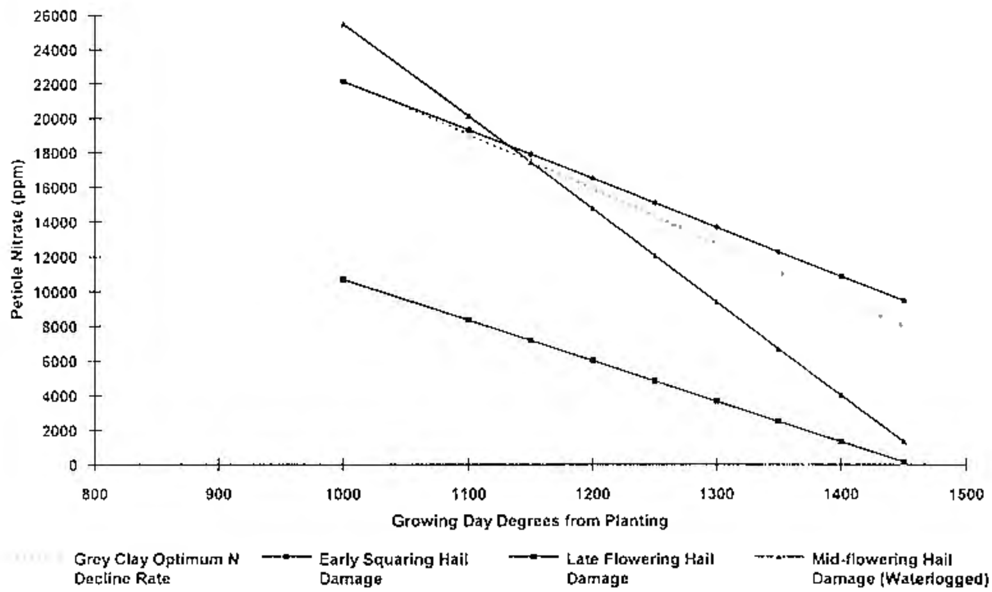
The crop growth stage at the time of damage and the timing of the hail strike within the available growing season dictates the amount of regrowth that could be expected following the hail strikes. Mature cotton has a reduced requirement for nitrogen as regrowth following damage is minimal compared to younger cotton following hail damage. Crops at a less mature growth stage at the time of damage under optimum weather conditions will initiate vegetative regrowth quickly and redevelop a full plant structure hence will have a greater nitrogen requirement.

Petiole nitrate levels were monitored in a series of hail damaged cotton crops to identify deficiency or stress as regrowth occurred. At each of these sites, nitrogen applied prior to the hail strike was considered adequate for production of a normal cotton crop. Following the hail strikes, overall petiole nitrate levels were high and the rate of decline of petiole nitrate as regrowth occurred was slower than or equal to optimum rates of declines indicating that nitrogen was not limiting for growth (Figure 6.2). Hence, further nitrogen fertilisation would not have increased yields. Only where prolonged waterlogging was imposed on young cotton attempting to regrow following damage, did nitrate decline at critical rates. Hence, monitoring the rate of decline of petiole nitrate in hail damaged cotton could be used to identify possible nitrogen deficiency.

But monitoring nitrogen levels by use of petiole analysis following hail damage is not usually practical. Either the rate of regrowth is too rapid to be able to diagnose a deficiency early enough to remedy the situation or wet weather conditions following damage make it impossible to carry out the petiole sampling. What these trials show is that nitrogen usage is similar in hail damaged crops regrowing after hail as in undamaged crops.

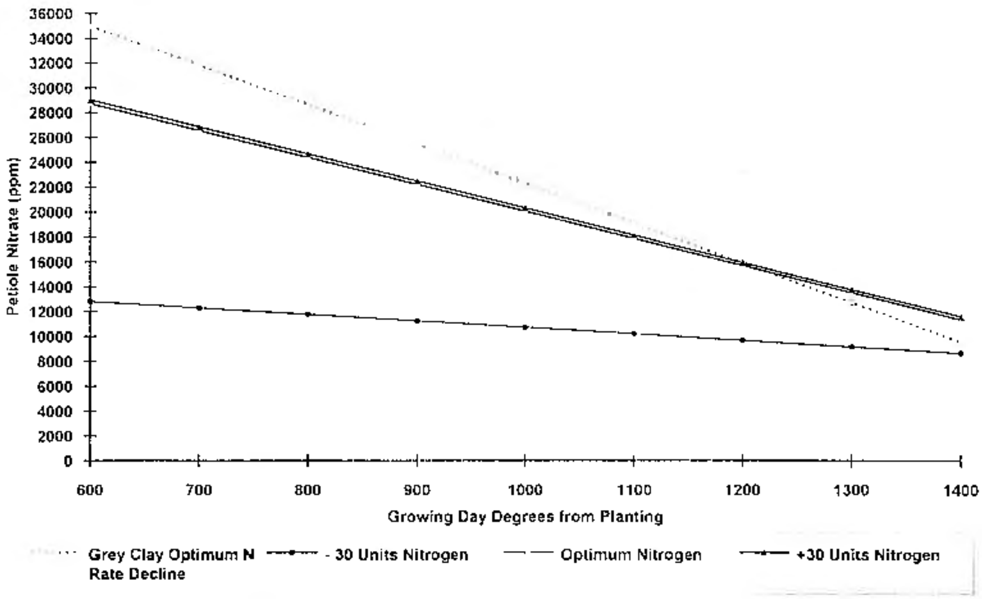
It is suggested that as a rule, larger quantities of nitrogen will only be required where the normal fertilisation program was not complete at the time of damage and hence less than optimum nitrogen levels were available to the crop or where conditions make the existing nitrogen inaccessible to the regrowing crop. A crop can only produce a given amount of growth in a season and in doing so uses nitrogen. Although some nitrogen is used in producing the plant material lost to hail damage, the growing season and yield potential is reduced and so the nitrogen requirements for the regrowth crop are proportionally reduced.

Figure 6.2: Decline in Petiole Nitrate in Cotton Regrowing After Hail Damage (Namoi Valley 1995/96)



The petiole nitrate decline plots show that the rate of nitrogen use in hail damaged cotton is similar to an undamaged cotton crop in the same growth phase. With the reduced growth season available and reduced yield potential, total nitrogen requirements for the crop should not be in excess of that for a normal crop. Confirming this idea, with a crop damaged by hail prior to the application of its full nitrogen requirement, a suitable site was available to test the response of a hail damaged crop to varying rates of applied nitrogen fertiliser. Petiole sampling results indicate that nitrogen would have been yield limiting where no nitrogen was applied. Application of sufficient nitrogen to bring levels up to the normal crop requirements brought petiole nitrate readings above critical levels (Figure 6.3). Addition of nitrogen in excess to a normal crop's requirement saw no further improvement in nitrogen uptake and it is suggested this application was excessive.

Figure 6.3: Decline in Petiole Nitrate Following the Application of Nitrogen to Cotton Regrowing After Early Season Hail Damage (Site: Auscott Narrabri, 1995/96).



FOLIAR FERTILISATION OF HAIL DAMAGED COTTON

Foliar fertiliser mixes are often applied to boost micronutrient levels in high yielding crops or to alleviating part of that stress imposed by waterlogging, hail damage etc. The effect of these applications on yield is difficult to measure.

In trials, the application of zinc or a foliar micronutrient mix was shown to aid in the more rapid replacement of the leaf canopy and earlier initiation of squaring in hail damaged cotton. But in tissue tests carried out in the trial areas following the hail strikes, zinc levels were found to be marginal. It is not accurate to suggest that the application of zinc to any hail damaged crop will assist in the early recovery of the crop. It is suggested that in these trials the applied zinc and micronutrient mix alleviated a deficiency pre-existing in the field or a zinc deficiency induced by climatic conditions and contributed to the earlier replacement of leaf area in zinc treated areas. Further work is needed to look at the effect of applied zinc and foliar micronutrient mixes on hail damaged cotton in fields where zinc is not expected to be a limiting factor to growth.

USE OF GROWTH REGULATORS IN THE MANAGEMENT OF HAIL DAMAGED COTTON

Controlling vegetative growth rates with the use of growth regulators should be important in maximising the setting, retention and maturation of fruit following hail damage. In managing the growth of cotton following hail damage, we are attempting to prevent vegetative growth from becoming excessive so as to maximise early fruit set on the regrowth. Hail damaged cotton is delayed in development ie. late cotton and so, the second aim in managing the regrowth of hail damaged cotton using growth regulators, is to mature whatever fruit are set before the climatic end of the season.

In case studies, growers who more successfully managed hailed crops where weather conditions following damage were conducive to moderate/vigorous early regrowth, applied early pix to reduce the rate of vegetative regrowth and encourage early fruit set on regrowth. But where weather conditions immediately following damage are not conducive to growth, pix was not applied within the first 4-6 weeks of regrowth. In these situations growers used pix to reduce late vegetative growth and 'pull up' crops to encourage earlier maturation of fruit on regrowth. The average micronaire of fibre in late developing hail damaged crops is low due to immature bolls and large price discounts are imposed. Where growers used late applications of pix between last square and last flower dates, the maturity of the crop was advanced sufficiently by the growth regulator treatment to improve the overall micronaire and reduce discounts. A similar result was achieved by growers who did not chase late set bolls and left late bolls on the bush. Defoliation was easier where the vegetative growth and maturity of crops was pegged back by growth regulators or water usage strategies and hence growers were able to avoid some of the late season adverse weather conditions.

Fields trials were carried out in a number of cotton production areas to determine the effect of the growth regulator, Pix, on the regrowth of hail damaged cotton and determine if the recommended rates for use of Pix are successful in controlling and managing the regrowth of cotton after hail.

In terms of vegetative plant vigour, cotton damaged at younger growth stages and regrowing under good growing conditions showed a greater response to the application of Pix by displaying a greater reduction in plant height.

In respect to the timing of the applications, the largest reductions in plant height (ie. vegetative vigour) were measured where Pix application treatments were made early in the regrowth phase, no matter what growth stage the crop was damaged at. Applications at first flower on regrowth as a single application or part of a split application were more effective in reducing vegetative vigour. By leaving Pix application to later eg. Last Square Date, plant height was reduced somewhat compared to using no Pix, but the earlier application was more effective.

Looking at yield recovery, trials show that the growth stage of the crop and the weather conditions following damage play a large part in the yield response to applied Pix. Weather conditions following the hail damage were only conducive to vigorous vegetative regrowth at three sites. With rain or overcast conditions or waterlogging following damage, conditions were less than ideal for rapid regrowth at a number of trial sites.

Under these more moderate weather conditions, the greatest yield recovery was measured where Pix was applied at Last Square Date, with an added earlier application of 300 ml /ha Pix at First Flower increasing the response at some sites. Here, the strategy has been to let the crop to regrow largely at its own rate, then stopping late vegetative growth with the dose of Pix at Last Square. But with good growing conditions following early hail damage, ie. optimal for growth, some pegging back of vegetative growth by First Flower application of Pix has been shown to be an advantage in terms of increased yield. **The key being to carefully monitor the rate of regrowth of the crop.**

With hail damage at late growth stages, no yield advantage was found in applying Pix.

With damage in the earlier growth stages, although Last Square applications of Pix produced the greater yield recovery, these same applications produced the most delayed cotton. Earliness was found to be increased but at the expense of some yield recovery if an application of Pix is applied at First Flower eg. 300 ml/ha (single or spilt application). This may be the more economic decision when taking into account discounts for low lint quality which are inherent with late maturing cotton.

High rates of Pix would not be recommended for stressed cotton or that displaying shorter plant height/ less vigorous growth as displayed in some trials. Growth rates were reduced by poor to moderate growing conditions and in these trials it was shown that high rates produced no additional effect on plant height. The higher doses of Pix applied at First Flower on regrowth (600 ml/ha) were detrimental to lint yield and no advantage was found in applying higher doses at Last Square.

But higher rates of pix were found to be useful in situations where there was insufficient water supplies to allocate extra water to a hail damaged crop which would have allowed it to regrow to its full potential. Pix , as single (600 ml/ha) and split applications (600/1000 ml/ha), were advantageous to yield recovery. The higher rates decreased early vegetative growth to a greater extent and forced more rapid fruiting in the limited time available. Although, had sufficient water been available, a greater yield recovery would have occurred with a less harsh growth regulator treatment.

With such high discounts for low micronaire cotton, lint quality is a factor of importance in growing both hail damaged and late cotton. As the cotton is maturing under cooler conditions low micronaire will be a problem, but if growth regulator strategies combined with other management strategies are able to bring the crop in as early as possible then micronaire problems will be reduced. The aim should be to get the crops regrowing after hail, set maximum fruit numbers before last square date and pull up the crop, then mature the fruit before first frost, then we are also aiming to increase the lint quality as we should be picking more mature lint.

Further trialing of the strategies is required to collate more lint quality data as this series of trials failed to produce significant improvements in lint quality. Points to note would be that with crops incurring late damage, low micronaire is not as large a problem, as the regrowth does not contribute bolls to yield. The cotton remaining after the hail strike and set before the strike contributes the larger proportion of the total lint yield and hence, as long as these bolls are left to mature fully, then the overall micronaire is not reduced. As we attempt to regrow a crop following earlier damage, we are growing a late crop and micronaire will be reduced in the late set bolls maturing under cooler conditions.

If growers are willing to accept a slightly lower yield recovery in turn for earlier maturity by the use of early single or split applications, then low micronaire problems can be reduced.

In all of the growth regulator trials described, prior to the hail damage, growers had applied the optimum amount of nitrogen for their expected yield (pre-hail). No nitrogen was applied post damage in excess of the normal crop requirement. Hence, vegetative regrowth was not excessive due to excess nitrogen. Vegetative regrowth was reduced at some sites due to less than ideal weather conditions following the hail damage. Further trialing of growth regulator strategies is required in situations where nitrogen usage has been excessive and where weather conditions are conducive to extremely vigorous vegetative regrowth. Rates of Pix in excess of the recommended rates may be necessary to control canopy growth under these growing conditions.

In respect to other plant growth regulators, PGR-IV is a new cotton growth regulator for management of vegetative and reproductive growth in cotton and was compared to Pix , to evaluate the potential use of PGR-IV in the management of regrowth of hail damaged cotton. PGR-IV was found to reduce plant height compared to untreated cotton and compared to Pix applied late in the season at Last Square date. But it failed to reduce plant height to the extent to which Pix applied at First Flower or in split applications. PGR-IV did not increase lint yields above that of untreated cotton. In the same trial, Pix applied at 300 ml/ha at First Flower pegged back vegetative growth sufficiently to produce a yield advantage of 8-10% over PGR-IV and untreated cotton. Boll numbers did not indicate that PGR-IV was able to increase boll retention rates as reported by Oosterhuis(1994). PGR-IV did not act to improve or lower lint quality compared to Pix treatments. Under the conditions experienced in this trial, PGR-IV offered no advantage over Pix in the management of regrowth of hail damaged cotton.

Whatever the choice of growth regulator or strategy, it is obvious that growers need to monitor the rate at which crops regrow following damage very closely to ensure the timely application of growth regulators.

FERTILISER AND GROWTH REGULATOR STRATEGIES FOR HAIL DAMAGED COTTON

In conclusion, following hail damage in the mid-season period, the suggested strategy is to attempt to replace a realistic proportion of the original yield potential and mature it within the growing season which remains available whilst containing input costs and hence reducing the overall financial loss. You are therefore aiming to get the cotton crop regrowing following hail damage and maximise fruit set up to last flower date then maturing it before first frost. Nutrients and growth regulators play an important part in being able to implement such a management strategy for hail damaged cotton.

In regard to fertilisers and growth regulators, the following points should be noted:-

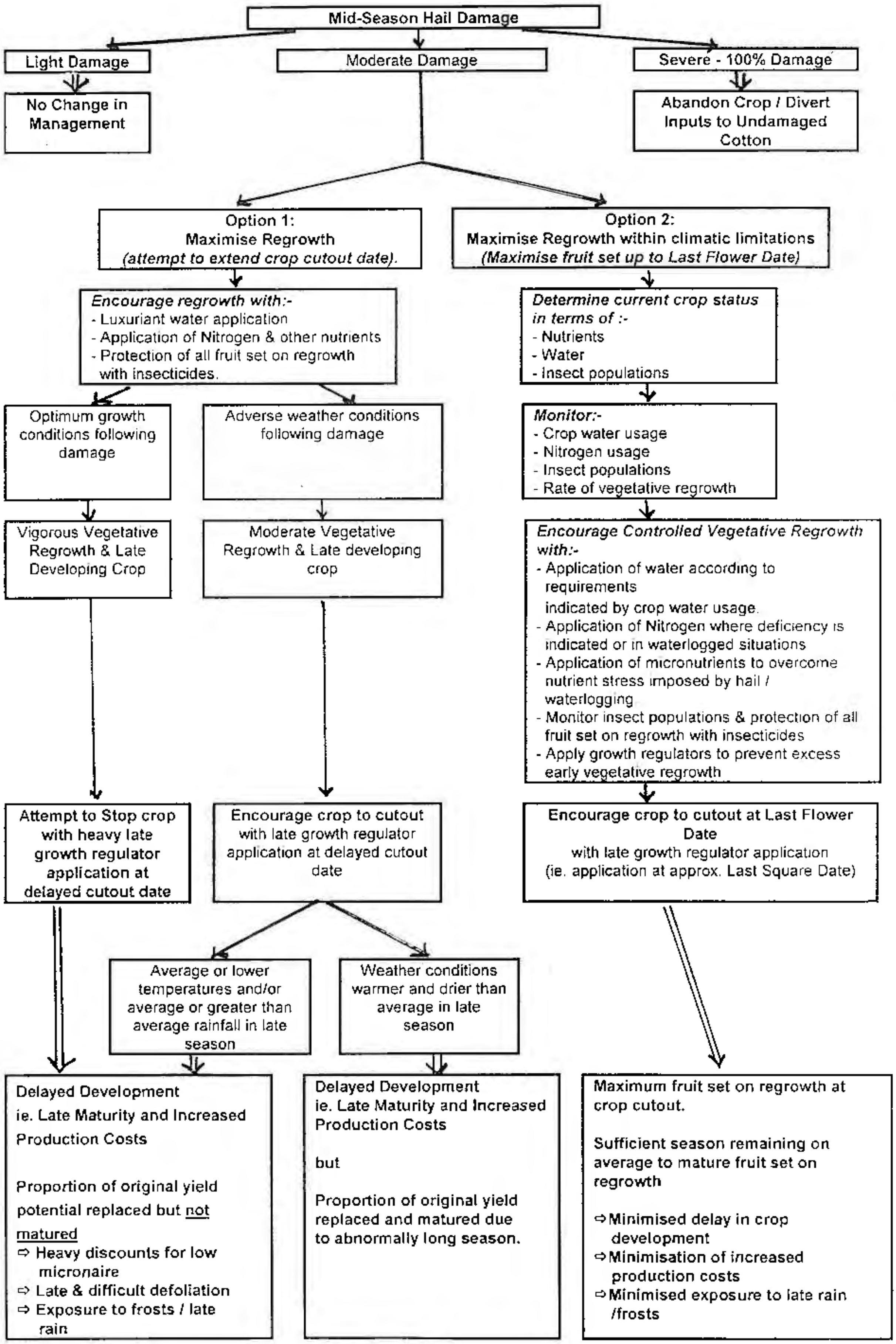
1. Where adequate nitrogen for a normal crop's requirement of nitrogen has been applied prior to the hail damage, no indication of nitrogen deficiency has been measured in petiole nitrate monitoring of nitrogen levels in hail damaged cotton following a hail strike. This suggests that additional nitrogen is not required except under conditions where this nitrogen is made inaccessible to the crop such as in waterlogged situations.

2. The application of foliar nutrients is widely practised following hail damage as a means of boosting regrowth or preventing micronutrient deficiency in the rapidly regrowing crops. Yield advantages in such applications are difficult to measure. But where a deficiency of a micronutrient pre-exists in a hail damaged crop or where climatic or soil conditions make the nutrient unavailable to the crop, foliar application of the nutrient was shown to increase the rate of early regrowth. Differences in yield responses were not measured.

3. Growth regulators such as Pix® (Mepiquat Chloride) have been found to be useful in managing vegetative regrowth following hail damage and in maximising fruit set on regrowth. Climatic conditions following the hail damage in these trials have not, in general, been such which have promoted extremely vigorous vegetative growth following the hail strike. Under these more moderate conditions, the recommended rates for use of the growth regulator have controlled vegetative growth and encouraged fruit set on regrowth. Under poor growing conditions, the higher recommended rates have been detrimental to regrowth and lint yield recovery.

4. Monitoring the rate of regrowth especially in the early period following damage is important in using a growth regulator such as Pix to manage regrowth following hail damage. Where weather conditions encourage moderate to vigorous early regrowth, an early application of Pix near first flower on regrowth has been found to be advantageous in pegging back vegetative growth and encouraging early fruit set. A later application at last square date provides extra control on vegetative growth where conditions have remained conducive to late growth. If weather or crop conditions are not conducive to good regrowth, by leaving the crop to regrow at its own pace and then pulling up the vegetative growth of the crop at last square date with the use of a growth regulator has been found to produce the greatest yield recovery. These same later applications produced the most delayed cotton. If part of the recovered yield is compromised, an early application of Pix (single or spilt application) will increase earliness and may be the more economic decision when taking into account discounts for low lint quality which may be imposed with late maturing cotton.

Figure 6.4: OPTIONS FOLLOWING MID-SEASON HAIL DAMAGE TO COTTON



6.4: Managing Late Season Hail Damage in Cotton

In surveys prior to initiating this work, major questions raised by growers in regard to damage in the later part of the season included:-

1. At what date in the growing season is regrowing the crop past being an option?
2. How do I decide whether to pull out immediately and rescue open or mature bolls or can I risk trying to mature the late and immature undamaged bolls?
3. What are the options for quick defoliation and picking?

Growers are very familiar with the use of the term 'last effective flower date', from which date onwards in the average season a flower set as a boll will not mature before the first frost. If regrowth following a hail strike is to contribute to lint yield then the crop needs to initiate new vegetative growth and then initiate squares to flower before the last flower date.

In hail damage simulation work, there was found to be an average delay of 450 GDDs recorded following a hail strike before the appearance of new squares on regrowth ie. up to 30 days. If this is added to the average period of 20 days required by a square to develop to a flower, then a hail strike occurring approximately 50 days prior to the last effective flower date will not produce regrowth which will contribute to lint yield.

Light to moderate hail damage with optimum weather conditions post damage may see earlier initiation of squares on regrowth and hence, push the last effective regrowth date back towards last square date. But some factors act to bring the last effective regrowth date forward further. The physiology of the cotton plant dictates that the fruit load of bolls acts as a stronger sink for assimilates than new vegetative growth, hence, where damage occurs at a mature growth stage and a portion of the boll load remains, the crop will mature this fruit before initiating new vegetative, this effectively delays the initiation of new squares brings forward the date for no effective regrowth.

Growers may argue exceptions to the last effective regrowth dates calculated in this work. In a year which is longer than the average growing season, effective regrowth can be achieved and case studies have been collated to support the fact. But in the average season this is not possible and in the three years of case studies covered in the work the last effective regrowth dates have been supported. The dates for each production area correspond approximately to the dates at which the average crop in a district is reaching cut out and therefore has the major proportion of its boll load set. Dryland and irrigated crops struck by hail on this date or later produced no effective regrowth to contribute to lint yield and hence these dates would be considered cut off dates for attempting to regrow crops.

The second question relates to the proportion of the boll load remaining after the hail damage that the grower aims to pick. Of course, the grower would aim to pick the maximum number of bolls whatever the stage of maturity the crop is at. With damage at or near cut -out a proportion of the bolls remaining would be immature and the mature bolls present may have avoided damage or suffered bruising. The proportion of mature bolls increases as the hail strike occurs at progressively later dates up to a fully mature and open crop. While a yield loss is incurred in not waiting for immature bolls to mature, risks are involved in chasing the immature bolls and costs involved in taking the crop through to maturity.

Table 6.1: Estimated Date for Nil Effective Regrowth Following Hail Damage

Region	Last Effective Flower	Last Effective Square	Delay to Squaring Following Hail Damage	Estimated Date for Nil Effective Regrowth Following Damage
	(Limited by Frost)	(20 Days prior to Last Effective Flower)	Average 450 GDDs (or 30 Days @ 27^{0}C max . Temp.)	
Namoi	4-Mar	12-Feb	30 Days	13-Jan
Gwydir	7-Mar	15-Feb	30 Days	16-Jan
Macquarie	19-Feb	30-Jan	30 Days	31-Dec
Lockyer	22-Mar	2-Mar	30 Days	31-Jan
Darling Downs	6-Mar	14-Feb	30 Days	15-Jan
St. George	15-Mar	23-Feb	30 Days	24-Jan
Theodore	23-Mar	3-Mar	30 Days	1-Feb
Biloela	23-Mar	3-Mar	30 Days	1-Feb
Emerald	6-Apr	17-Mar	30 Days	15-Feb
Mc Intyre	13-Mar	21-Feb	30 Days	22-Jan
Bourke	15-Mar	23-Feb	30 Days	24-Jan
Mungindi	15-Mar	23-Feb	30 Days	24-Jan
Walgett	7-Mar	15-Feb	30 Days	16-Jan
Boggabri	1-Mar	9-Feb	30 Days	10-Jan
Breeza	19-Feb	30-Jan	30 Days	31-Dec

Following damage at this late stage, if regrowth is not going to contribute to lint yield, any vegetative growth that occurs can potentially make the crop attractive to insects and contribute to defoliation and picking problems. A major factor increasing losses following late season damage is adverse weather conditions whether rain or even high humidity which encourages development of any boll bruise into boll rot.

In the dryland situation, the initiation of regrowth occurs after a rainfall event therefore there is little control over the initiation of vegetative regrowth. Following the hail strike the crop will mature the remaining bolls on the remaining soil moisture reserves. As in an undamaged crop, if insufficient moisture is available part of the top crop will not mature and will be aborted or small pinched immature bolls will result. Production costs will still be incurred as in an undamaged crop to protect late fruit although the crop with less fresh foliage and young fruit is usually less attractive to insects.

Further rainfall events will provide moisture to mature more of the boll load in both hail damaged and undamaged crops. But the same rainfall events will initiate new vegetative growth in hail damaged cotton which will make the crops attractive to insects necessitating late application of insecticides. With sufficient time and good growing conditions, the vegetative growth may require controlling with growth regulators and the new leaf material will require full defoliation programs (2-3 applications) as opposed to where little regrowth is recorded and the canopy has been thinned by hail, a reduced program is often required. Hence overall production costs are increased by the rain events.

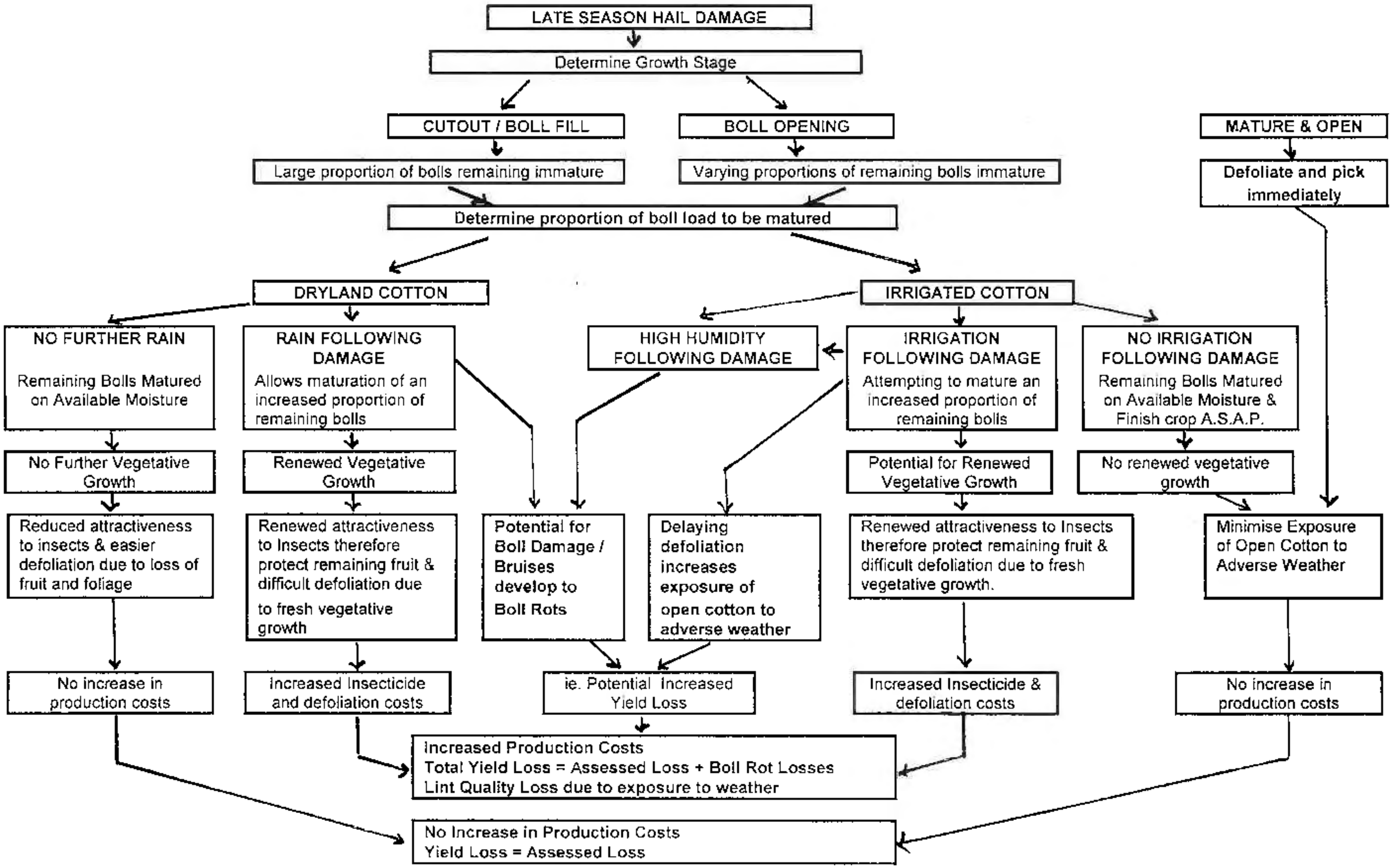
Lint yield has been reduced by the loss of fruit in the original hail strike. Yield losses attributed to hail are now only increased by loss of damaged bolls to boll rot or due to picking problems. Maturity of the crop is not delayed by late hail and in some instances where the top crop is removed by the hail, maturity is advanced.

On the other hand, lint quality will be affected by the number of immature bolls picked. Hence, if a growers chooses to chase late bolls following hail, time and conditions must allow bolls to fully mature if low micronaire problems are to be avoided. Low lint quality is therefore a belated loss due to hail. In dryland crops the same problem exists for undamaged crops where moisture is limiting causing abortion of the top crop.

Under irrigation, following hail damage in the late season, similar problems exist but growers also have the advantage of being able to water the crop to mature any immature bolls remaining. But in watering the crop, it predisposes the crop to the same vegetative regrowth as can occur with rain events in dryland cotton and hence the similar increased production costs per bale of cotton. To this can be added the costs of the irrigation. With a traditionally more vegetative crop than in the dryland situation, following hail, although defoliated to some degree, significant leaf material may remain and so with rain and/or high humidity is maintained within the canopy and the boll rot problem is made dramatically worse. Large numbers of bolls assessed as being partly lost to hail bruising now become totally unpickable.

Hence, the decision needs to be made as to what proportion of the immature boll load a grower wishes to chase to counteract possible increases in production costs, further lint yield losses due to boll rot and losses in lint quality.

Figure 6.5: OPTIONS FOLLOWING LATE SEASON HAIL DAMAGE



6.5: Other Factors in the Management of Hail Damaged Cotton

A commonly raised question in regard to the management of hail damaged cotton is whether one cotton variety will recover better from hail damage than another?

Previous work comparing the regrowth of cotton varieties following simulated hail damage suggests that as long as two varieties are allowed to go through to their natural maturity then the only difference in lint yield at a given site will be the difference in yield potential between the varieties normally observed at that site. The key fact being that the varieties are allowed to go through to their natural maturity. Season conditions, disease and crop management may prevent one variety reaching its full yield potential and hence, a yield advantage is observed in the other variety.

After hail damage, the season is reduced and the time available to replace lost yield is reduced. The management strategies described in this work attempt to manipulate the growth pattern of a crop to maximise the fruit set in the limited time available and mature the crop before the season end. An inherent ability to set fruit more rapidly could emphasise gains made with these strategies. A variety which lends itself to recover more quickly from hail damage should it not only initiate fruit rapidly following damage but also square at a high rate to make maximum use of the season remaining.

In terms of responses to hail damage or recovery from hail damage, it is obvious that varieties of longer season length displaying longer periods to initiation of squaring and lower squaring rates would be slower to initiate fruit following hail damage. This may not be a disadvantage in longer season areas but would be detrimental to recovery of yield potential in moderate and shorter season areas, or where management options available will not allow a variety to grow out to its full potential (eg. where water allocations are low). Where earlier and more rapid fruit set occurs following damage an increased yield response could be expected under such conditions.

This is illustrated at the long season site, where Siokra 1-4, DP90 and Sicala V2 were the earliest varieties to reach first square and were only surpassed by CS189+ and the new line Exp 97 in high squaring rates. The combination of earliness to first square and high squaring rate in these three varieties have produced advanced maturity compared to other varieties. This did not translate to higher lint yield at this site as the longer season varieties were only slightly later in reaching first square and have moderate squaring rates and fruited over a longer period and with the longer season available reached a higher final lint yield.

At the short season site, CS8S, Siokra 1-4 and Siokra S324 were well advanced in date to initial opening (10% open bolls). Where CS8S and Siokra S324 have conspicuously earlier dates to first square, Siokra 1-4 displays a high squaring rate than all other varieties and these characteristics combine to produce earlier maturity. Hence, planting the short season varieties in the short season area would increase the chances of recovering a proportion of lost yield should a crop be damaged by hail.

The differences in date to first square and maturity measured in these trials were not large when looking at a commercial situation but when combined with agronomic management strategies increased fruiting rates and earliness to maturity may contribute to increased recovery within the reduced growing season following hail damage. In the future, new varieties may display shorter square period and faster squaring rates than those in production today and may be more useful in regard to recovery from hail damage.

6.5: Improvements in Loss Assessment

As previously discussed, the reason for carrying out this work was that current insurance policies are seen to be inadequate in some respects in failing to cover the grower for the true cost of hail damage to a crop. This forces many growers to carry on with hail damaged crops to attempt to recover costs or some level of profit. Current loss assessment methods involve assessment of loss at the time of the damage. It has been suggested that a more equitable insurance scheme would involve end-of-season loss assessment where a grower could be reimbursed for any yield loss incurred and also the extra costs involved in bringing a hail damaged crop through to maturity. An estimate of the original yield potential of the crop would be required in any such scheme and one means of obtaining this estimate is by use of crop computer yield models.

Crop yield simulation models have been developed in the cotton industry which may assist in predicting the potential yield of a cotton crop prior to any damage by hail. Crop data has been collated on the yield response of cotton damaged by hail at various stages of crop growth. This data was used to evaluate the C.S.I.R.O. OZCOT cotton yield simulation model for its ability to predict crop yield for hail damaged and undamaged cotton.

OZCOT did not simulate the yield of hail damaged crops as well as it simulated intact crops. However the model has the potential to predict the yield loss caused by hail damage more accurately. There are a number of options that could be explored in future work to improve the ability of OZCOT to predict the yield loss caused by hail damage. Such modifications would make the model extremely useful for loss adjustment purposes. In particular, hail damage causes severe damage to the branching structure of the plant. The branching structure of the crop is not explicitly modelled in OZCOT. The modification of the model to be sensitive to hail damage would require data collation on some aspects of the dynamics of the branching structure of the cotton plant.

Several groups of researchers are currently carrying out work related to modelling the growth of the cotton plant, ie. virtual modelling at CTPM, Victor Sadras at ACRI studying response to terminal damage by pests, and Steve Milroy, Mike Bange and Brian Hearn at ACRI developing OZCOT/CERCOT. Interest has been shown by these groups in modifying the model to take into account hail damage should the cotton or insurance industry indicate the importance of such a move.

6.6: Concluding Remarks

From this study of hail damaged crops, it has become quite obvious that there is no magic formula for regrowing hail damaged cotton. The management of each field hit by hail will vary depending on the severity and type of damage, the growth stage at the time of damage, where the crop is grown (ie. season available) and the finance and other resources available to the grower. The success of any management strategy employed will be at the mercy of weather conditions following the damage as this is the major factor determining the rate and degree of any regrowth.

Recovery from hail damage is not a case of good luck but good management. In defining recovery from hail damage we should not be looking at yield recovery. It should be more important to look at reducing the financial loss.

There is a limit to the amount of cotton that can be grown and matured within a season. Part of a set yield is lost in a hail strike, then following the strike there is a limited amount of time available to replace the lost yield and mature it before the season end. As a grower attempts to regrow a crop following damage, it is important to be realistic and identify the amount of cotton that can be realistically regrown and matured following the hail strike and the risk and costs involved.

APPENDIX 1.1:

Estimating Yield Depletion with Delayed Planting or Early Season Hail Damage in Cotton

Regression Analyses

MINITAB Statistical Software (Version 9) was used for the regression analyses carried out in this exercise.

Site: EMERALD

Regression Analysis

```
MTB > Name c10 = 'JD2'
MTB > Let 'JD2' = 'JD'* 'JD'
MTB > Name c11 = 'FITS1' c12 = 'RESI1' c13 = 'COEF1'
MTB > Regress 'Yield4' 2 'JD' 'JD2';
SUBC>   Fits 'FITS1';
SUBC>   Residuals 'RESI1';
SUBC>   Coefficients 'COEF1'.
* NOTE *      JD is highly correlated with other  predictor variables
* NOTE *     JD2 is highly correlated with other  predictor variables
```

The regression equation is
Yield4 = - 3646 + 42.1 JD - 0.0747 JD2

Predictor	Coef	Stdev	t-ratio	p
Constant	-3646.2	996.8	3.66	0.022
JD	42.096	6.582	6.40	0.003
JD2	-0.07469	0.01078	-6.93	0.002

s = 22.23   R-sq = 98.1%   R-sq(adj) = 97.1%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	2	99447	49724	100.62	0.000
Error	4	1977	494		
Total	6	101424			

SOURCE	DF	SEQ SS
JD	1	75722
JD2	1	23725

Site: BILOELA

Regression Analysis

MTB > Name c10 = 'JD2'
MTB > Let 'JD2' = 'JD'* 'JD'
MTB > Name c11 = 'FITS1' c12 = 'COEF1'
MTB > Regress 'Yield4' 2 'JD' 'JD2';
SUBC> Fits 'FITS1';
SUBC> Coefficients 'COEF1'.
* NOTE * JD is highly correlated with other predictor variables
* NOTE * JD2 is highly correlated with other predictor variables

The regression equation is
Yield4 = - 8836 + 77.5 JD - 0.136 JD2

Predictor	Coef	Stdev	t-ratio	p
Constant	-8836	1568	-5.63	0.005
JD	77.52	10.36	7.49	0.002
JD2	-0.13598	0.01696	-8.02	0.001

s = 34.98 R-sq = 98.2% R-sq(adj) = 97.3%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	2	264244	132122	107.99	0.000
Error	4	4894	1223		
Total	6	269138			

SOURCE	DF	SEQ SS
JD	1	185608
JD2	1	78636

Site: DALBY

Regression Analysis - Dalby

MTB > Name c10 = 'JD2'
MTB > Let 'JD2' = 'JD'* 'JD'
MTB > Name c11 = 'FITS1' c12 = 'COEF1'
MTB > Regress 'Yield4' 2 'JD' 'JD2';
SUBC> Fits 'FITS1';
SUBC> Coefficients 'COEF1'.
* NOTE * JD is highly correlated with other predictor variables
* NOTE * JD2 is highly correlated with other predictor variables

The regression equation is
Yield4 = - 10670 + 90.9 JD - 0.164 JD2

Predictor	Coef	Stdev	t-ratio	p
Constant	-10670	1201	-8.89	0.001
JD	90.865	7.927	11.46	0.000
JD2	-0.16381	0.01298	-12.62	0.000

s = 26.77 R-sq = 99.5% R-sq(adj) = 99.3%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	2	631488	315744	440.44	0.000
Error	4	2868	717		
Total	6	634356			

SOURCE	DF	SEQ SS
JD	1	517371
JD2	1	114117

Site: ST. GEORGE

Regression Analysis - St. George

MTB > Name c10 = 'JD2'
MTB > Let 'JD2' = 'JD'* 'JD'
MTB > Name c11 = 'FITS1' c12 = 'COEF1'
MTB > Regress 'Yield4' 2 'JD' 'JD2';
SUBC> Fits 'FITS1';
SUBC> Coefficients 'COEF1'.
* NOTE * JD is highly correlated with other predictor variables
* NOTE * JD2 is highly correlated with other predictor variables

The regression equation is
Yield4 = - 6339 + 60.5 JD - 0.107 JD2

Predictor	Coef	Stdev	t-ratio	p
Constant	-6339	1506	-4.21	0.014
JD	60.540	9.941	6.09	0.004
JD2	-0.10665	0.01628	-6.55	0.003

s = 33.58 R-sq = 97.5% R-sq(adj) = 96.3%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	2	176724	88362	78.37	0.001
Error	4	4510	1127		
Total	6	181234			

SOURCE	DF	SEQ SS
JD	1	128359
JD2	1	48365

Site: GOONDIWINDI

Regression Analysis - Goondiwindi

```
MTB > Name c10 = 'JD2'
MTB > Let 'JD2' = 'JD'* 'JD'
MTB > Name c11 = 'FITS1' c12 = 'COEF1'
MTB > Regress 'Yield4' 2 'JD' 'JD2';
SUBC>   Fits 'FITS1';
SUBC>   Coefficients 'COEF1'.
* NOTE *    JD is highly correlated with other  predictor variables
* NOTE *    JD2 is highly correlated with other  predictor variables
```

The regression equation is
Yield4 = - 11480 + 96.4 JD - 0.170 JD2

Predictor	Coef	Stdev	t-ratio	p
Constant	-11480	1144	-10.03	0.001
JD	96.413	7.556	12.76	0.000
JD2	-0.17023	0.01237	-13.76	0.000

s = 25.52   R-sq = 99.4%   R-sq(adj) = 99.2%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	2	470639	235319	361.35	0.000
Error	4	2605	651		
Total	6	473243			

SOURCE	DF	SEQ SS
JD	1	347412
JD2	1	123226

Site: MOREE

Regression Analysis - Moree

MTB > Name c10 = 'JD2'
MTB > Let 'JD2' = 'JD'* 'JD'
MTB > Name c11 = 'FITS1' c12 = 'COEF1'
MTB > Regress 'Yield4' 2 'JD' 'JD2';
SUBC> Fits 'FITS1';
SUBC> Coefficients 'COEF1'.
* NOTE * JD is highly correlated with other predictor variables
* NOTE * JD2 is highly correlated with other predictor variables

The regression equation is
Yield4 = - 12510 + 103 JD - 0.181 JD2

Predictor	Coef	Stdev	t-ratio	p
Constant	-12509.6	801.1	-15.62	0.000
JD	102.741	5.289	19.42	0.000
JD2	-0.180926	0.008663	-20.89	0.000

s = 17.86 R-sq = 99.7% R-sq(adj) = 99.6%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	2	505351	252675	791.75	0.000
Error	4	1277	319		
Total	6	506628			

SOURCE	DF	SEQ SS
JD	1	366149
JD2	1	139202

Site: MYALL VALE

Regression Analysis - Myall Vale

```
MTB > Name c10 = 'JD2'
MTB > Let 'JD2' = 'JD'* 'JD'
MTB > Name c11 = 'FITS1' c12 = 'COEF1'
MTB > Regress 'Yield4' 2 'JD' 'JD2';
SUBC>   Fits 'FITS1';
SUBC>   Coefficients 'COEF1'.
* NOTE *    JD is highly correlated with other predictor variables
* NOTE *    JD2 is highly correlated with other predictor variables
```

The regression equation is
Yield4 = - 13469 + 109 JD - 0.192 JD2

Predictor	Coef	Stdev	t-ratio	p
Constant	-13469.1	484.1	-27.82	0.000
JD	108.971	3.197	34.09	0.000
JD2	-0.192138	0.005236	-36.70	0.000

s = 10.80 R-sq = 99.9% R-sq(adj) = 99.9%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	2	584052	292026	2505.29	0.000
Error	4	466	117		
Total	6	584518			

SOURCE	DF	SEQ SS
JD	1	427063
JD2	1	156989

Site: BREEZA

Regression Analysis - Breeza

```
MTB > Name c10 = 'JD2'
MTB > Let 'JD2' = 'JD'* 'JD'
MTB > Name c11 = 'FITS1' c12 = 'COEF1'
MTB > Regress 'Yield4' 2 'JD' 'JD2';
SUBC>   Fits 'FITS1';
SUBC>   Coefficients 'COEF1'.
* NOTE *      JD is highly correlated with other predictor variables
* NOTE *      JD2 is highly correlated with other predictor variables
```

The regression equation is
Yield4 = - 1403 + 25.0 JD - 0.0512 JD2

Predictor	Coef	Stdev	t-ratio	p
Constant	-1403	2394	-0.59	0.589
JD	25.04	15.81	1.58	0.188
JD2	-0.05121	0.02589	-1.98	0.119

s = 53.40   R-sq = 95.7%   R-sq(adj) = 93.5%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	2	253492	126746	44.45	0.002
Error	4	11405	2851		
Total	6	264897			

SOURCE	DF	SEQ SS
JD	1	242339
JD2	1	11153

Site: WALGETT

Regression Analysis - Walgett

```
MTB > Name c10 = 'JD2'
MTB > Let 'JD2' = 'JD'* 'JD'
MTB > Name c11 = 'FITS1' c12 = 'COEF1'
MTB > Regress 'Yield4' 2 'JD' 'JD2';
SUBC>   Fits 'FITS1';
SUBC>   Coefficients 'COEF1'.
* NOTE *     JD is highly correlated with other  predictor variables
* NOTE *     JD2 is highly correlated with other  predictor variables
```

The regression equation is
Yield4 = - 9924 + 85.0 JD - 0.149 JD2

Predictor	Coef	Stdev	-ratio	p
Constant	-9924	1802	-5.51	0.005
JD	85.05	11.90	7.15	0.002
JD2	-0.14909	0.01949	-7.65	0.002

s = 40.19 R-sq = 98.0% R-sq(adj) = 97.0%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	2	313756	156878	97.14	0.000
Error	4	6460	1615		
Total	6	320216			

SOURCE	DF	SEQ SS
JD	1	219232
JD2	1	94524

Site: BOURKE

Regression Analysis - Bourke

MTB > Name c10 = 'JD2'
MTB > Let 'JD2' = 'JD'* 'JD'
MTB > Name c11 = 'FITS1' c12 = 'COEF1'
MTB > Regress 'Yield4' 2 'JD' 'JD2';
SUBC> Fits 'FITS1';
SUBC> Coefficients 'COEF1'.
* NOTE * JD is highly correlated with other predictor variables
* NOTE * JD2 is highly correlated with other predictor variables

The regression equation is
Yield4 = - 7480 + 68.2 JD - 0.120 JD2

Predictor	Coef	Stdev	t-ratio	p
Constant	-7480	1616	-4.63	0.010
JD	68.23	10.67	6.39	0.003
JD2	-0.11992	0.01747	-6.86	0.002

s = 36.04 R-sq = 97.6% R-sq(adj) = 96.4%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	2	213995	106998	82.40	0.001
Error	4	5194	1299		
Total	6	219189			

SOURCE	DF	SEQ SS
JD	1	152840
JD2	1	61155

Site: TRANGIE

Regression Analysis - Trangie

```
MTB > Name c10 = 'JD2'
MTB > Let 'JD2' = 'JD'* 'JD'
MTB > Name c11 = 'FITS1' c12 = 'COEF1'
MTB > Regress 'Yield4' 2 'JD' 'JD2';
SUBC>   Fits 'FITS1';
SUBC>   Coefficients 'COEF1'.
* NOTE *    JD is highly correlated with other predictor variables
* NOTE *    JD2 is highly correlated with other predictor variables
```

The regression equation is
Yield4 = - 17890 + 135 JD - 0.235 JD2

Predictor	Coef	Stdev	t-ratio	p
Constant	-17890.0	840.2	-21.29	0.000
JD	135.332	5.548	24.39	0.000
JD2	-0.235201	0.009086	-25.89	0.000

s = 18.74 R-sq = 99.8% R-sq(adj) = 99.7%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	2	652706	326353	929.54	0.000
Error	4	1404	351		
Total	6	654111			

SOURCE	DF	SEQ SS
JD	1	417460
JD2	1	235246

Site: HILLSTON

Regression Analysis - Hillston

```
MTB > Name c10 = 'JD2'
MTB > Let 'JD2' = 'JD'* 'JD'
MTB > Name c11 = 'FITS1' c12 = 'COEF1'
MTB > Regress 'Yield4' 2 'JD' 'JD2';
SUBC>   Fits 'FITS1';
SUBC>   Coefficients 'COEF1'.
* NOTE *     JD is highly correlated with other  predictor variables
* NOTE *     JD2 is highly correlated with other  predictor variables
```

The regression equation is
Yield4 = - 17765 + 135 JD - 0.236 JD2

Predictor	Coef	Stdev	t-ratio	p
Constant	-17764.9	517.0	-34.36	0.000
JD	135.222	3.414	39.61	0.000
JD2	-0.235672	0.005591	-42.15	0.000

s = 11.53 R-sq = 99.9% R-sq(adj) = 99.9%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	2	695453	347727	615.76	0.000
Error	4	532	133		
Total	6	695985			

SOURCE	DF	SEQ SS
JD	1	459264
JD2	1	236189

Appendix 2.1: Climatic Data 1993/94 - 1995/96

Appendix 2.1.1:

Climatic Data for Myall Vale Weather Station - 26 Year Average

	Rain (mm)	Evaporation (mm)	Average Daily Maximum Temperature (^0C)	Average Daily Minimum Temperature (^0C)	Radiation (Langley)	Average Soil Temperature (^0C)	Average Relative Humidity (%)	Total Growing Day Degrees	Accumulated Growing Day Degrees
Oct	51.4	6.7	25.9	12	493	17.6	57	223	223
Nov	57.5	8.9	29.5	15.1	570	21.3	53	308	531
Dec	54.7	10.5	32.2	17.8	605	24.4	54	403	934
Jan	103.9	9.5	32.5	19.2	590	25.6	60	430	1364
Feb	56.6	8.7	32.5	19.3	547	25.5	63	390	1754
Mar	50.2	7.6	30.1	16.8	484	23.2	62	355	2109
Apr	28.7	5.6	26.4	12.2	380	18.8	63	228	2337
May	43.5	3.6	21.2	7.9	278	14.1	70	142	2479
Total/mean	446.5	61.1	28.79	15.04	3947	21.31	60.25	2479	2479

Appendix Table 2.1.2:

Climatic Data for Myall Vale Weather Station 1993/94

	Rain (mm)	Evaporation (mm)	Average Daily Maximum Temperature (^0C)	Average Daily Minimum Temperature (^0C)	Radiation (Langley)	Average Soil Temperature (^0C)	Average Relative Humidity (%)	Total Growing Day Degrees	Accumulated Growing Day Degrees
Oct	73.8	6.1	24.9	11.7	477	16.6	61	219	219
Nov	33.3	9.1	30.3	14.8	597	20	51	315	534
Dec	76.5	9.3	30.7	16.8	585	21.3	49	370	904
Jan	7.2	11.3	35.6	19.1	664	21.6	46	477	1381
Feb	122.1	7.3	30.8	19.2	447	22.2	67	364	1745
Mar	56.1	4.8	27.3	14.3	461	19.8	64	281	2026
Apr	6	3.4	27.3	10.9	395	15.5	58	240	2266
May	0	1.5	23.2	5.5	315	9.3	54	176	2442
Total/mean	375	52.8	28.76	14.04	3941	18.29	56.25	2442	2442

Appendix Table 2.1.3:

Climatic Data for Myall Vale Weather Station 1994/95

	Rain (mm)	Average Daily Maximum Temperature (⁰C)	Average Daily Minimum Temperature (⁰C)	Radiation (Langley)	Average Soil Temperature (⁰C)	Total Growing Day Degrees	Accumulated Growing Day Degrees
Oct	34.5	28.0	11.4	273	16.4	273	273
Nov	48.0	30.3	16.3	345	19.6	345	618
Dec	18.4	34.1	19.3	456	22.1	456	1074
Jan	264.0	29.9	19.0	386	22.4	386	1461
Feb	22.2	30.2	18.3	342	22.5	342	1803
Mar	2.7	31.0	15.2	349	20.0	349	2152
Apr	1.5	25.3	9.4	205	14.2	205	2357
May	76.5	21.4	10.6	139		139	2497
Total/mean	467.8	28.8	14.9	117049	30.0	2497	2497

Appendix Table 2.1.4:

Climatic Data for Myall Vale Weather Station 1995/96

	Rain (mm)	Evaporation (mm)	Average Daily Maximum Temperature (⁰C)	Average Daily Minimum Temperature (⁰C)	Average Soil Temperature (⁰C)	Total Growing Day Degrees	Accumulated Growing Day Degrees
Oct	57	152	26.7	12.8	16.6	239	239
Nov	132	157	29.8	16.3	19.5	330	570
Dec	72	187	30.3	16.2	21.3	349	918
Jan	424	167	30.8	19.0	23.1	399	1317
Feb	24	170	30.1	16.6	22.0	330	1646
Mar	72	165	30.0	15.0	18.6	326	1972
Apr	5	116	25.9	9.4	14.0	168	2140
May	65	190	24.2	11.5	14.8	326	2466
Total/mean	851	1303	28.5	14.6	18.7	2466	2466

Appendix Table 2.1.5

Climatic Data for Emerald DPI Weather Station 1994/95

	Rain (mm)	Evaporation (mm)	Average Daily Maximum Temperature (⁰C)	Average Daily Minimum Temperature (⁰C)	Total Growing Day Degrees	Accumulated Growing Day Degrees
Sept	0	237	29.5	12.5	283	283
Oct	30	251	32.3	16.7	375	667
Nov	15	329	35.0	18.8	448	1115
Dec	12	300	35.1	20.6	476	1606
Jan	84	276	34.9	21.8	491	2118
Feb	149	182	32.7	20.6	410	2529
Mar	6	231	35.3	20.8	465	3010
Apr	40	196	30.7	16.2	345	3355
Total/mean	336	2002	33.2	18.5	3293	3293

Appendix Table 2.1.6

Climatic Data for Dalby DPI Weather Station 1994/95

	Rain (mm)	Evaporation (mm)	Average Daily Maximum Temperature (⁰C)	Average Daily Minimum Temperature (⁰C)	Total Growing Day Degrees	Accumulated Growing Day Degrees
Oct	23	194	27.2	10.2	109	109
Nov	12	167	31.4	15.0	304	413
Dec	33	177	32.4	16.4	378	791
Jan	152	161	30.8	17.5	376	1166
Feb	71	119	29.0	18.0	322	1488
Mar	31	144	31.0	15.3	334	1823
Apr	6	102	26.9	9.1	88	1911
May	39	62	22.7	9.8	106	2018
Total/mean	366	1126	28.9	13.9	2018	2018

Appendix Table 2.1.7

Climatic Data for Trangie Research Station Weather Station 1994/95

	Average Daily Maximum Temperature (^{0}C)	Average Daily Minimum Temperature (^{0}C)	Total Growing Day Degrees	Accumulated Growing Day Degrees		Accumulated Growing Day Degrees (33 year mean)
Oct	26.1	10.6	235	235		189
Nov	28.7	14.6	304	539		273
Dec	34.4	19.0	460	999		377
Jan	29.2	18.8	373	1373		415
Feb	30.7	17.1	334	1706		350
Mar	28.3	13.7	303	2009		302
Apr	18.4	7.6				
Total/mean	27.1	13.3	2009	2009		1905

Appendix 2.2: Agronomic Calendars for Hail Trials (1993/94 - 1995/96)

APPENDIX 2.2: CROP HISTORIES

Refer Chapter 2 (2.4)

SITE: "Arundal" Dalby (Field 4) 1994/95

TRIAL: Pix Growth Regulator Trial

VARIETY: Coloured Cotton
PLANTING DATE: 12-13/10/94
PLANTING RATE: 14 kg/ha (10 Plants/m)

	DATE		TYPE		RATE (per ha)
FERTILISERS:	Aug-94	1.	Anhyrous Ammonia		140 units
	29-30/11/94	2.	Urea		60 units
	12/01/95	3.	Urea + SF90		12 + 5 kg (Foliar)
		4.			
HERBICIDES:	12-13/10/94	1.	Stomp + Cotogard		4.5 + 5.5 litres (50% band)
		2.			
		3.			
		4.			
GROWTH REGULATORS:	5/02/95	1.	Pix		1.0 litres
		2.			
		3.			
		4.			
INSECTICIDES:	12/10/94	1.	Temik		3 kg
	25/11/94	2.	Endosulfan EC		2.1 litres
	5/12/94	3.	Endosulfan EC		2.1 litres
	11/12/94	4.	Endosulfan ULV		3.0 litres
	15/12/94	5.	Endosulfan + Larvin		3.0 + 1.0 litres
	23/12/94	6.	Decis + Larvin		3.5 + 0.65 litres
	4/01/95	7.	Decis + Larvin		3.5 + 0.65 litres
	12/01/95	8.	Decis + Larvin		3.5 + 0.60 litres
	26/01/95	9.	Decis + Larvin		3.5 + 0.60 litres
	5/02/95	10.	Decis + Lannate		3.5 + 1.0 litres
	13/02/95	11	Decis + Lannate		3.5 + 1.0 litres
		12.			
DEFOLIATION:	30/04/95	1.	Dropp + DC-Tron + Prep		100g + 1.5 + 1.0 litres
		2.			
		3.			
IRRIGATION DATES:		1.	31/12/94	5.	
		2.	7/02/95	6.	
		3.		7.	
		4.		8.	
PICKING DATES:		1.	24/05/95	2.	

NOTES:

Appendix 2.2: Continued

APPENDIX 2.2: CROP HISTORIES

Refer Chapter 2 (2.4)

SITE: "Abbey Green" Narrabri (Field 7) 1994/95

TRIAL: Pix Growth Regulator Trial

VARIETY: Sicala V1
PLANTING DATE: 14/10/94
PLANTING RATE: 30 plants seeds permetre

	DATE		TYPE		RATE (per ha)
FERTILISERS:	15/09/94	1.	Urea (ground rig)		280 kg
	27/11/94	2.	Ocean Fish Foliar		1.0 litres
	11/01/95	3.	Ocean Fish Foliar		1.0 litre
	15/01/95	4.	Urea (air)		86 kg
	16/01/95	5.	Ocean Fish Foliar + Zinc		1.0 litre + 0.750 kg
HERBICIDES:	2/10/94	1.	Cotogard		2.0 litres
	14/10/09	2.	Cotogard + Gesagard		2.0 + 1.0 litres
	26/01/95	3.	Gesagard		3.0 litres
		4.			
GROWTH REGULATORS:	12/02/95	1.	Pix		0.5 litres
	4/03/95	2.	Pix		0.35 litres
		3.			
		4.			
INSECTICIDES:	14/10/94	1.	Temik		5 kg
	27/11/94	2.	Endosulfan + Dipel		2.0 litres
	20/12/94	3.	Karate ULV + Larvin + DC-Tron		3.25 + 1.0 + 0.75 litres
	1/01/95	4.	Bulldock + Larvin + DC-Tron		2.5 + 1.0 + 1.5 litres
	24/01/95	5.	Thiodan ULV + Larvin + DC-Tron		3.1 + 1.0 + 0.9 litres
	7/02/95	6.	Larvin + Rogor + Primmabuff + Synertrol		2.5 + 0.5 + 0.2 + 0.5 litres
	12/02/95	7.	Curacron + Synertrol		2.0 + 0.5 litres
	21/02/95	8.	Bulldock + Larvin + DC-Tron		2.7 + 1.0 + 1.3 litres
	4/03/95	9.	Curacron + Synertrol + Primmabuff		1.7 + 0.25 + 0.25 litres
	16/03/95	10.	Curacron + Primmabuff + Synertrol		1.75 + 0.25 + 0.25 litres
	27/03/95	11.	Cruacron + Primmabuff + Synertrol		2.0 + 0.25 + 0.25 litres
DEFOLIATION:	23/04/95	1.	Harvade + DC-Tron + Prep		0.35 + 2.00 +0.3 litres
	8/05/95	2.	Prep + DC-Tron		2.5 + 2.0 litres
	8/05/95	3.	Harvade + DC-Tron + Prep		0.35 + 0.50 + 2.00 litres
IRRIGATION DATES:		1.	14/9/94 (Pre-watering)	5.	24/02/95
		2.	16/10/94 (Flushing)	6.	10/03/95
		3.	26/12/94	7.	
		4.	Rain 2/1/95	8.	
PICKING DATES:		1.	29/5/96	2.	

NOTES: Hail Strike 2/1/95

Appendix 2.2: Continued

APPENDIX 2.2: CROP HISTORIES

Refer Chapter 2 (2.4)

SITE: Lot 159 Will's Rd. Emerald

TRIAL: Pix Growth Regulator Trial

VARIETY: CS 50
PLANTING DATE: 28/10/94 into moisture
PLANTING RATE:

FERTILISERS:

DATE		TYPE		RATE (per ha)
Aug-94	1.	Urea + P + K + S		180 + 40 + 40 + 10 kg
18-21/12/94	2.	Anhydrous Ammonia (Water run)		50 units
	3.			
	4.			

HERBICIDES:

	1.	Lay-by		
	2.			
	3.			
	4.			

GROWTH REGULATORS:

	1.			
	2.			
	3.			
	4.			

INSECTICIDES:

	1.			
	2.			
	3.			
	4.			
	5.			
	6.			
	7.			
	8.			
	9.			
	10.			
	11			
	12.			

DEFOLIATION:

	1.			
	2.			
	3.			

IRRIGATION DATES:

	1.	24/9/94 Pre-watering	5.	27-31/12/94
	2.	20-25/11/94	6.	
	3.	8/12/94	7.	
	4.	18-21/12/94	8.	

PICKING DATES:

	1.	21/03/95	2.	

NOTES:

Hail damage 18/12/94 whilst irrigating and applying anhydrous.
Limited water saw crop cut off before full maturity of late set bolls.

Appendix 2.2: Continued

APPENDIX 2.2: CROP HISTORIES

Refer Chapter 2 (2.4)

SITE: "Kimberley" Warren (Field 21) 1994/95

TRIAL: Pix Growth Regulator Trial

VARIETY: CS 50
PLANTING DATE: 23/10/94 Replant
PLANTING RATE: 9.5 plants per metre

	DATE		TYPE		RATE (per ha)
FERTILISERS:	8/09/94	1.	Anhydrous Ammonia		53 kg
	20/12/94	2.	Anhydrous Ammonia		60 kg
		3.			
		4.			
HERBICIDES:	10/09/94	1.	Treflan + Diuron		2.0 + 2.0 litres
	23/10/94	2.	Stomp + Cotogard		3.0 + 4.0 litres
	3/01/95	3.	Diuron		3.0 litres
		4.			
GROWTH REGULATORS:	31/01/95	1.	Pix		0.6 litres
		2.			
		3.			
		4.			
INSECTICIDES:	23/10/94	1.	Temik		3 kg
	1/12/94	2.	Endosulfan EC		2.1 litres
	4/12/94	3.	Endosulfan EC		2.1 litres
	17/12/94	4.	Endosulfan ULV		2.0 litres
	20/12/94	5.	Larvin		2.0 LItres
	10/01/95	6.	Dominex ULV + Methomyl		2.5 + 0.5 litres
	31/01/95	7.	Karate + Parathion		0.42 + 2.0 litres
	10/02/95	8.	Larvin + DC-Tron		2.0 + 3.0 litres
	16/02/95	9.	Curacron + Methomyl		2.0 + 1.0 litres
	27/02/95	10.	Dominex + Comite		0.5 + 2.5 litres
	18/03/95	11	Curacron ULV		4.0 litres
		12.			
DEFOLIATION:	6/04/95	1.	Harvade + Catapult		0.35 + 0.5 litres
	14/04/95	2.	Salt		18 litres
	20/04/95	3.	Salt		20 litres
IRRIGATION DATES:		1.	29/8/94 Pre-watering	5.	11/02/95
		2.	12/12/94	6.	28/02/95
		3.	1/01/95	7.	14/03/95
		4.	20/01/95	8.	
PICKING DATES:		1.	10/05/95	2.	
NOTES:	Hail damage 2/1/95.				

Appendix 2.2: Continued

APPENDIX 2.2: CROP HISTORIES

Refer Chapter 2 (2.4)

SITE: "Carnavon" Mullaley (Field 3) 1994/95

TRIAL: Pix Growth Regulator Trial

VARIETY: CS 189+
PLANTING DATE: 11-14/10/94
PLANTING RATE: 10-11 Plants per metre

	DATE		TYPE		RATE (per ha)
FERTILISERS:	Jul-94	1.	Anhydrous Ammonia		160 kg/ha N
		2.			
		3.			
		4.			
HERBICIDES:	Sep-94	1.	Tridan		3.2 litres
	Oct-94	2.	Cotogard		3.5 litres (50% Band)
	Oct-94	3.	Roundup CT		1.0 litres
		4.			
GROWTH REGULATORS:	3/02/95	1.	Pix		600 ml
		2.			
		3.			
		4.			
INSECTICIDES:	11-14/10/94	1.	Temik		3 kg
	18/11/94	2.	Endosulfan + Rogor 400		2.1 + 0.5 litres (50% band)
	13/12/94	3.	Endosulfan + Larvin		2.1 + 0.5 litres (50% Band
	9/01/95	4.	Larvin		1.0 litres
	10/02/95	5.	Curacron		
	20/02/95	6.	Endosulfan + Condor		2.1 litres
	25/02/95	7.	Curacron		
	10/03/95	8.	Larvin + DC-Tron + Rogor		
	26/03/95	9.	Parathion		2.0 litres
		10.			
		11			
		12.			
DEFOLIATION:	12/05/95	1.	Prep		2.5 litres
		2.			
		3.			
IRRIGATION DATES:		1.	February	5.	
		2.	Early March	6.	
		3.		7.	
		4.		8.	
PICKING DATES:		1.	Jul-95	2.	
NOTES:					

Appendix 2.2: Continued

APPENDIX 2.2: CROP HISTORIES

Refer Chapter 2 (2.4)

SITE: "Wild Willows" Wee Waa (Field 11) 1994/95

TRIAL: Pix Growth Regulator Trial

VARIETY: CS 189+
PLANTING DATE: 10/11/94
PLANTING RATE: 14 plants per metre

FERTILISERS:

DATE		TYPE		RATE (per ha)
10/09/94	1.	Anhydrous Ammonia		160 kg N
3/12/94	2.	Zinc + Iron + Urea		0.75 + 0.75 litres + 2kg
	3.			
	4.			

HERBICIDES:

DATE		TYPE		RATE (per ha)
3/10/94	1.	Treflan + Cotoran		2.5 + 2.5 litres
10/10/94	2.	Cotoran		3.0 litres
	3.			
	4.			

GROWTH REGULATORS:

DATE		TYPE		RATE (per ha)
16/02/95	1.	Pix		0.8 litres
	2.			
	3.			
	4.			

INSECTICIDES:

DATE		TYPE		RATE (per ha)
10/10/94	1.	Thimet		3 kg
3/12/94	2.	Endosulfan		3.0 litres
31/12/94	3.	Endosulfan + Larvin		3.0 + 0.5 litres
31/12/94	4.	Larvin		0.5 litres
21/01/95	5.	Karate + PBO		3.0 + 0.4 litres
8/02/95	6.	Karate + Curacron		3.0 + 2.0 litres
18/02/95	7.	Karate + Curacron		3.0 + 2.0 litres
1/03/95	8.	Karate + Curacron		3.0 + 2.0 litres
12/03/95	9.	Karate + Curacron		3.0 + 2.0 litres
27/03/95	10.	Karate + Rogor		0.36 + 0.5 litres
	11			
	12.			

DEFOLIATION:

DATE		TYPE		RATE (per ha)
15/05/95	1.	Salt + Harvade + Prep		20 + 0.3 + 0.5 litres
24/05/95	2.	Salt		20 litres
	3.			

IRRIGATION DATES:

	1.	2/12/94	5.	10/03/95
	2.	24/12/94	6.	24/03/95
	3.	10/02/95	7.	12/04/95
	4.	24/02/95	8.	

PICKING DATES:

	1.	15/06/95 (Rain delayed)	2.	

NOTES: Note rain and wet weather following hail damage on 2/1/95

Appendix 2.2: Continued

APPENDIX 2.2: CROP HISTORIES

Refer Chapter 2 (2.4)

SITE: Auscott Narrabri (Field 22) 1995/96

TRIAL: Growth Regulator Trial

VARIETY: Sicala V2
PLANTING DATE: 11/10/95 into moisture
PLANTING RATE: 10.6 plants per metre or 13.9 kg/ha

FERTILISERS:

DATE		TYPE		RATE (per ha)
May-94	1.	Urea		30 units
Jul-95	2.	Urea		30 units
Nov-95	3.	Urea		30 units
	4.			

HERBICIDES:

23/08/95	1.	Treflan + Diurex		2.89 litres + 0.96 kg
11/10/95	2.	Cotoran + Diurex		4.0 litres + 0.5 kg
	3.			(50% band)
	4.			

GROWTH REGULATORS:

	1.			
	2.			
	3.			
	4.			

INSECTICIDES:

29/12/95	1.	Thiodan + BT + DC-Tron		3.0 + 0.5 + 1.5 litres
19/01/96	2.	Curacron ULV		3.5 litres
24/01/96	3.	Larvin + Dipel + DC-Tron		3.8 + 0.75 + 0.5 litres
29/01/96	4.	Decis + PBO		3.5 + 0.34 litres
3/02/96	5.	Decis + Comite		2.7 + 2.5 litres
18/02/96	6.	Larvin + Comite + Dipel		2.5 + 2.4 + 0.5 litres
1/03/96	7.	Larvin + Delfin + DC-Tron		2.0 + 0.5 + 2.5 litres
8/03/96	8.	Decis + Parathion		3.8 + 2.4 litres
14/03/96	9.	Parathion + Dipel + DC-Tron		2.5 + 0.5 litres
	10.			
	11			
	12.			

DEFOLIATION:

21/04/96	1.	Dropp ULV + DC-Tron		0.35 + 2.5 litres
26/04/96	2.	Dropp ULV + DC-Tron		0.26 + 2.0 litres
	3.			

IRRIGATION DATES:

	1.	11/02/96	5.	
	2.	5/03/96	6.	
	3.		7.	
	4.		8.	

PICKING DATES:

	1.	10/5/96 (Rain delayed)	2.	

NOTES:

Applied Nitrogen equals 144 units available to the plant as with skip row planting, 62.5% of area is planted.

Rain 561 mm from November to February.

Appendix 2.2: Continued

APPENDIX 2.2: CROP HISTORIES

Refer Chapter 2 (2.4)

SITE: "Coolabah" Field 1 Merah North

TRIAL: Growth Regulator Trial

VARIETY: CS50
PLANTING DATE: 8/10/95
PLANTING RATE: 12 plants per metre

FERTILISERS:

DATE		TYPE		RATE (per ha)
24/08/95	1.	Urea		100 units
	2.			
	3.			
	4.			

HERBICIDES:

DATE		TYPE		RATE (per ha)
20/09/95	1.	Treflan		2.8 litres
23/09/95	2.	Diuron		2.0 litres
4/10/95	3.	Cotoran		2.0 litres
	4.			

GROWTH REGULATORS:

DATE		TYPE		RATE (per ha)
2/02/96	1.	Pix		700 ml
	2.			
	3.			
	4.			

INSECTICIDES:

DATE		TYPE		RATE (per ha)
4/10/95	1.	Lorsban		1.0 litres
17/11/95	2.	Endosulfan ULV		2.0 litres
2/12/95	3.	Endosulfan ULV		3.0 litres
15/12/95	4.	Talstar		0.80 litres
31/12/95	5.	Karate + Larvin		3.5 + 0.5 litres
16/01/96	6.	Larvin + Rogor		2.0 + 0.5 litres
25/01/96	7.	Curacron		3.5 litres
3/02/96	8.	Karate + Comite		0.42 + 2.5 litres
14/02/96	9.	Larvin + Rogor		2.0 + 0.5 litres
23/02/96	10.	Larvin + Rogor		2.0 + 0.5 litres
4/03/96	11	Comite + Karate		2.5 + 0.42 litres
28/03/96	12.	Larvin + Rogor		2.0 + 0.5 litres

DEFOLIATION:

DATE		TYPE		RATE (per ha)
18/03/96	1.	Dropp Ultra + Prep		0.20 + 2.5 litres
11/04/96	2.	Dropp Ultra		0.30 litres
	3.			

IRRIGATION DATES:

	1.	8/10/96 (watering up)	5.	
	2.	21/12/95	6.	
	3.	20/02/96	7.	
	4.	11/03/96	8.	

PICKING DATES:

	1.	20/05/96	2.	

NOTES:

Appendix 2.2: Continued

APPENDIX 2.2: CROP HISTORIES

Refer Chapter 2 (2.4)

SITE: "Wiilawood" Merah North (Field 9) 1995/96

TRIAL: Pix Growth Regulator Trial

VARIETY: Sicala V2
PLANTING DATE: 18/10/95
PLANTING RATE: 16 Plants per metre into moisture

	DATE		TYPE		RATE (per ha)
FERTILISERS:	30/07/95	1.	Anhydrous Ammonia		120 Units
	19/01/96	2.	Nitram		50 units
		3.			
		4.			
HERBICIDES:	28/08/95	1.	Trifluralin		2.8 litres
	28/09/95	2.	Diuron		3.0 litres
		3.			
		4.			
GROWTH REGULATORS:	7/03/96	1.	Pix		1.0 litres
		2.			
		3.			
		4.			
INSECTICIDES:	1/12/95	1.	Endosulfan ULV		3.0 litres
	18/12/95	2.	Talstar		0.81 litres
	6/01/96	3.	Bulldock ULV		2.5 litres
	26/01/96	4.	Curacron ULV		3.5 litres
	21/02/96	5.	Larvin + Rogor		2.0 + 0.5 litres
	2/03/96	6.	Larvin		2.0 litres
	12/03/96	7.	Comite + Karate + Rogor		2.5 + 0.4 + 0.5 litres
	26/03/96	8.	Talstar + Rogor		0.8 + 0.5 litres
		9.			
		10.			
		11.			
		12.			
DEFOLIATION:	16/05/96	1.	Dropp Ultra		0.35 litres
	29/05/96	2.	Salt + Reglone		16 + 1.0 litres
		3.			
IRRIGATION DATES:		1.	22/12/95	5.	
		2.	plus 5 waterings	6.	
		3.		7.	
		4.		8.	
PICKING DATES:		1.		2.	
NOTES:					

Appendix 2.2: Continued

APPENDIX 2.2: CROP HISTORIES

Refer Chapter 2 (2.5)

SITE: Leitch's Block (C. S. I. R. O. Trial Blocks) 1993/94

TRIAL: Pix Growth Regulator and Nitrogen trial

VARIETY: Siokra L23
PLANTING DATE: 8/10/93
PLANTING RATE: 15 kg/ha

FERTILISERS:

DATE		TYPE		RATE (per ha)
23/08/93	1.	Anhydrous Ammonia		180 kg N
3/12/93	2.	Urea side dressed on trial treatments		50 units
	3.			
	4.			

HERBICIDES:

8/10/93	1.	Cotoran + Stomp + Round-Up		2.0 + 3.4 + 1.0 litres
	2.			
	3.			
	4.			

GROWTH REGULATORS:

20/01/94	1.	Pix on trial treatment areas		
22/02/94	2.	Pix on trial treatment areas		
	3.			
	4.			

INSECTICIDES:

1/02/94	1.	Helix		2.5 litres
22/02/94	2.	Dipel		3.0 litres
26/02/94	3.	Curacron + Helix		1.5 + 2.0 litres
4/03/94	4.	Curacron		2.0 litres
	5.			
	6.			
	7.			
	8.			
	9.			
	10.			
	11			
	12.			

DEFOLIATION:

21/04/94	1.	Reglone		2.5 litres
	2.			
	3.			

IRRIGATION DATES:

	1.	4/01/94	5.	
	2.	20/01/94	6.	
	3.	5/02/94	7.	
	4.		8.	

PICKING DATES:

	1.	6/05/94	2.	

NOTES: Hail Damage 21/11/93.

Appendix 2.2: Continued

APPENDIX 2.2: CROP HISTORIES

Refer Chapter 2 (2.5)

SITE: "Myall Vale" Narrabri (Field 21) 1993/94

TRIAL: Pix Growth Regulator and Nitrogen Trial

VARIETY: CS 189
PLANTING DATE: 28/09/93
PLANTING RATE:

	DATE		TYPE		RATE (per ha)
FERTILISERS:	Aug-94	1.	Anhydrous Ammonia		157 units
	3/12/93	2.	Urea applied to trial treatments		50 units
		3.			
		4.			
HERBICIDES:	28/09/93	1.	Fluorometron + Stomp		4.2 + 3.0 litres
		2.			(40% band)
		3.			
		4.			
GROWTH REGULATORS:	22/01/94	1.	Pix applied to trial treatments		
	22/02/94	2.	Pix applied to trial treatments		
		3.			
		4.			
INSECTICIDES:		1.			
		2.			
		3.			
		4.			
		5.			
		6.			
		7.			
		8.			
		9.			
		10.			
		11			
		12.			
DEFOLIATION:	23/04/94	1.	Prep		2.0 litres
		2.			
		3.			
IRRIGATION DATES:		1.	2/12/93	5.	27/01/94
		2.	23/12/93	6.	11/02/94
		3.	1/01/94	7.	
		4.	14/01/94	8.	
PICKING DATES:		1.	26/04/94	2.	

NOTES: Hail storm 21/11/93.

Appendix 2.2: Continued

SITE: Auscott Narrabri (Field 5) 1995/96

TRIAL: 1. Response of Hail Damaged Cotton to Foliar Fertiliser
2. Response of Hail Damage Cotton to Nitrogen and Foliar Zinc

VARIETY: Sicala V2
PLANTING DATE: 12/10/1995
PLANTING RATE: 13-14 kg/ha

	DATE		TYPE		RATE (per ha)
FERTILISERS:	May-94	1.	Nitrogen as Urea		30 units
	Jul-95	2.	Nitrogen as Urea		30 units
	Dec-95	3.	Nitrogen as Urea		40 units
		4.			
HERBICIDES:	22/09/95	1.	Treflan + Diurex		2.9 litres + 0.94 kg
	11/10/95	2.	Cotoran + Diurex		3.97 litres + 0.5 kg
		3.			(50% band)
		4.			
GROWTH REGULATORS:	15/02/96	1.	Pix		1.3 litres
		2.			
		3.			
		4.			
INSECTICIDES:	18/12/95	1.	Thiodan ULV + BT + DC-Tron		3.0 + 0.5 + 1.5 litres
	8/01/96	2.	Talstar + BT		0.8 + 0.5 litres
	24/01/96	3.	Larvin + Decis + Dipel		1.0 + 3.5 + 0.5 litres
	29/01/96	4.	Decis + PBO		3.5 + 0.34 litres
	15/02/96	5.	Decis + Comite		0.7 + 2.5 litres
	26/02/96	6.	Decis + Delfin + DC-Tron		3.5 + 0.5 + 1.0 litres
	4/03/96	7.	Larvin + Delfin + DC-Tron		2.0 + 0.5 + 2.5 litres
	12/03/96	8.	Decis + Delfin + DC-Tron		3.5 + 0.5 + 1.0 litres
	2/04/96	9.	Rogor (edge spray)		0.3 litres
		10.			
		11			
		12.			
DEFOLIATION:	13/04/96	1.	Dropp + Prep		3.5 + 2.0 litres
		2.	Prep		2.5 litres
		3.			
IRRIGATION DATES:	Sep-96	1.	Pre-watering	5.	
		2.	12/02/96	6.	
		3.	3/03/96	7.	
		4.		8.	
PICKING DATES:		1.	25-28/5/96	2.	

NOTES: 561 mm rain from Nov-Feb. (See rainfall records).

Appendix 2.2: Continued

APPENDIX 2.2: CROP HISTORIES

Refer Chapter 2 (2.5)

SITE: Australian Cotton Research Institute (Field B2) 1994/95

TRIAL: Pix Growth Regulator and Nitrogen Trial

VARIETY: Sicala V2
PLANTING DATE: 10/10/94
PLANTING RATE: 15 seeds per metre

	DATE		TYPE		RATE (per ha)
FERTILISERS:	5/08/94	1.	Anhydrous Ammonia		100 units
	16/12/94	2.	Urea (to Treatment areas only)		50 units
		3.			
		4.			
HERBICIDES:	23/09/94	1.	Stomp		3.0 litres
	10/10/94	2.	Cotoran		3.0 litres
		3.			
		4.			
GROWTH REGULATORS:	24/01/95	1.	Pix (to appropriate treatments only)		
	16/02/95	2.	Pix (to appropriate treatments only)		
		3.			
		4.			
INSECTICIDES:	17/12/94	1.	Endosulfan + Rogor		2.2 + 0.5 litres
	23/12/94	2.	Talstar		0.8 litres
	14/01/95	3.	Larvin		2.5 litres
	22/01/95	4.	Talstar		0.8 litres
	10/02/95	5.	Curacron ULV		4.0 litres
	24/02/95	6.	Larvin + Rogor		2.5 + 0.5 litres
	5/03/95	7.	Curacron ULV		4.0 litres
		8.			
		9.			
		10.			
		11			
		12.			
DEFOLIATION:	8/04/95	1.	Dropp + Prep + DC-Tron + Harvade		100 g + 1.3 + 2.0 + 0.3 litr
		2.			
		3.			
IRRIGATION DATES:		1.	29/9/94 Pre-watering	5.	1/03/95
		2.	20/12/94	6.	16/03/95
		3.	12/01/95	7.	
		4.	13/02/95	8.	
PICKING DATES:		1.		2.	

NOTES:

Hail Damage Simulation 13/12/94.
Pix and side dressed Urea were applied only to the treatments as per the trial plan.

Appendix 2.2: Continued

APPENDIX 2.2: CROP HISTORIES

Refer Chapter 2 (2.5)

SITE: Auscott Narrabri (Field 10) 1993/94

TRIAL: Pix Growth Regulator and Nitrogen Trial

VARIETY: Sicala V1
PLANTING DATE: 14/10/1993 into moisture
PLANTING RATE: 12.8 kg/ha

	DATE		TYPE		RATE (per ha)
FERTILISERS:	24/08/93	1.	Anhydrous Ammonia		100 kgN/ha
	27/08/93	2.	Urea flown on		30 kg/ha
	27/08/93	3.	Urea flown on		30 kg/ha
		4.			
HERBICIDES:	27/08/93	1.	Treflan + Diurex		3.21 litres + 1.0 kg
	14/10/93	2.	Cotoran		3.38 litres
		4.			
GROWTH REGULATORS:		1.			
		2.			
		3.			
		4.			
INSECTICIDES:	13/12/93	1.	Endosulfan ULV		3.0 litres
	27/12/93	2.	Larvin LV + Dipel LS		0.75 + 1.5 litres
	31/12/93	3.	Endosulfan ULV + Curacron + Dipel		1.5 +3.51 + 1.5 litres
	17/01/94	4.	Curacron ULV		3.5 litres
	31/01/94	5.	Decis ULV + Dipel LS		3.5 + 1.0 litres
	18/02/94	6.	Curacron ULV		3.5 litres/ha
	24/02/94	7.	Helix ULV		2.5 litres
	23/03/94	8.	Dipel LS + Parathion		1.5 + 2.0 litres
		9.			
		10.			
		11			
		12.			
DEFOLIATION:	11/04/94	1.	Dropp + DC-Tron		0.1 kg + 2.0 litres
	15/04/94	2.	Leafex		14 litres
	26/04/94	3.	Leafex		14 litres
IRRIGATION DATES:		1.	22/12/93	5.	
		2.	9/01/94	6.	
		3.	21/01/94	7.	
		4.	5/02/94	8.	
PICKING DATES:		1.	2/05/94	2.	

NOTES: Hail Damage Simulated at R9.9 growth stage on 21/1/94.

Appendix 2.3: Product Labels

Pix®

CAUTION

KEEP OUT OF REACH OF CHILDREN

READ SAFETY DIRECTIONS BEFORE OPENING OR USING

Pix®

Plant Growth Regulator

ACTIVE CONSTITUENT: 38 g/L mepiquat present as the chloride

For the management of fruiting and vegetative growth in cotton.

Appendix 2.3: Product Labels (continued)

Pix®

GENERAL INSTRUCTIONS

MODE OF ACTION

Pix is a foliar applied plant regulator which modifies the cotton plant by regulating its growth pattern and behaviour. Pix may produce one or more of the following effects in cotton. darker leaf colour, reduction of internodal length, more open canopy, better boll retention, earlier maturity. Some of these effects may favourably influence the yield potential of the cotton plant.

APPLICATION

Pix as a crop management tool is best applied as split - application "Multiple Low Rates" rather than a single application. First spray should be applied early (early squaring) and repeated as suggested in the Directions for Use Table.

APPLICATION METHOD

May be applied by air or ground. Best results can be obtained with total spray volumes of at least 50 L/ha for aerial application and 150-200 L/ha for application by ground rig

MIXING

Pix has an aqueous base and mixes readily with water. Add the required amount of Pix to the partly filled spray tank and agitate to give even mixing.

COMPATIBILITY

Pix has been found to be compatible with the following insecticides: Endosulfan, Permethrin, Deltamethrin, Fenvalerate, Methomyl. Care should be taken that there is no conflict in application techniques between Pix and the insecticide when applying products together. Do not tank-mix with foliar fertilizers as the benefits from such mixes have not been established.

LODGING

Under strong winds Pix-treated cotton that has set bolls packed tightly together against the stem may be more susceptible to lodging.

PROTECTION OF WILDLIFE, FISH, CRUSTACEANS AND ENVIRONMENT

Do not contaminate dams, waterways or drains with Pix or used containers.

STORAGE AND DISPOSAL

Store in the closed, original container in a dry, well-ventilated area, as cool as possible. Do not store for prolonged periods in direct sunlight. Triple rinse containers before disposal. Add rinsings to tank mix or dispose of rinsate in a disposal pit. This pit must be away from aquatic areas and in a suitable area specifically marked and set up for the purpose. Do not dispose of undiluted chemicals on-site. Destroy empty containers by breaking, crushing or puncturing them. Dispose of the containers at a local authority landfill that does not burn its refuse. If there is no local authority landfill readily available in your area, bury the containers at a depth of 500 mm or more at a licensed/approved disposal site. In some States wastes can only be buried at a licensed landfill. Do not burn empty containers or product.

SAFETY DIRECTIONS

Avoid contact with eyes and skin. Wash hands after use.

FIRST AID

If poisoning occurs, contact a doctor or the Poisons Information Centre.

MATERIAL SAFETY DATA SHEET

Additional information is listed in the Material Safety Data Sheet available from Hoechst Schering AgrEvo Pty. Ltd.

CONDITIONS OF SALE

All conditions and warranties rights and remedies implied by law or arising in contract or tort whether due to the negligence of BASF Australia Ltd. or otherwise are hereby expressly excluded so far as the same may legally be done provided however that any rights of the Buyer pursuant to non excludable conditions of warranties of the Trade Practices Act 1974 or any relevant legislation of any State are expressly preserved but the liability of BASF Australia Ltd. or any intermediate Seller pursuant thereto shall be limited if so permitted by the said legislation to the replacement of the goods or the supply of equivalent goods and all liability for indirect or consequential loss or damage or whatsoever nature is expressly excluded. This product must be used or applied strictly in accordance with the instructions appearing hereon. This product is sold solely for use in Australia and must not be exported without prior written consent of BASF Australia Limited.

NRA Approval No. 41651/4721

® Pix is a Registered Trademark of and is produced by BASF

DIRECTIONS FOR USE (For Use in Qld, NSW only)

RESTRAINTS

DO NOT apply to crops that have restricted growth due to drought stress, waterlogging, nutrient deficiency, poor soil structure or any other cause as this can result in a yield decrease.

DO NOT apply if adequate insect and mite pest control and supply of water and nutrients later in the crop is in doubt, or if "stressing" is a normal management practice. If severe drought conditions occur after Pix application, Pix results can be unsatisfactory and/or yield decreases can occur.

DO NOT apply Pix if rainfall is expected within 8 hours of application as effectiveness of Pix may be reduced.

DO NOT apply to new commercial varieties of cotton before checking with the manufacturer.

DIRECTIONS FOR USE TABLE:

CROP	PURPOSE	APPLICATION RATE	CRITICAL COMMENTS
COTTON	To regulate fruiting and Vegetative growth		**Split application/ Multiple Low Rates.** Apply no more than 1.5 L in total, spread over 2 to 3 application times as suggested below:
		250 to 600 mL/ha	1st spray at: early squaring - squares the size of match heads.
		250 to 600 mL/ha	2nd spray at approximately: 1st flower
		250 to 600 mL/ha	3rd spray at approximately: 14 days (2 weeks) later
	Control of excess growth	750 mL to 1 L/ha	**Single application:** Apply at 1st flower. Use this rate where crop growth is excessive.

NOT TO BE USED FOR ANY PURPOSE, OR IN ANY MANNER, CONTRARY TO THIS LABEL UNLESS AUTHORISED UNDER APPROPRIATE LEGISLATION.

WITHHOLDING PERIOD:
DO NOT APPLY LATER THAN 4 WEEKS BEFORE HARVEST.

DIRECTIONS FOR USE:

AGITATE CONTENTS WELL BEFORE DILUTION

SUITABLE FOR APPLICATION BY:
Boom spray, trickle, sprinkler under tree jet or aerial

APPLICATION RATES:

CROP	RATE PER Ha	COMMENTS
Turf	20 Lt	200mL per 100m²
Horticultural	1 to 2 Lt	Cover the foliage thoroughly, allowing a small amount of run off
Fruit Trees	1 to 3 Lt	
Nursery Plants	1 to 2 Lt	Do not apply during heat of the day, before rain or irrigation
Broad Acre —Cotton & Grains	1 to 2 Lt	Ratio to water: In the range 1:50-1:100 minimum

Ratio to water —in the range — 1:50-1:100
—aerial application — use maximum practical water rates.

NOTE: *This product's effectiveness increased when applied in conjunction with Supa Humus.

STANDARD MIXING & SPRAYING INSTRUCTIONS

1. Fill tank to minimum of half volume.
2. Add compatible chemicals as required maintaining agitation.
3. Stir and/or agitate well.
4. Add Supa Wet 77 or Supa-Stik 100 or Supa Buffa or Supa Link as required per labelled instruction.
5. Add Supa Crop fertilizers and compatible trace elements as required.
6. Bring volume to full with water while maintaining agitation.
7. Add Supa Humus as required.

NOTE: The above suggested rates of application should be used as a guide only. Each farmer's climatic conditions and soil types will necessitate corrections to maximise yields. Where possible, it is recommended that regular leaf (sap) tests are conducted to determine actual plant nutrient availability during each growing cycle. Soil tests at least once a year are essential.

SOLE MANUFACTURERS:
AGRICHEM MANUFACTURING INDUSTRIES PTY. LTD.
PHONE (07) 808 2464 FAX: (07) 808 4701
51 RANDALL STREET, SLACKS CREEK, QLD. 4127
P.O. BOX 342, SPRINGWOOD, QLD. 4127

TRIPLE 7

7%N, 7%Zn, 7%Fe, 0.5%Cu, 7.5%S

National Fertilizer Solutions Association
MEMBER

HIGH ANALYSIS TRACE ELEMENT LIQUID IN A READILY AVAILABLE FORM FOR CORRECTING NUTRIENT DEFICIENCIES AND OR MAINTAINING LEVELS TO ASSIST IN THE GROWTH AND MATURITY OF CROPS

SUPA CROP

"Together we Grow .... Naturally"

SPECIMEN ONLY

TRIPLE 7

Analysis:

			W.V.%
NITROGEN	(N)	as Urea	7.0
IRON	(Fe)	as Ferrous Sulphate	7.0
ZINC	(Zn)	as Zinc Sulphate	7.0
COPPER	(Cu)	as Copper Sulphate	0.5
SULPHUR	(S)	as Sulphate	7.5

Water: 50.0% W.V.
Total Solids: 83.0% W.V.
Biuret Maximum: 0.22% W.V.

TRIPLE 7 is compatible with a wide range of commonly used spray chemicals. When mixing with other chemicals, always mix a small quantity and observe precipitation (fall out) in mixture. If precipitation occurs, DO NOT proceed with application. Should precipitation occur when mixed with N.P.K. fertilizers — use SUPA LINK as per labelled instructions.

MIX ENOUGH TRIPLE 7 FOR 1 DAY'S APPLICATION. DO NOT STORE TRIPLE 7 MIXED WITH WATER OR OTHER CHEMICALS.

CONDITIONS OF SALE

1. All goods supplied are made from high grade materials and are believed to be suitable for use
2. As no control can be exercised over storage, handling, mixing application or use or weather, plant or soil conditions before, during or after application (any or all of which may affect the performance) losses, damages, or injuries (consequential or otherwise) arising from such storage, mixing, application, or use will be accepted under any circumstances whatsoever, and buyer assumes all responsibility for use of the product
3. These conditions can not be modified, varied or waived by our staff distributors or retailers, whether or not they advise or assist in the storage, handling, mixing or use of the goods, and such persons shall be entitled to the benefit of Clause 2
4. MAXIMUM LIABILITY. Liability is limited to replacement of faulty goods only

NETT CONTENTS	5 Litre	25 Litre	200 Litre	1000 Litre

Appendix 2.4: Lint Quality Measurement

Lint quality of samples was determined by the C. S. I. R. O. Cotton laboratory at the Australian Cotton Research Institute, Narrabri. Results are produced by two high volume instruments (H. V. I.); a Shirley Development Ltd Fineness Maturity Tester (FMT3) and a Spinlab (Zellweger Uster) high volume instrument.

The Shirley Development Ltd Fineness Maturity Tester (FMT3) works on the double airflow method. At present, cotton is universally tested for micronaire but not for the individual components of micronaire - fineness and maturity. Hence, there is no premium for desirable fine and mature cotton. Rather there is a penalty for low micronaire cotton (below 3.5) even though in some cases it may be fine but still mature. A monetary penalty is also imposed on cotton reading over 5.0, on the assumption that it is too coarse. Wide adoption of the FMT could correct these anomalies, but the market trendsetter, the U. S. A., shows reluctance to routinely use the instrument. Precision of the fineness and maturity readings from the Shirley FMT is relatively poor. The C. S. I. R. O. carries out two tests on each sample which are averaged.

1. Maturity Ratio (Mat)

This is an estimate of cell wall thickness to fibre diameter and is the British form of expression of maturity. Spinners using faster machinery prefer finer cotton if it is also mature. Maturity is environmentally controlled and can be lowered by any factor causing an impediment to growth.

Principle of operation - Sample is blended to open, clean and randomise fibres. Readings of pressure drop across the sample of known mass are taken at two different compressions (low compression and high air-flow followed by high compression and low air-flow). The high compression causes an increase in fibre surface area and the difference between the air permeabilities at the two different compressions is related to maturity.

Units of measure: Ratio (1.0 is theoretical full potential but readings commonly go higher).
Scale of Value:

<	0.70	Immature
0.70 -	0.80	Below average
0.81 -	0.95	Average
>	0.95	Above average

2. Percent Mature Fibres (PM)

The American form of expression and is directly converted from maturity ratio readings.

Unit of measure: Percentage (N.B.: 87% = 1.0 mat. ratio).
Scale of Value:

<	60	Immature
60 -	70	Below average
71 -	83	Average
>	83	Above average

3. Fineness (F)

Not a direct measurement but a linear density estimate of fibre perimeter. Directly related to maturity ratio readings. Fineness is genetically influenced to a great degree.

Unit of Measure: millitex (milligrams per metre).
Scale of Measure:

>	155	Very fine
155 -	165	Fine
166 -	180	Average
181 -	190	Coarse
>	190	Very Coarse

Prior to testing, a beard of fibres held randomly along their in a fibrocomb is manually prepared in an instrument called a fibreblender. This "beard" is then combed to straighten and parallel the fibres and brushed to remove crimp. In the latest model of the instrument, the beard is formed automatically, rather than manually. Commercially, two tests are done on each sample and the results meaned, however for greater accuracy C. S. I. R. O. do three.

4. Length (Len)

Of the two optional levels of expression, we currently use the upper half mean length (UHML) which is the mean length of the longest 50% of fibres in the beard. This gives a figure very close to the classers visually assessed staple length and slightly longer than the 2.5% span length used by the C. S. I. R. O. until 1993. Precision is good and is much more accurate than the classers' subjective assessment. Mean length (ie. mean of all fibres) is also assessed to determine length uniformity.

Principle of Operation: Mass of the beard is determined optically by measuring light absorption. Density readings are converted by software into a fibrogram from which length values are extracted.

Unit of Measure: Inches
Scale of Value:

<	1.00	Very Short
1.00 -	1.14	Medium
1.15 -	1.29	Long
>	1.29	Extra Long

5. Length Uniformity Index (UI)

Fibre length distribution is important. An excess of short fibres requires the yarn to be given greater twist resulting in a harsh feel and a slowing of the spinning operation. Measurement has relatively low precision, partly because fibres under 4 mm are not measured. For the same reason it is not a good indicator of short (below 13 mm) fibre content.

Determination: Simply a ratio of mean length (ML) over upper half mean length (UHML).

Unit of Measure: Percent.

Scale of Value:

<	75	Very low
75 -	78	Low
79 -	82	Average
83 -	85	High (and desirable)
>	85	Very high (and desirable)

Prior to 1993, the C. S. I. R.O. used Uniformity Ratio (50% span length over 2.5% span length). Its scale of values was:

<	41	Very low
41 -	43	Low
44 -	46	Average
47 -	48	High
>	48	Very high

6. Strength or Tenacity (grams/tex)

Fibre strength has become increasingly important as faster spinning methods produce weaker yarn. The fibrocomb holding the beard is moved automatically into the instrument a second time following the length test. (In the latest Spinlab model, two tests are performed in one pass). Clamps used to secure the beard prior to breaking are spaced 3.2 mm (1/8 inch) apart, ie. 3.2 mm gauge. Original strength testing instruments (Stelometer and Pressley) used zero gauge but readings did not relate as well with yarn strength. The level of expression the C. S. I. R. O. use is called HVI strength and these readings are slightly lower than the optional Pressley level (used by the C. S. I. R. O. until 1993) and this in turn is 25% higher than the other optional level - Stelometer. (Conversion - Stelometer to Pressley = x 1.26, Stelometer to HVI = x 1.25). Readings have a relatively low precision and are strongly influenced by moisture content.

Principle of operation: After clamps are positioned over the beard, the break is made using a stop motor, mass is calculated from the micronaire reading and break force is translated by microprocessor into engineering units. Final readings is linear density.

Unit of measure: Grams per tex (Tex = 1000m of fibre) at H. V. I. level.
Scale of Measure:

3.2 mm gauge Stelometer (gms/tex)		**3.2 gauge HVI (& Pressley) (gms/tex)**		0 mm gauge Pressley (p.s.i.)		
<	19	**<**	**24**	<	77,000	Very Low
19 -	21	**24 -**	**26**	77 -	83,000	Low
22 -	24	**27 -**	**30**	84 -	90,000	Average
25 -	27	**31 -**	**34**	91 -	97,000	High
>	27	**>**	**34**	>	97,000	Very High

7. Elongation or extension (EL).

Measured in the strength operation. The reading is the distance the fibres extend before breaking and is expressed as a percentage of fibre length. It is important in high speed processing and in determining fabric properties. The test has a relatively low precision and is not able to be routinely calibrated.

Unit of Measure: Percent of fibre length
Scale of Measure:

<	5.0	Very Low
5.0 -	5.8	Low
5.9 -	6.7	Average
6.8 -	7.6	High
>	7.6	Very High

8. Micronaire (micrograms per inch)

A measure produced in the first cycle (low compression, high air flow) of Shirley FMT, although the test can also be done on the Spinlab instrument. Micronaire is a linear density expression of fineness and maturity weighted roughly two thirds towards maturity. The reading is of limited value without knowledge of the components. Readings are highly repeatable. Two tests per sample are carried out on each sample.

Principle of Operation: Surface area is assessed by forcing a metered air stream through a known mass of fibre in a chamber of known volume and recording the pressure differential.

Unit of measure: Micrograms per inch.
Scale of Value:

3.5 to 5.0 accepted without penalty. 3.2 - 3.8 is optimum for rotor spinning and 2.7 to 3.2 is optimum for friction and air-jet spinning provided the fibre is known to be mature. Realistically, though, readings below 3.5 are not consistently achievable from conventional upland cotton varieties without a deterioration in maturity.

APPENDIX 4.1:

Fruiting Pattern Trials - Crop Histories and Trial Designs

Trial: **Cotton Seed Distribntors Ltd. Cotton Variety Trial**
Trial Site: **"Togo Station " Narrabri (Field 44) 1994/95**

Trial Design:	
Rep 1	
1	Siokra 1-4
2	DP90
3	Siokra L23
4	CS50
5	CS8S
6	CS189+
7	Sicala V2
8	Siokra V15
9	Exp 613
Rep 2	
1	CS189+
2	Siokra L23
3	CS8S
4	Sicala V2
5	DP90
6	Siokra 1-4
7	Exp 613
8	CS50
9	Siokra V15
Rep 3	
1	Sicala V2
2	CS8S
3	Siokra L23
4	CS50
5	Exp 613
6	DP90
7	Siokra 1-4
8	CS189+
9	Siokra V15
Rep 4	
1	Exp 613
2	CS50
3	Siokra L23
4	CS8S
5	Siokra 1-4
6	CS189+
7	Sicala V2
8	DP90
9	Siokra V15

Planting Date:
6/10/94 watered up
Planting Rate:
15 kg/ha
Varieties: 9
Replicates: 4
Rows/rep: 12
Cropping History:
Fallow after wheat
Herbicide Program:
2.81 l/ha Treflan pre plant
2 l/ha Cotogard pre plant
1 l/ha Cotogard post plant
1.5 l/ha diuron post plant
Fertiliser Program:
120 units N as NH3 pre plant
Additional Comments:
3 kg/ha Thimet

APPENDIX 4.1: continued

Fruiting Pattern Trials - Crop Histories and Trial Designs

Trial: **Cotton Seed Distributors Ltd. Cotton Variety Trial**
Trial Site: **"Nandewar" Boggabri (Field 2) 1994/95**

Trial Design:	
Rep 1	
1	Siokra 1-4
2	CS8S
3	Siokra S324
4	Sicala V2
5	Siokra V15
6	Exp 613
7	Exp 523
Rep 2	
1	Siokra V15
2	Siokra S324
3	Exp 613
4	CS8S
5	Sicala V2
6	Exp 523
7	Siokra 1-4
Rep 3	
1	Exp 523
2	Sicala V2
3	Siokra 1-4
4	Exp 613
5	Siokra S324
6	Siokra V15
7	CS8S
Rep 4	
1	Siokra S324
2	CS8S
3	Exp 523
4	Siokra 1-4
5	Exp 613
6	Sicala V2
7	Siokra V15

Planting Date:
8/10/94 into moisture
Planting Rate:
13 kg/ha
Varieties: 7
Replicates: 4
Rows/rep: 16
Cropping History:
Fallow after barley
Herbicide Program:
3 l/ha Treflan pre plant
3 l/ha Cotogard pre plant
3 l/ha Cotogard 30% band at plant.
Fertiliser Program:
125 units N as NH_3 pre plant
Additional Comments:
5 kg/ha Thimet

APPENDIX 4.1: continued

Fruiting Pattern Trials - Crop Histories and Trial Designs

Trial: **Cotton Seed Distributors Ltd. Cotton Variety Trial**
Trial Site: **"Coolabah" Merah North (Field 4B) 1994/95**

Trial Design:	
Rep 1	
1	Siokra 1-4
2	DP90
3	Siokra L23
4	CS50
5	CS189+
6	Sicala V2
7	Siokra V15
8	Exp 613
9	Exp 97
Rep 2	
1	CS189+
2	Siokra V15
3	DP90
4	Sicala V2
5	Exp 97
6	Siokra 1-4
7	CS50
8	Exp 613
9	Siokra L23
Rep 3	
1	CS50
2	CS189+
3	Siokra 1-4
4	Sicala V2
5	DP90
6	Siokra V15
7	Exp 613
8	Siokra L23
9	Exp 97
Rep 4	
1	CS189+
2	Siokra V15
3	CS50
4	Sicala V2
5	Exp 613
6	Siokra L23
7	Exp 97
8	DP90
9	Siokra 1-4

Planting Date:
4/10/94 into moisture
Planting Rate:
15 seeds/m
Varieties: 9
Replicates: 4
Rows/rep: 8 & 16
Cropping History:
Fallow after wheat
Herbicide Program:
3 l/ha Stomp post plant
3 l/ha Cotogard post plant
Fertiliser Program:
120 units N as urea pre plant
15 units P + 15 units S /ha pre plant
Additional Comments: