FINAL REPORT

CRDC ID: CSP 1905
Project Title: IPM to support the management of emerging pests

Confidential or for public release? Public Release

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Part 1 – Contact Details & Submission Checklist

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Submission checklist.

Please ensure all documentation has been completed and included with this final report:

☒ Final report template (this document)
☒ Final Technical Report
☒ Final Schedule 2: IP register
☒ Final Schedule 3: Acknowledgment
☒ Final financial report
☐ PDF of all journal articles (for CRDC's records)

Signature of Research Provider Representative: ________________________

Date submitted: ____________

Part 2 - Monitoring & Evaluation

This data is for CRDC's internal M&E requirements. Please complete all fields and add additional rows into each table if required.

Achievement against milestones in the Full Research Proposal

Milestone	Achieved/ Partially Achieved/ Not Achieved	Explanation

1. Impact of insecticides on beneficials	Achieved	Noting that some reports to chemical companies (Syngenta, ISK, BASF, Innovate Ag, FMC) are still to be finalised
2. Improved understanding of invertebrate composition and movement	Partially achieved	*MS2.1 achieved Studies on movement MS2.2 & Soil Fauna MS2.3 were not carried out*
3. Incorporating physiological fruit loss into IPM decisions	Achieved	The experiments in small chambers were problematic, but the field trials provided detailed findings.
4. Impact and IPM fit of various chemicals for SLW management	Achieved	We had difficulties rearing sufficient Silverleaf whitefly numbers to reliably interpret results
5. Support new IPM tactics and enhance IPM best practise	Partially achieved	Noting that a variation to this MS was granted – the approach and questionnaires were developed but the surveys were not conducted.
6. Support the continued development of existing industry education initiatives	Achieved	Report submitted to CRDC in November 2021. Trudy Staines CSP1905 "Developing Capability to Service the Cotton Industry".
7. Final report	Achieved	

Outputs produced *(Please refer to examples document to assist in completing this section).*

Output	Description
Report	1. *Final report on the management of emerging pests. Report covers investigations into biotic and abiotic factors of fruit loss and plant responses, the impact of novel chemicals on beneficials, chemicals used for SLW control, invertebrate composition in cotton fields and the development of a survey on the economics of IPM.* 2. CSD Pest Management Summaries (2018/19, 2019/20, 2020/21)
Presentations	1. Annual updates at CCA Meetings (June 2019, June 2021) 2. Three-minute Thesis – Australian Cotton Conference August 2018 3. International Whitefly Symposium (Fremantle, Sept 2018) outlining the impact of management practices on SLW populations and subsequent effects of honeydew on cotton quality. 4. Entomophagy Talk for Primary School March 2021

	5. Cotton Spinning Presentation Narrabri west Primary School March 2021 6. Cotton IPM Course - Cotton crop compensation – damage and thresholds (2019-2021 7. UNE Cotton Production Course Pest Management Module – Lecture on Hemiptera (2019-2020) 8. Cotton Talks – Internal at CSIRO on Fruit removal Dec 2020 9. IPM presentation to young consultants (MW)
Publications	Downes, S., Whitehouse, M., Heimoana, S., Tay, W., Walsh, T. 2018. Terminating the mega-pest. Biosecurity a key to effective Integrated Pest Management. *The Australian Cottongrower* 39(4): 14-17. Heimoana, S.; Wilson, L.J. *et al.* (2018-2021). Impact of insecticides and miticides on predators, parasitoids and bees in cotton. In: The Australian Cotton Industry CottonInfo Team (eds) Cotton Pest Management Guide 2019-20. Cotton Research and Development Corporation, pp 10-11. Heimoana, S.C. (2020). What are ssunflowers doing in the cotton. Narrabri Courier Article, February 2020. Lowe, E.C., Latty, T., Webb, C.E., Whitehouse, M.E.A., Saunders, M.E. 2019 Engaging urban stakeholders in the sustainable management of arthropod pests. *Journal of Pest Science* https://doi.org/10.1007/s10340-019-01087-8. Mansfield, S., Ferguson, C.M., White, T., Hardwick, S., Marshall, S.D.G., Zydenbos, S.M., Heimoana, S.C., Gorddard, R. and Whitehouse, M.E.A. (2019). Barriers to IPM adoption for insect pests in New Zealand. Journal of New Zealand Grasslands 81:139-148. Rendon, D., Hagler, J., Taylor, P.W., Whitehouse, M.E.A. 2018. Integrating immunomarking with ecological and behavioural approaches for assessing consumption of *Helicoverpa* spp. larvae by wolf spiders in cotton. *Biological Control* 122:51-59. Rendon, D., Taylor, P.W., Whitehouse, M.E.A. Multiple intraguild predators reduce mortality risk of a mutual agricultural pest prey in simple, but not in complex, experimental settings *Austral Ecology* 44(6):1065-1075. Sequeira, R., Whitehouse, M.E.A., Williams, S., Maas, S. 2018. Revised mirid spray thresholds – what they mean and how to use them. *The Australian Cottongrower* 39(3): 42-45. Thomas, A., Williams, S., Whitehouse, M., Dickinson, S., Twine, A. 2018. Does high mirid pressure at early squaring have an effect on yield? *The Australian Cottongrower* 39(4): 28-31. Walsh, T.K., Joußen, N., Tian, K.T., McGaughran, A., Anderson, C.J., Qiu, X., Ahn, S.J., Bird, L., Pavlidi, N., Vontas, J., Ryu, J., Rasool, A., Barony Macedo, I., Tay, W.T., Zhang, Y.J., Whitehouse, M., Sylvie, P., Downes, S., Nemec, L. and Heckel, D.H. Multiple recombination events between two cytochrome P450 loci contribute to global pyrethroid resistance in *Helicoverpa armigera*.. *PLoS ONE* 13 (11) e0197760.

	Whitehouse, M.E.A. 2019. The mirid Challenge – Does cloudiness affect mirid damage in the Murrumbidgee? IREC Farmer's Newsletter no. 202:9-11.

Outcomes from project outputs *(Refer to examples document).*

Outcome	Description
Increased knowledge about practices and products	Increased knowledge about practices and products by growers and industry stakeholders. E.g. BioPestOil, Skope, Buprofezin, Pymetrozine (high rate) and others.
Industry capacity building	Knowledge and skills of project stakeholders increased. Researchers developed better knowledge of fruit loss tolerance of cotton, insect communities in cotton and SLW /Beneficial interactions.
Collaboration	Consultation with Mr Ben Simpson (CRDC) and Ms Janine Powell (AgEcon) to develop a survey to identify whether an IPM approach to growing cotton is costly (or whether there is no correlation in cost).
Extension	Extension of knowledge to Schools, IPM Training Courses and UNE Cotton Production Course and Farmer Groups (via CottonInfo).

Part 3 – Technical Report

Executive Summary

The implementation of Integrated Pest Management and use of *Bt* varieties has drastically reduced insecticide sprays on cotton farms. This enabled the industry to focus on agronomy, leading to continued growth in yields and profitability over the last 20 years. However, there are still ongoing challenges being faced by growers each season concerning sustainable pest management. Our research in this project focused on some of the more complex issues growers face that occur from the interactions between multiple biotic and abiotic factors that can be unique to each season. We aimed to generate new knowledge to support IPM adoption and potentially reduce the risk of IPM dis-adoption that we see as a growing threat to the future sustainability of cotton. What we achieved in this project included:

- Further contributions to Table 4 of the Cotton Pest Management Guide, evaluating the effects of new pesticide compounds on non-target species (predators and parasitoids) and ranking them according to the standard that is now a well-known IPM resource.

- We examined insecticides specifically aimed at controlling silverleaf whitefly (SLW) given the increased likelihood of resistance to some commonly used products. In both years the impacts of the insecticides were not significantly different from each other or the unsprayed control. However, our trials did show that predators and parasitoids, if not interfered with, can control pest numbers.

- We tested an app that assessed SLW nymphs on leaves to make SLW monitoring more time efficient. The app captured about 51% of the variance of the nymphs on leaves. However, with refinement, these types of tools will become increasingly important for monitoring pest populations.

- We conducted experiments to examine the effect of early season pest damage on yield of BGIII cotton and compensation for early fruit loss by plants. We simulated pest damage by tipping and removing fruit from the lower and mid-canopy fruiting

branches. Tipping of cotton between nodes 5 and 7 or loss of fruit from the lower six fruiting branches (FB 1-6) in a portion of the crop (33%) did not result in significant yield loss or a delay in maturity. However, fruit loss from fruiting branches in mid-canopy (FB 7-12) and/or a higher proportion of the crop (100%) has the potential to incur greater yield loss and significantly delay maturity. The potential for loss was greater in higher yielding crops. Our results suggested that low levels of insect damage could be tolerated, which has implication for mirid management and future research.

- There was no significant compensation for losses but the severity and timing of damage changed fruit development and contribution to yield within plants. In undamaged plants, the contribution to yield by bolls from the plant core (FB 1-12, Position 1&2 bolls) was 65%, contribution from bolls on vegetative branches was 21% and 14% from bolls on the remainder of the plant (FB 13+ and FB1-12 P3 bolls). This pattern remained when only every third plant was damaged (FB1-6 or FB 7-12) but damage to FB 7-12 or to more plants (100%) shifted yield contribution to vegetative branches and upper canopy in roughly equal proportions. The most extreme damage (FB1-12 x 100%) shifted 51% of fruit and yield production to the upper and outer canopy, and 33% to vegetative branches.

- We conducted experiments to test the effect of cloudiness and mirid damage (both simulated and actual damage via mirids themselves) on cotton yield. Our findings showed that plants can compensate for both factors in this controlled environment, and there was no impact on bolls and lint weight at the end of the season.

- We attempted to link changes in whole invertebrate communities to the cumulative application of multiple insecticide products across a season (via the BDI, beneficial disruption index). This exploratory approach showed that BDI is only one of many factors that influence community turnover and change and our experimental design could not unpick these interacting factors.

- Endemic pest issues are further compounded by the continued threat of exotic incursions. During this project, we contributed to the Australia-wide response to the arrival of fall armyworm. This species has established in maize at ACRI and is already being attacked by parasitoids. We also contributed to the cotton industry plans to respond to future threats like blue disease.

- An incentive-based approach to enhance IPM best practice that focussed on exploring the economic benefits of IPM to individual growers, especially long term; and encouraging realistic expectations of yield based on seasonal constraints. In consultation with Mr Ben Simpson (CRDC) and Ms Janine Powell (AgEcon) we developed a survey instrument to identify whether an IPM approach to growing cotton is costly (or whether there is no correlation in cost), however, the survey itself was not conducted

Our work during this project supports the importance of early season crop management which can greatly impact on outcomes at the end of the season and beyond. The use of pesticides to control thrips, cutworm, wireworm and mirids is likely to increase the risks of resistance development and can negatively affect beneficial species. In some years that risk may be manageable and in others it may not. Furthermore, plants can compensate for certain levels of pest damage, even when combined with other factors (such as physiological fruit loss and cloudiness). Capacity-building of growers and consultants as well as a re-evaluation of what knowledge tools are required will help in these complex scenarios.

Our team faced many challenges throughout this project, beyond the risk of extreme seasonal weather events. Both the impacts of Covid-19, staff changes and personal crises influenced the timing and success of some experiments but we implemented contingency plans wherever possible. Furthermore, we see the need to better understand the complex interactions between the crop, insects and abiotic processes in order to answer pertinent industry questions and improve on current IPM practices.

Background

The implementation of IPM and use of *Bt* varieties drastically reduced insecticide sprays on cotton farms. This enabled the industry to focus on agronomy, leading to continued growth in yields and profitability over the last 20 years. But some growers query whether IPM principles remain relevant. Recent increases in insecticidal control of mirids flared mites and silver leaf whitefly (SLW). Further, what was apparently physiologically induced early season fruit loss was blamed on pests, increasing sprays of dubious benefit.

CSIRO researchers at ACRI have provided knowledge and tools to support IPM adoption in the Australian cotton industry for over 20 years. This project continues this long history and builds on our knowledge of how to manage Green Vegetable Bugs (GVB), mirids and SLW, including the impact of predators and parasitoids on their survival. The first part of our work focusses on creating further depth in important IPM principles so growers can continue to manage pests in a sustainable manner. The second part focusses on capability development with activities to retain, attract and develop educated and highly qualified workers to support businesses and create a more scientifically aware community.

Our objectives for part one were:

- To investigate the impact of novel insecticides on target pests and beneficials and incorporate the data into the Cotton Pest Management Guide
- Identify how cotton invertebrate communities counter field invasion by pests and proliferation of pests including mealybugs
- Evaluate the capability of Bollgard 3 to compensate for early tip damage and fruit loss in different climatic regions
- Measure the impact of physiological stress interacting with pest damage on fruit loss and test these findings on industry leading farms
- Assess the efficacy of various chemicals available for the control of SLW and consider their best fit in SLW management
- Improve tactics to encourage the use of IPM principles.

In part two we used IPM training activities to inspire and educate children about popular topics in agriculture as a pathway to future careers in the cotton industry; supported and mentored students and scholars that are at an early phase in their career development and linked with agricultural investments in education and business. This part of the project was detailed in a report provided to CRDC in November 2021 (Trudy Staines CSP1905 “Developing Capability to Service the Cotton Industry”) and is not dealt with further in this report.

Milestone 1: Impact of Insecticides on Beneficials

***MS1.1 – Assessing the IPM fit of novel insecticides* - Heimoana**

Early season experiments are designed to evaluate the fit of new insecticides into the IPM systems in cotton and to provide information to the cotton industry via the Cotton Pest Management Guide. This is done by evaluating the effect of new compounds on non-target species (predators and parasites) and ranking them according to a standardised system.

Methods

Each season we contacted each of the main agrochemical companies servicing Australian Cotton to review options for testing. Our experiments accommodated up to 9 treatments (in 4 replications) – an unsprayed control and 8 spray options. The experiments required development of mite outbreaks on cotton seedlings in the glasshouse – which were then used to infest plots. Mites are a useful bio-indicator of the effects of sprays on beneficials. The experiments were comprehensively sampled visually, with suction samplers and with plant/leaf samples to capture a wide range of insects. Samples were processed, stored in the freezer and identified and counted using a stereo microscope. We compared to Decis Options @ 4.95 g a.i./ha (Industry Standard) and Control (no spray). Data was analysed in a two-way ANOVA (Treatment x Date) using Genstat 19th edition.

Results and Discussion

The range of products and rates evaluated over the three years of the project is given in Table 1. Each year detailed reports were prepared for each compound, sent to CRDC for approval and provided to the companies. All reports are confidential to the companies and only include data for their compound(s), and the controls. As the products were registered, the information in the reports was used to update the Cotton Pest Management Guide each year in the section on the 'Impact of insecticides and miticides on predators, parasitoids and bees in cotton.' (Appendix 1). Depending on availability we included additional information of the effect of a range of insecticides on bees, and *Eretmocerus hayati*, a parasitoid of Silverleaf whitefly, based on research completed by Dr Jamie Hopkinson (QDAF).

***MS1.2 – Maintaining knowledge about emerging insect resistance problems & biosecurity issues* - Heimoana**

Heimoana provided live aphids and mirids to Grant Herron for culturing and resistance testing in 2018/19. We have had longstanding cooperation with Grant Herron's team at NSW DPI to keep informed about pest resistance. This work has now been allocated elsewhere and collaboration has ceased. Heimoana continues to participate in the Bollgard 3 and IRMS reviews and the TIMS panel meetings, and she represents CSIRO on cotton-related biosecurity panels and meetings.

***MS 1.3 – Raising issues of unexpected pests and biosecurity risks* - Heimoana**

In December 12018, Heimoana met with Tek Tay and others who share concern about the significance of whiteflies as carriers of viruses and ecological/industry biosecurity risks, to discuss the need for an Australia-wide look at whitefly specimen to identify cryptic species (e.g. MED or Q-biotype). Heimoana provided 2012 whitefly samples from the Namoi to check for Q-biotype. SLW Q-biotype was not detected confirming previous monitoring by QDAF after a reported detection in 2007. Nevertheless, the risk remains, particularly close to ports of entry and that was again emphasized when Heimoana attended a biosecurity surveillance workshop in Brisbane in March.

Heimoana found FAW in maize at ACRI and collaborated with Tek Tay by sending material for DNA testing. All collected specimen were parasitised with *Cotesia* spp. larvae. We kept these specimen for possible future projects that may investigate wasp DNA at T=0, since no commercial sprays have been applied for FAW control in this area. Heimoana also participated in the Plant Health Australia Plant Surveillance Workshop which aimed to bring together different parties in the Biosecurity sphere and consider the potential extent of interaction and sharing of information. The cotton industry followed with its own Biosecurity Blueprint in Toowoomba, which brought together stakeholders in the cotton industry to establish responses to a biosecurity incursion (Blue disease). This exercise helped to clarify the roles of growers, consultants, scientists, CRDC, Cotton Australia and Biosecurity Australia in the event of a biosecurity incursion that would affect the cotton industry. It was a worthwhile exercise that also emphasized the proximity of some of the more serious biosecurity risks (diseases and insect vectors) to Australia, e.g. Indonesia, East Timor and SE Asia).

Heimoana participated in several Fall Armyworm updates, discussions and Webex sessions since December 2019. She attended the ICAC Meeting in Brisbane in December and connected with Jean Paul Gourlot who is an international authority on SLW Honeydew and sticky cotton.

Table 1: Compounds tested for their effects on target pests and non-target beneficials in the early season experiment 2018/19-2020/21

Treatment	Supplier	A.I.	g a.i./ha	Product Rate	Target Pests	2018/19	2019/20	2020/21
Skope (acetamiprid + emamectin) (Full rate)	Adama	218 g ai/L Acetamiprid 32.5 g ai/L Emamectin benzoate	76.3 g ai/ha Acetamiprid 11.36 g ai/ha Emamectin	175 ml/ha	Mirid, Aphid, Wfly, GVB, Heli	✓		
Biopest oil (Full rate)	Sacoa	815 g ai /L	1630 g ai/ha	2 L/ha	Aphids, Mites, Scale insects	✓	✓	
Biopest oil (Double rate)	Sacoa	815 g ai /L	3260 g ai/ha	4 L/ha	Aphids, mites, scale insects	✓	✓	
Buprofezin (Applaud)	Dow	440 g ai/L	440 g ai/ha	1 L/ha	SLW,	✓	✓	
Pymetrozine (End Game)	Nufarm	500 g ai/L	200 g ai/ha	40 g/ha + BS1000 @2%	SLW	✓	✓	
Dimethoate (Saboteur)		400ml/L	40g ai/ha	100ml/ha	Mirids, Aphids, GVB, Thrips, mites, ADB, Rutherglen, Brown smudge, Jassids	✓		
Skope (acetamiprid + emamectin) (Full rate)	Adama	218 g ai/L Acetamiprid 32.5 g ai/L Emamectin benzoate	76.3 g ai/ha Acetamiprid 11.36 g ai/ha Emamectin	175 ml/ha	Mirid, Aphid, Wfly, GVB, Heli	✓		
SYNFOI 21 (Phoenix 100DC) +Agral	Syngenta	100 g ai/L	60 g ai/ha	600 ml/ha + 10 ml/100L Agral	Thrips, GVB, RGB, Jassids, Beetles, Mites	✓	✓	✓
Cyclotide Diamide (Teppan)	ISK	50 g ai/L	4g ai/ha	80 ml/ha (80ml/100L)	Lepidoptera	✓	✓	✓
BAS 550 I - Dimpropyridaz	BASF	120 g ai/L	120 g ai/ha	1L/ha	Mirid, Whitefly	✓	✓	✓
H293-200928 Cyclotide Rate 1	Innovate Ag			1L/ha	Lepidoptera			✓
H293-200928 Cyclotide Rate 2	Innovate Ag			2L/ha (in 50L)	Lepidoptera			✓
Eco Neem	OCP	11.8 g ai/L	4.3 g ai/ha	375 ml/ha	SLW			✓
Parachute Paraffinic nC27Oil	FMC	792 g ai/L	3960 g ai/ha	5 L/100L (ha) 5%	Mirids, SLW, Aphids			✓
Decis Options (deltamethrin) CONTROL	Bayer Crop Science	27.5g/L	4.95 g ai/ha	180 ml/ha	Mirid, GVB, Jassid, Rutherglen bug, Heli	✓	✓	✓

Milestone 2: Improved understanding of invertebrate composition and movement

***MS 2.1 Effects of cumulative chemical sprays on invertebrate communities* – Whitehouse**
***MS 2.3 Development of early season invertebrate communities under different management regimes* - Whitehouse**

Ideally, we would like to be able to identify invertebrate communities effective at both controlling pests established in the crop and countering a sudden influx of pests into the crop at any point during the season. To improve our understanding, we compared the invertebrate communities of crops that had received different insecticide applications to see which part of the community was lost, and whether that was associated with flaring of other pest species populations. We identified how early season communities in IPM and non-IPM focused farms develop differently and identified invertebrates that may be relevant to cotton pest management.

Methods
Over three years the invertebrate communities of a pair of fields (one likely to experience harder insecticide options, the other likely to experience softer options, see Table 2 for farm locations) were sampled, and both the canopy and the ground communities were compared. Canopy communities were sampled with beat sheets while visual checks provided information about crop stage and sedentary pests, such as *Helicoverpa* eggs. We sampled 58 species groups common in cotton, including pests and beneficials (Appendix B, Table B1). At each sampling date, between 10 and 20 beat sheets were undertaken each on each farm (whole plot).

Analysis
Changes in community composition in response to environmental variables were analysed using direct ordination techniques, as calculated using the program Canoco 5. When species gradients were less than 3 SD (standard deviations), the linear models RDA (Redundancy analysis) and PCA (Principal components analysis) were used to calculate direct and indirect community responses. When they were greater than 3 SD the species were responding to environmental variables unimodally, so the unimodal models CCA (canonical correspondence analysis) and DCA (detrended correspondence analysis) were used. Occasionally, Principal Response Curves were used to compare heavier and lighter sprayed fields within a season. All data was arranged into split plots (individual beat sheets or pitfall trap samples) and whole plots (all the samples taken on a field on a particular day). Some environmental variables only varied between fields (whole plots) such as "days since planting" and "day degrees"; while others varied between split plots (eg "number of *Helicoverpa* eggs"). The structure of the analysis varied to accommodate these differences.

Two estimates of day degrees are provided in Table 2. In the analyses, the 1532DD was used, so all references to DD (day degrees) in the text refer to that measurement. Both forms of DD and in crop rainfall were calculated from the CSD website.

Table 2: Sampling regime at the different sites over the three seasons. Access to sample sites was often affected by rain and irrigation regimes. The table shows the sampling effort with respect to the crop development stage, two expressions of Day Degrees, BDI (Beneficial Disruption Index) and accumulated rainfall. The asterisks indicate the sampling dates used in the combined beat sheet analysis.

			Ground level communities					Canopy communities					
Year	Farm	Plant date	Sampling date pitfall traps	DD base 12	DD 1532	Rainfall mm (from planting)	BDI	Sampling date beatsheets	DD base 12	DD 1532	Rainfall mm (from planting)	Accumulated BDI when sampled	
2018/19	Farm 1	14/10/2018	26/11/2018	519.5	331.9	106.4	0						
	"softer"		3/12/2018	601.5	382.5	106.4	0	12/12/2018	731.5	471.3	106.4	0	*
			12/12/2018	731.5	471.3	106.4	0	19/12/2018	843.1	546.5	142.2	0	*
			27/12/2018	969.1	629.7	167	0	27/12/2018	969.1	629.7	167	0	
			2/01/2019	1079.1	701.2	167.4	0	2/01/2019	1079.1	701.2	167.4	0	*
			9/01/2019	1210.9	787.4	167.4	0	9/01/2019	1210.9	787.4	167.4	0	*
			30/01/2019	1637.8	1059	182.4	0	16/01/2019	1351.1	873.5	167.4	0	
			6/02/2019	1764.9	1143	182.4	4	30/01/2019	1637.8	1059	182.4	0	
			13/02/2019	1873.7	1212	192.2	4	13/02/2019	1873.7	1212.4	192.2	4	
2018/19	Farm 2	10/10/2018	26/11/2018	549.3	347	153.2	0	3/12/2018	631.3	397.6	153.2	0	*
	"harder"		3/12/2018	631.3	397.6	153.2	0	19/12/2018	873	561.6	189	0	*
			12/12/2018	761.4	486.4	153.2	0	27/12/2018	999	644.7	213.8	0	
			2/01/2019	1109	716.3	214.2	0	2/01/2019	1109	716.3	214.2	0	*
			9/01/2019	1240.7	802.4	214.2	0	9/01/2019	1240.7	802.4	214.2	0	*
			30/01/2019	1667.6	1074	229.2	4	16/01/2019	1381	888.6	214.2	4	
			6/02/2019	1794.7	1158	229.2	10						
			13/02/2019	1903.6	1228	239	10						
2019/20	Farm 3	25/10/2019	16/12/2019	700.7	428.5	56.9	0	16/12/2019	700.7	428.5	56.9	0	
	"softer"		15/01/2020	1288.6	796.7	58.1	3	20/01/2020	1355.1	845.9	73.3	3	
			3/02/2020	1627.9	1027	121.9	3	22/02/2020	1869.7	1192.4	274.6	10	
2019/20	Farm 4	21/10/2019	16/12/2019	745.5	455.9	53.6	0	16/12/2019	745.5	455.9	53.6	0	
	"harder"		14/01/2020	1313.6	814	54.6	0	21/01/2020	1417.7	884.9	67.4	0	
			28/01/2020	1541.7	968.6	121.9	0	22/02/2020	1912	1218	284.6	3	
			10/02/2020	1750.6	1106	214.9	3						
2020/21	Farm 5	20/10/2020	16/12/2020	748.5	461.9	97.9	4	10/12/2020	673.5	409.3	90.5	0	*
	"softer"		23/12/2020	843	524	182.3	4	23/12/2020	843	524	182.3	4	*
			19/01/2021	1181.2	755.4	236	7	19/01/2021	1181.2	755.4	236	7	*
			25/01/2021	1268.6	812.9	239.4	7	25/01/2021	1268.6	812.9	239.4	7	*
			1/02/2021	1388	891.5	239.7	7	1/02/2021	1388	891.5	239.7	7	
2020/21	Farm 6	18/10/2020	10/12/2020	689.5	417.9	99.5	12	10/12/2020	689.5	417.9	99.5	12	*
	"harder"		23/12/2020	859	532.6	191.3	16	23/12/2020	859	532.6	191.3	16	*
			19/01/2021	1197.2	764	245	16	19/01/2021	1197.2	764	245	16	*
			25/01/2021	1513.5	939.9	113.5	16	25/01/2021	1513.5	939.9	113.5	16	*
			1/02/2021	1652.4	1033	121.9	16	1/02/2021	1652.4	1032.9	121.9	16	

From 1st Square
From 1st Flower
From 1st Open Boll

The community data was interrogated using nine environmental variables. Those of interest included measurements of crop development, such as Day Degrees, Days since planting, Crop development stage (squaring, flowering or open bolls) and BDI (Beneficial Disruption Index). The BDI was used to compare the disruption caused by insecticides across different fields, following Mansfield *et al.* (2006). To calculate the BDI, insecticides are given a ranking based on the degree to which they disrupt invertebrate communities (largely based on the Cotton Pest Management Guide, see Appendix A). As more insecticides are applied to the field, the BDI increases (Table 3).

The invertebrate canopy community was also challenged by biotic factors, such as plant growth factors (average nodes, squares, or bolls per beat sheet) and pest numbers (mirid numbers or *Helicoverpa* egg lays) to determine if they affected the invertebrate canopy community. Other factors that could have influenced community composition, such as the field surface moisture (dry/tacky/wet/very wet) or the time of day (measured as minutes after midnight) were also used to challenge the data, although these were often used as co-variates.

Table 3: Insecticide regimes at the different fields sampled and the Beneficial Disruption Index calculated from the inputs. We note that the BDI for seed treatments is for the actual chemical but if applied as a seed treatment the exposure to canopy predators and parasitoids and the actual BDI may be different. The impact of seed treatments is difficult to assess because there is limited data. In canola, for instance only <20% gets taken up by the plant, the remainder ends up in the soil and soil dwelling predators may be greatly impacted. The amount that is

taken up by the plant is expressed in many tissues, hence predators feeding on phytophagous pests could be impacted indirectly.

Initial Category	Year	Planted	Farm	Insecticide (per ha)	Date	Insecticide BDI
"softer"	2018/19	14/10/2018	Farm 1	Zeemet: Phorate- Organophosphorus		7
				Transform (sulfoxaflor) 150g	3/02/2019	4
"harder"	2018/19	10/10/2018	Farm 2	Cruiser on seed (Thiamethoxam)		6
				Regent (Fipronil) 70mL	14/01/2019	4
				Pegasus (Diarenthiuron)770mL	8/02/2019	3
				Regent 60mL	8/02/2019	4
"softer"	2019/20	25/10/2019	Farm 3	Gaucho on seed (Imidacloprid 600 g/L).		6
				Salt 300g	14/01/2020	0
				Regent (Fipronil) 40mL	14/01/2020	3
				Pegasus (Diarenthiuron)800mL	4/02/2020	3
				Regent (Fipronil) 60mL	4/02/2020	4
				Salt 300g	4/02/2020	0
				Agrimec (Abamectin) 600mL	17/03/2020	2
"harder"	2019/20	21/11/2019	Farm 4	In furrow Fipronil		6
				Pegasus (Diarenthiuron)800mL	3/02/2020	3
"softer"	2020/21	20/10/2020	Farm 5	Fipronil800@400ml/t, Imidacloprid 600@3L/t		6
				Transform (Sulfoxaflor) 100g	14/12/2020	4
				Steward (Indoxacarb) 600mL	27/12/2020	3
				Hayati wasps	14/01/2021	0
				Mainman (Flonicamid) 140g	12/02/2021	3
"harder"	2020/21	18/10/2020	Farm 6	Talstar 250 (bifenthrin) @150ml/ha in furrow		7
				Rogor (Dimetholate) 250mL	8/11/2020	6
				Rogor (Dimetholate) 500mL	4/12/2020	6
				Regent (Fipronil) 60mL	18/12/2020	4
				Skope (Acetamiprid&Emamectin) 300mL	8/02/2021	5
				Intruder (Acetamiprid) 100mL	22/02/2021	4

Results and Discussion

Each year we compared communities in crops managed with either a "harder" or "softer" emphasis on chemical control. The BDIs in Table 3 illustrate that the demands of the season disrupted this dichotomy, with many fields not receiving insecticide applications until late in the season, and many insecticides were applied after the sampling period (Tables 2 & 3). This caused challenges when measuring the effect of heavy and light insecticide use on invertebrate communities (only in the 2020/21 season could a clear comparison be made).

2018/19 season

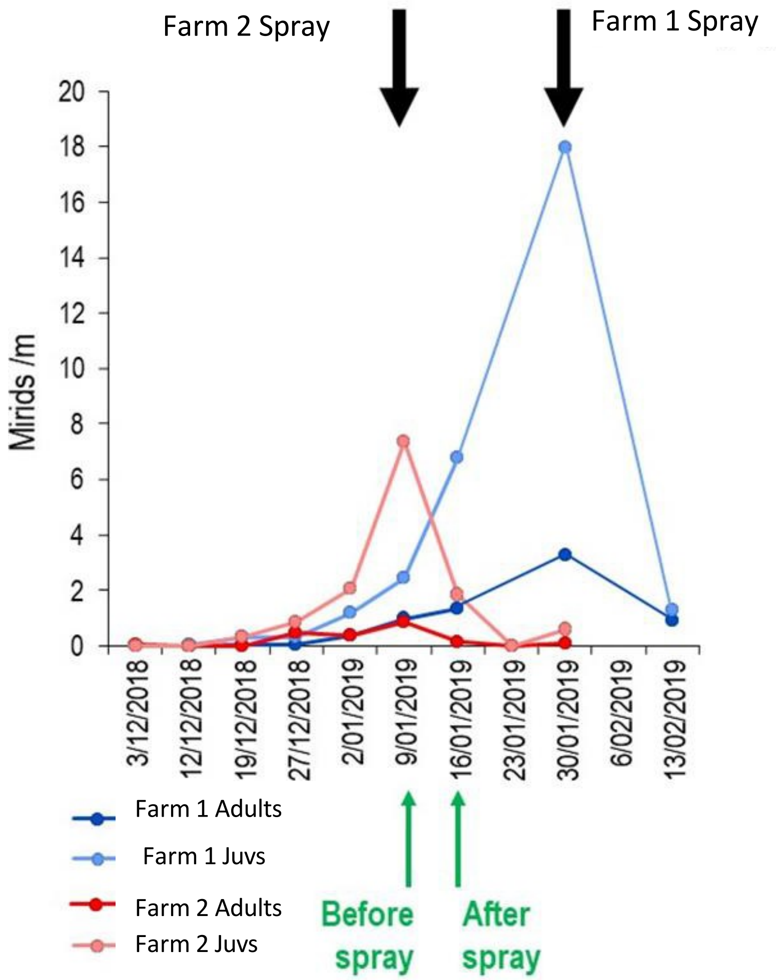

Figure 1: Beat sheet samples taken at Farm 1 and Farm 2 in the 2018/19 season showing mirid pressure (adults and juveniles). Further analysis focused on the sampling dates before and after Farm 2 sprayed.

The fields sampled during the 2018/19 season at Farm 1 and Farm 2 both experienced heavy mirid pressure in early January (Fig. 1). Farm 2 was sprayed for mirids on the 14th of Jan at a lower pest threshold and before Farm 1 was sprayed. At that time mirid numbers at Farm 1 were lower by about 5 juvenile mirids/m though adult numbers were the same. Mirid numbers at Farm 1 then rose quickly causing crop damage before they were sprayed on the 3rd of February. This suggests that the Farm 1 invertebrate community was different from the Farm 2 community and may have delayed the increase in mirid numbers.

Both fields were sampled (9th Jan 2021) prior to the Fipronil application at Farm 2, and again straight after (16th Jan 2021, Fig. 2) and analysed for community content. Because the SD gradient of the species was 1.8, linear ordination techniques were used in this analysis.

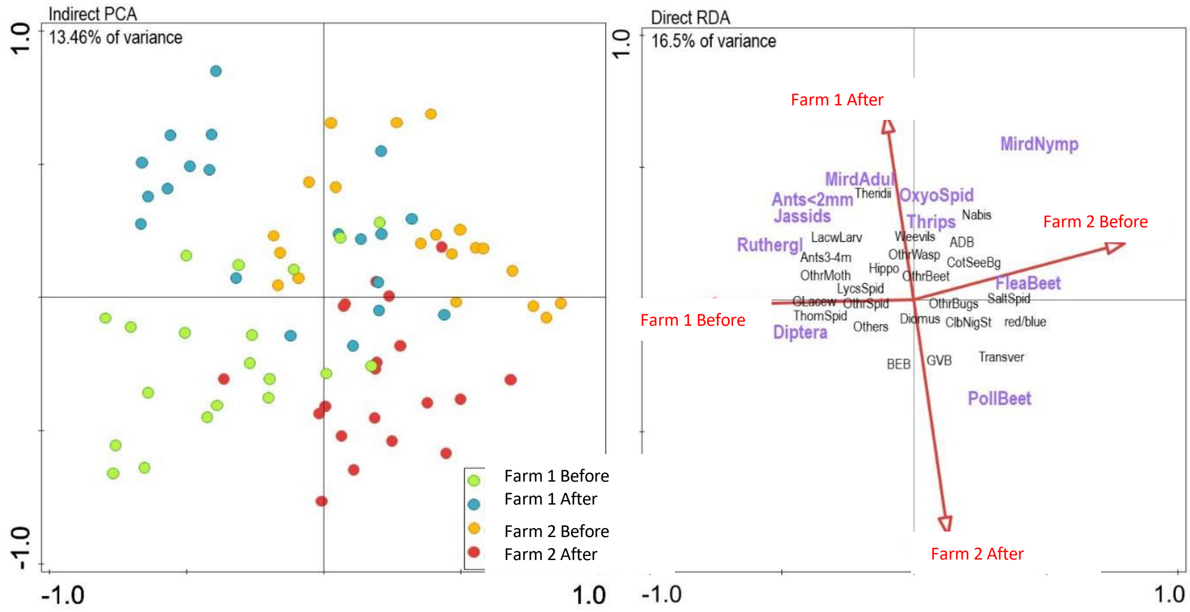

Figure 2a & b: The indirect PCA (Principal Components Analysis) and direct RDA (Redundancy Analysis) of the Farm 1 and Farm 2 communities sampled via beat sheets before and after Farm 2 was sprayed for mirids. The species highlighted in purple are those that most contributed to the diagram.

The PCA diagram illustrates 13.46% of the variance between beat sheet communities (Fig 2a). It shows that the beat sheet communities at the different sampling times were quite distinct, with the main differences occurring between fields (as indicated by their differentiation along the x-axis).

The RDA diagram illustrates 16.5% of the variance between beat sheet samples after their "direct" alignment to the four sampled communities, and the species associated with those communities. All four of these sample blocks had a strong significant effect (P=0.002) on community composition (each explaining: 6.7% - Farm 2 After; 6.6% Farm 2 Before; 6.6% Farm 1 Before; and 5.1% Farm 1 After of the variance). The species highlighted in purple are the ten that had the strongest influence on this community composition (the full names of these species can be found in Appendix B). Not surprisingly, mirid nymphs were strongly associated with Farm 2's field just before it was sprayed, and at Farm 1 after the spray event, where mirid adults also featured strongly.

Although there are key predators that are more associated with the Farm 1 field before the spray event compared to the Farm 2 field (for example crab spiders "ThomSpid", Green lacewings "Glacew", wolf spiders "LycoSpid" and other spiders) those driving the community differences were mainly "others" (Fig. 2b). These included Diptera, Rutherglen bugs, Jassids and small ants.

The effect on spraying on communities showed up clearly as the Farm 2 community structure changed significantly after the spray in terms of number of individuals (Fig. 3, ANOVA: abundance: df=3, F=16.98, P<0.001) and number of species (Fig. 3, ANOVA: species richness: df=3, F=9.13, P<0.001). While both fields initially contained similar numbers of individuals before the spray application, the Farm 2 field contained fewer individuals and species after the insecticide application. Species abundance and richness did not change in the unsprayed field at Farm 1.

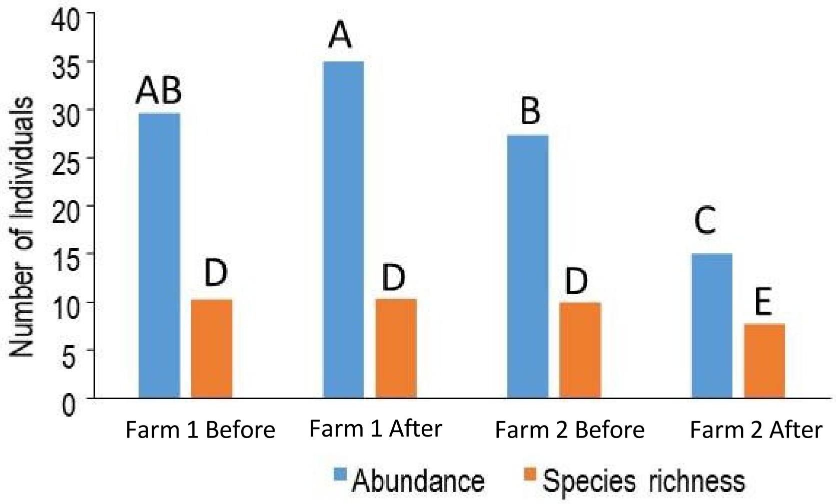

Figure 3: The abundance and species richness of the four communities at different points in time. Different numbers above the histograms indicate communities were significantly different.

2019/20 Season

In this season, the farm that was expected to be "softer" applied more insecticide than the one that was expected to be harder. In both cases, insecticide use did not start until at least mid-January. Nevertheless, we were able to test for the effect of BDI on the community. The indirect ordination (DCA) combining Farm 3 and Farm 4 samples and capturing 49% of the variance showed that the two fields' communities were very similar at the three developmental stages sampled (Fig.4). In addition, most species were more associated with the flowering and bolls communities. This is unsurprising given the very small samples of invertebrates in the squaring samples.

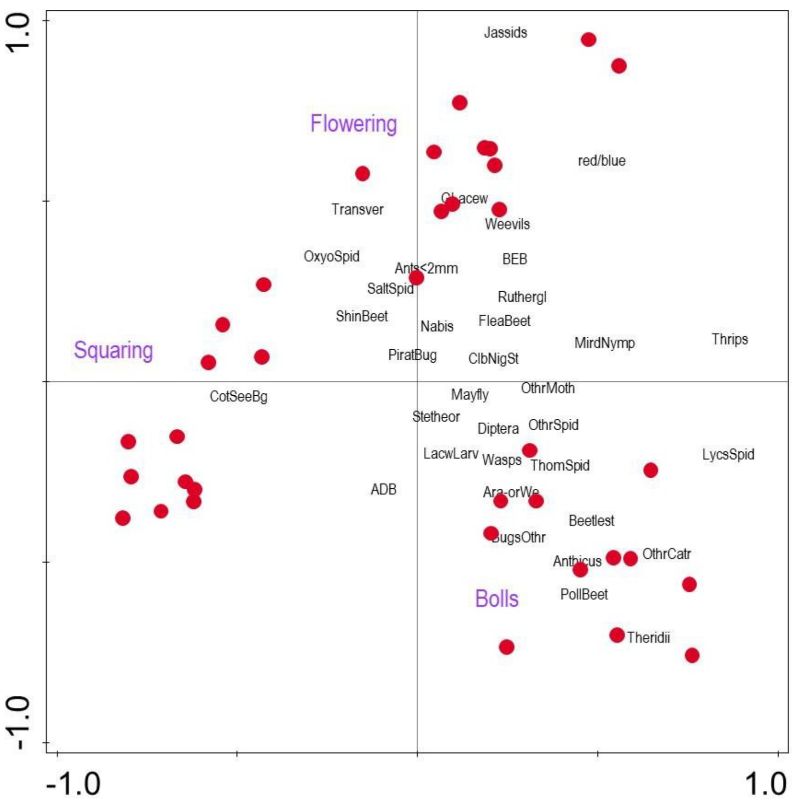

Figure 4: The indirect PCA (Principal Components Analysis) of the Farm 3 and Farm 4 communities combined, showing clustering of communities of both farms at the 3

developmental stages sampled. The diagram explains 49% of the variance between communities.

In the 2018/19 season, “other” species, such as jassids, had a strong effect on the relationship between beat sheet communities. In the 2019/20 season, both mirid numbers and *Helicoverpa* egg numbers were too low to have a potential effect on these communities. However, jassids were in high enough numbers to have an effect. While jassids didn’t have a direct effect (P=0.306) they did have a significant conditional effect (P=0.018) on communities once the effect of other factors had been accounted for. As in 2018/19, jassids were associated with the samples with low BDI. Of the ten species that had the strongest influence on communities in the 2018/19 season, six also had a strong effect in the 2019/20 season: jassids, pollen beetles, Theridiid spiders (Tangleweb spiders), thrips, and flies.

2020/21 Season

In the 2020/21 season, multiple insecticides (4) were applied to Farm 6, while Farm 5 received fewer (2). Because the species gradient was over 4 SD, the communities were analysed using unimodal models (DCA and CCA). Despite the large difference in insecticide regime, the communities overlapped in the indirect DCA (Fig. 5).

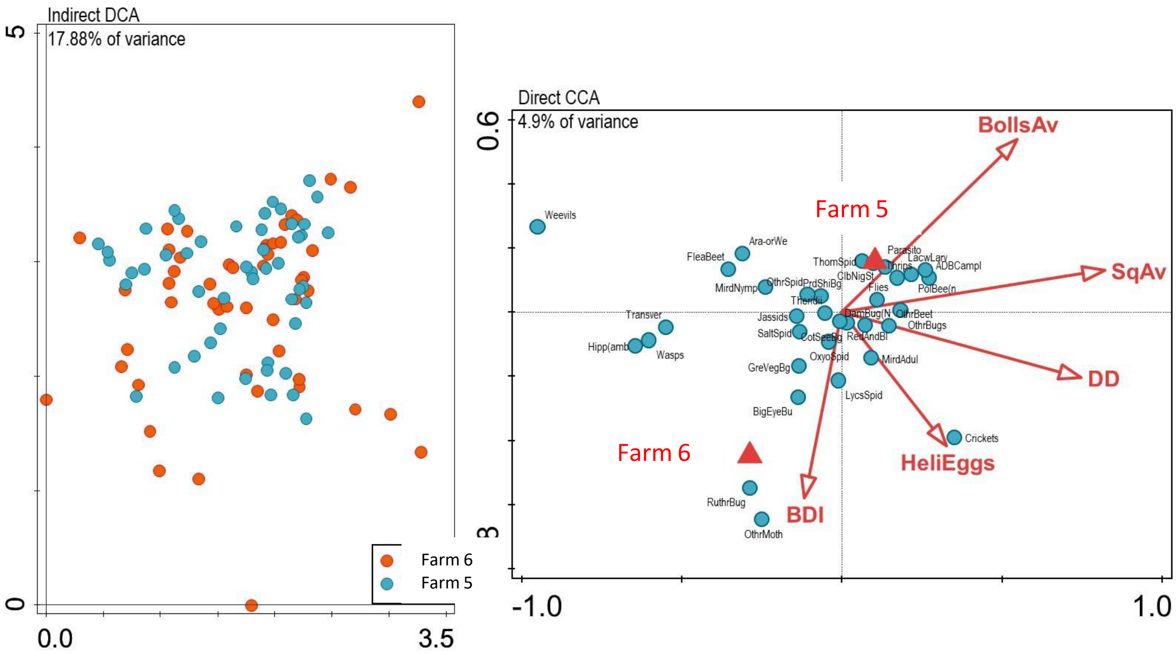

Figure 5: The indirect DCA (Detrended Correspondence Analysis) and direct CCA (Canoco Correspondence Analysis) of the Farm 6 and Farm 5 communities throughout the season from early December to early January. In the direct analysis, only the average number of squares (SqAv) affected community composition.

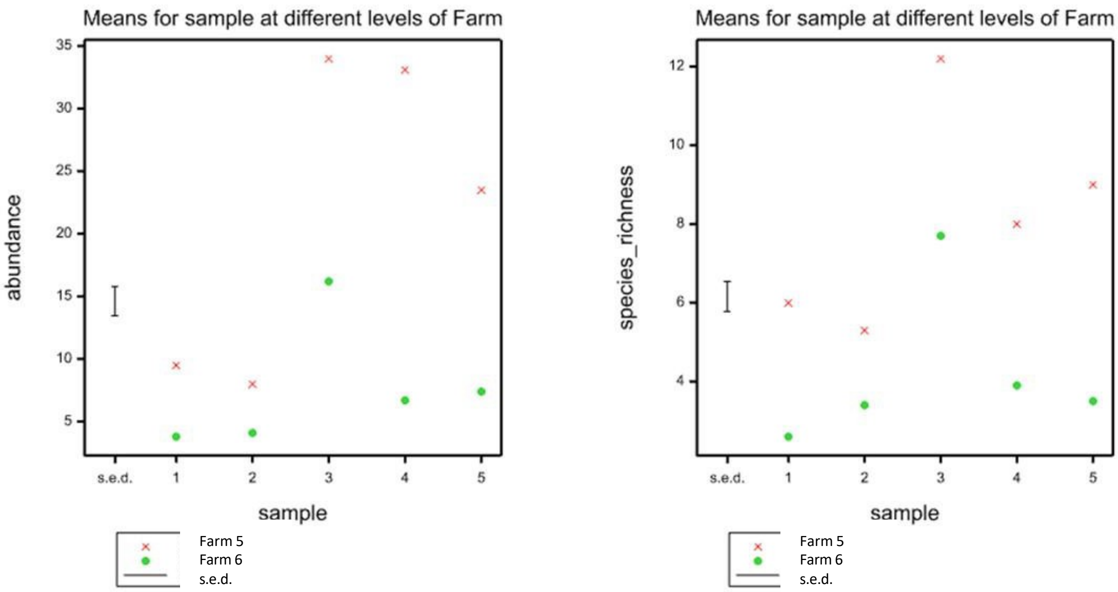

Figure 6: Differences in abundance and species richness between Farm 5 and Farm 6.

In the direct analysis, soil conditions (dry/very wet/wet) had a significant effect on the community as did the time that the beat sheet was undertaken. Consequently, these factors were included in the analysis as co-variates. However, the subsequent CCA revealed little effect of the environmental variables of interest, and while the x-axis did explain a significant amount of variance ($P=0.002$) all combined axes did not ($P=0.078$), with only the average number of squares significantly influencing community composition both independently ($P=0.002$) and conditionally ($P=0.002$ which considers the contributions of other factors). Further interrogation of the data revealed that the Farm 6 samples throughout the season contained few individuals (Fig. 6). The communities in the Farm 6 field contained significantly fewer individuals (ANOVA, df=1,4; $F=181.37$, $P<0.001$) and species (ANOVA, df=1,4; $F=131.29$, $P<0.001$) which introduced a lot of variance into the analysis and made it difficult to characterize the community in this field and compare it to the field at Farm 5.

Summary

Our observation studies over the three years have shown that we can characterise the changing invertebrate community in fields but we could not conclusively link these patterns to high or low insecticide use. Partly this was since only in one year was there a strong difference between the insecticide use patterns in the two fields examined. This illustrates the challenges of conducting research using growers fields and practices, in terms of un-controlled experimentation, but is also a reflection of what happens in the real world. The fact that two fields so geographically close to each other would receive dramatically different applications of insecticides is due to a diversity of factors. Future research should consider greater replication to obtain fields across a gradient of BDIs and see if strong patterns can be observed. Also, removal of certain functional groups using selective products may be another way to manipulate the community composition in replicable ways.

MS 2.2 The effect of weather patterns on mirid population levels **- Whitehouse**
We were unable to complete this work due to the staff involved leaving CSIRO.

Milestone 3. Incorporating physiological fruit loss into IPM decisions

MS 3.1 Factors affecting fruit loss and compensation **- Whitehouse**
We know that plants modify their behaviour with respect to changes in climatic conditions, but we are unclear on how changes in climatic conditions affect their pests, or the predators of their pests. We know from previous experiments that mirids damage bolls and cause squares to be shed and that lynx spiders can reduce mirid numbers and mirid damage. Therefore, we planned to carry out experiments during early flowering to answer the following questions:

- Are mirids more likely or less likely to damage fruit under raised ambient temperatures?
- Do plants recover from mirid attack faster or slower under raised ambient temperatures?
- Do plants respond to mirids in chambers as they do in the field?

Methods

Week 1

- Place individual insect net bags over 6 cotton plants in each of Katie Broughton's growth chambers (and also in the associated field).
- Measure plant stress levels both in and out of the bags.
- One bagged plant is the control, the second contains 6 half-grown mirids.
- After a week we measure light levels.
- Place a plastic bag over the plant in the net bag and spray the contents with a pyrethroid to kill any insects or spiders (Mortein "Insect Seeking Fly Spray", active ingredients Allethrin (2.09 g/kg) and Resmethrin (0.39 g/kg))
- Remove the bags, count the insects killed within, and count fruit and measure retention.
- At the end of the season, count bolls and lint to check if the plants differ in their ability to recover from the insect pressure.

Week 2

- Measure light levels inside and outside a no-mirid cage with the spectrophotometer at each of the 6 plots.
- Get large plastic autoclave bag cut a hole in the middle at the top
- Release the top of the caged bag plant from its support, put the autoclave bag over the caged plant
- If necessary, Zippy-tie the bottom of the bag to the base of the plant. Open the top of the caged bag out through the hole in the top of the plastic bag and spray Mortein into the cage for 5 seconds.
- Close up the cage and the plastic bag, possibly with zippy ties, leave for at least 10 minutes.
- Shake cage, then carefully open the plastic bag and cage from the top, counting any insects, particularly the mirids, encountered in the cage.
- Drop cage
- Measure height (from cotyledons) and number of nodes
- Count squares and bolls (squares include candles, bolls include open flower).
- Recover with cage, leave for week?

- End of season, maturity pick & weigh

Results and Discussion

Working in the small chambers caused unexpected logistical problems which prevented the collection of reliable data, hence, results we obtained will not be presented.

***MS 3.2 Establish if fruit loss caused by physiological stress is increased or unaffected by the presence of pests : effect of temperature on mirids and lynx spiders on cotton* - Whitehouse**

Often physiological damage to plants can be mistaken as insect damage. We investigated tolerance or compensation of BGIII cotton to fruit loss by mirids or artificially removing fruit. These trials were designed to identify if or when pest pressure contributes to fruit loss caused by physiological stress and assess if pests remain on plants recovering from fruit loss caused by physiological stress.

Experiment A – Griffith & Namoi Caged Field Experiment – 2018/19

Mirids are a challenging pest for cotton growers because their effect on yield appears variable. This is particularly the case with pre-flowering damage. Further, it would seem that mirids affect cotton crops differently in different regions, particularly in response to seasonal conditions. Previous field experiments on early season mirid damage showed that mirid pressure in pre-flowering, squaring cotton did not affect yield. To further test these findings, and to separate the effects of fruit loss due to cloud cover from loss due to mirids, we simulated cloud cover using fine-meshed field cages in long and short season growing areas.

In the northern cotton-growing region (northern NSW and Queensland), which has a long season of ample light and heat, light reduction would probably have little effect. However, in the south (southern NSW and northern Victoria) where cotton is grown at the edge of its climatic range, insect damage during reduced light levels could reduce the plants' ability to compensate for such damage.

Methods

Experiments were carried out at the IREC Field Station at Whitton (Griffith) and at ACRI, Narrabri (Namoi). We mimicked cloudiness using white cages, which at their base covered one metre of cotton row and reduced the amount of lux (the standard measure of light intensity) reaching the plants by 20–50%. Plants were caged at the squaring stage (11 nodes, with an average of 16 squares per metre).

We applied five treatments, in 15 replications randomly allocated to five rows:
1) Control (no cage, no mirids, no fruit removal) – represents normal crop in field
2) No cage, all squares removed – represents extreme mirid damage
3) Cage only (no mirids, no fruit removal) – represents cloudiness
4) Cage + all fruit removed - represents cloudiness + extreme mirid damage
5) Cage containing four mirids – represents cloudiness and natural mirid damage
(this was twice the mirid threshold for Griffith, based on work published by Sequeira and Whitehouse, the *Australian Cottongrower* 39-3, pp 42–44).

After one week, cages were removed to count the fruit in all treatment plots. At the end of the season and prior to picking the number of bolls per metre were recorded, Bolls were handpicked, weighed and ginned

Results and Discussion

Namoi
Being in a warm season area, the Namoi crop was more advanced than the Griffith crop as seen by the higher number of squares counted (Fig. 7). There was no apparent effect of simulated cloudiness (cage only) when compared to the uncaged Control treatment. Adding mirids at twice the threshold did not cause significant square loss over the period of one week. The extreme mirid damage, as represented by total fruit loss, remained significantly different after one week irrespective of cloudiness (caging). This damage was also significantly lower than the Control, cloudiness, and a combination of cloudiness and natural mirid damage.

Cloudiness alone did not reduce the number of bolls per metre (Fig. 8) but slightly elevated it (Range 100-118 bolls/m). The combination of cloudiness and natural mirid damage increased the number of bolls harvested significantly when compared to the Control, as did the extreme mirid damage and its combination with cloudiness. Significant differences in harvested boll numbers did not carry through the ginning process as the ginned lint weight per meter was close to 200 g/m (mean 8.8 bales/ha) for all treatments. However, there was a weak trend towards higher lint weight for the plots damaged by mirids or hand.

Griffith
As in the Namoi, there was no significant effect of simulated cloudiness on the number of squares counted after one week (cage only) when compared to the uncaged Control treatment though the number of squares counted in the caged plots was slightly depressed (4 squares/m, Fig. 7). However, caged plots with mirids had significantly fewer squares than the Control indicating that the mirid treatment caused square loss. Fruit removal representing extreme mirid damage had significantly fewer squares than the control and cloudiness treatments. Differences between the effect of cloudiness and damage (Cage + mirids) and simulated cloudiness (cage only) suggest that mirid damage is additive to any square loss due to cloudiness. At the end of the season however, neither simulated cloudiness, nor mirid or manual damage to squares had an effect on the number of bolls/m or ginned lint weight. Boll numbers ranged from 135 to 146 bolls/m (Fig. 8). Weight of ginned lint ranged from 284 to 294 g/m (12.5 – 12.95 bales/ha).

These results indicate that high early season mirid pressure can cause significant square loss within a week at the Griffith location. Differences in plant development between the two locations (peak flower in the Namoi, early flowering in Griffith) means that the crops had different damage and compensation potentials. Neither cloudiness nor mirid damage in either location reduced yield, though boll numbers at the end of the season in the Namoi crop were higher in damaged treatments. This indicates that over the season, plants compensated or overcompensated after fruit removal caused a shift in resource allocation. At Griffith, the crop compensated but there was no indication of overcompensation, likely due to the different climatic conditions. These results would imply that early season mirid damage does not lead to yield loss and that chemical control of early mirids may not be warranted.

Cloudiness has long been implicated in fruit loss in cotton. Goodman (1955) reported that square shedding in Sudanese cotton after periods of cloudy weather were often in excess of the natural shedding seen in cotton growing in cloudless conditions, with shedding occurring 2-8 days following a cloudiness event. While the effects of cloudiness could not be demonstrated here, there was an indication at the Griffith site that shading of plants can affect square retention. Likewise, shading affects compensation as final boll number, which determines yield, is correlated to the radiation environment during flowering. Grundy *et al.* (2020) have provided a detailed study on the effects of fruit loss and compensation in a monsoon environment.

Limitations to this study pertained to unknown mirid survival over the week in the cage, and that the cage netting may not adequately represent cloudiness. Further, in a field situation, mirid damage may be ongoing at low levels over the flowering period, which was not captured here as pests monitoring data for the remainder of the period was not available. Short term compensation was not observed as one week was too short for plants to replace lost fruit.

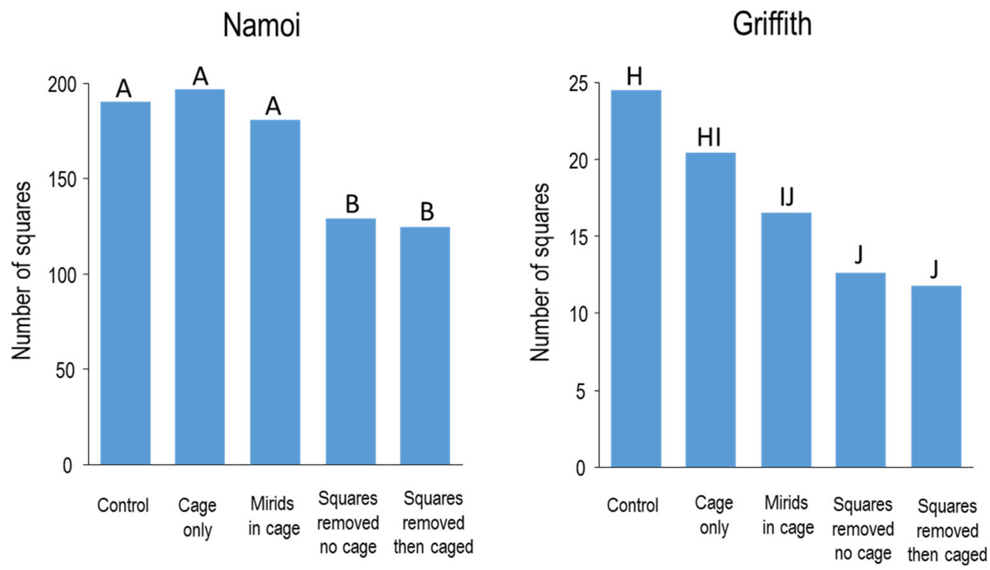

Figure 7: Number of squares after one week for caged and uncaged treatments. The crop in the Namoi was more advanced than that at Griffith.

Namoi **Griffith**

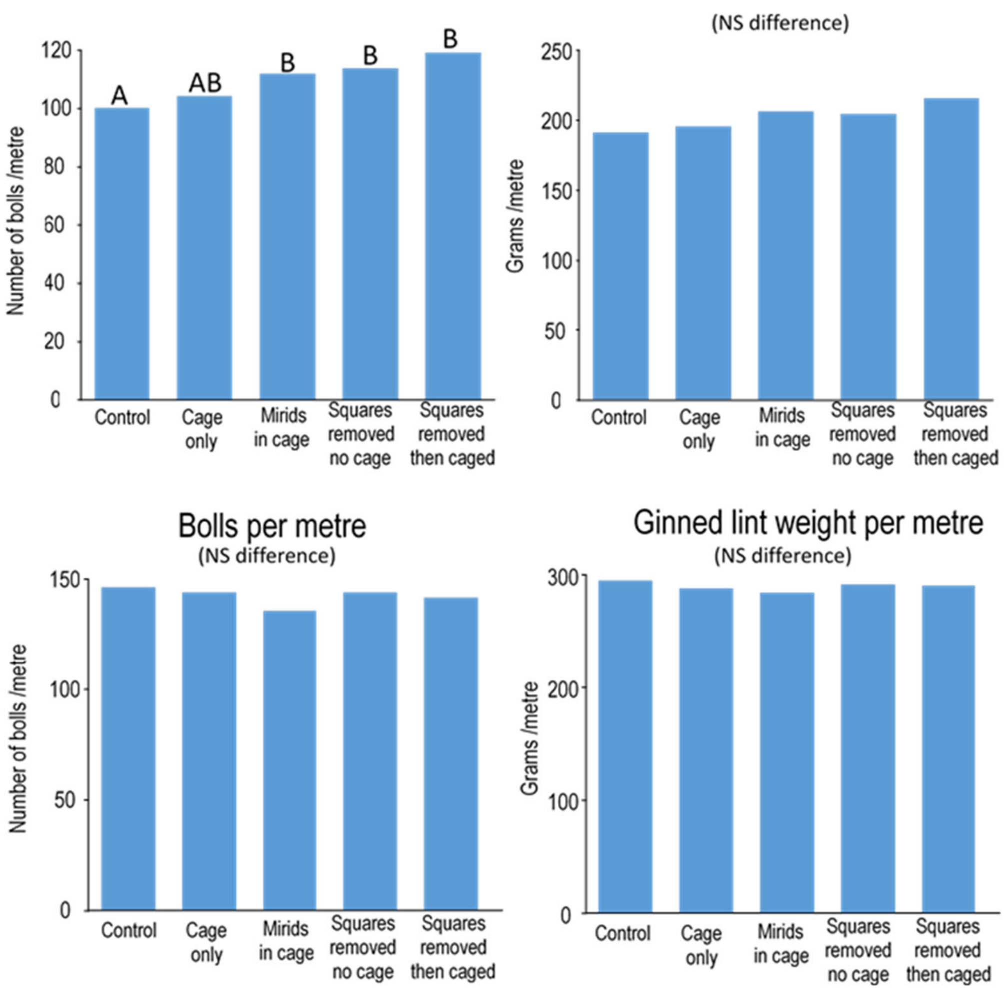

Figure 8: Number of Bolls per metre at picking, and amount of ginned lint (in grams) at the Namoi and Griffith sites.

Experiment B – ACRI Glasshouse

The objective of this experiment was to observe whether lynx spiders are more or less effective at controlling mirids and mirid damage under hotter conditions?

Methods

The experiment was set up as a pot trial in two glasshouses at ACRI, Narrabri. One glasshouse was kept at a constant temperature of 30º C during the day and 22ºC at night while the other glasshouse was set to a simulated heat wave at 40º C during the day and 30ºC at night for 7 days.

Cotton plants were raised in large pots with 4 plants per pot in 5 replications and were randomly allocated to 2 glasshouse tables. The following three treatments were applied in each glasshouse:

- Control – no mirids or spiders
- + 6 Mirids of mixed developmental stages : 2 x adults, 2 x penultimate (5^{th}) or 4^{th} instar; 2 x 2^{nd} or 3^{rd} instar
- + 6 Mirids of mixed developmental stages + 3 Lynx spiders (*A. molaris*, 1x male, 1x female, 1x juvenile

Plants developed squares at 27-38 days and treatments were applied when plants began to flower approximately 3 weeks later. Plant height, the number of nodes, fruit and bolls (wilted flowers were designated as bolls) in each pot were recorded and each pot was covered in a fine net cage. Mirids or mirids plus spiders were added to designated pots for one week. The glasshouse temperature was carefully monitored. After one week plant parameters were counted again as well as the number of remaining mirids and lynx spiders.

Results and Discussion

There were no significant differences between fruit numbers in the different treatments at the beginning of the experiment and the initial square, boll or total fruit numbers were used as a co-variate in the ANOVAs. There was a strong effect of heat on square numbers, and total fruit numbers, but not on boll numbers. However, within each glasshouse, the presence of mirids and spiders did not affect fruit numbers, although treatments with mirids only, had slightly more fruit. At 30°C the inclusion of spiders into cages did not result in higher boll numbers. At 40°C there was a trend of higher boll numbers in cages with spiders, although we are not confident about this result. At that temperature there were significantly fewer mirids but we could not ascribe this to the presence of spiders as spider survival was affected by the heat. Out of the five cages with spiders, one cages retained all three spiders while only 1 spider survived in the other four cages (3 females and 1 male). At 30°C, there were significantly fewer mirids in the presence of spiders as all spiders survived.

The results suggest that temperature has an overriding effect on square and boll retention rather than the presence of mirids. The effects of heat stress on cotton growth, development and yield are well documented and growth rate and yield potential decline in temperatures above 35°C (Osterhuis, 2002). High temperature stress tends to be associated with water stress and consequently plant damage occurs due to high canopy temperatures. Given the changing climate, where hot dry conditions are predicted to occur more frequently, diminishing yield due to fruit loss is a serious concern.

Both mirids and lynx spiders suffered high mortalities in the heat wave conditions, although lynx spider females may be better at surviving these heatwaves than males and juveniles. Hanna (2007) reported the thermal maximum temperatures, at which green lynx spider

(*Peucetia viridans*) females showed discomfort, to be 40-41°C, with muscular spasms occurring at 42-43°C and death at 47-49°C. Males also fitted in this range but already died at 46°C. A glasshouse temperature of 40°C would have affected spider comfort and ability to function normally and we observed that Lynx spiders effectively reduced the number of mirids at 30°C degrees, but not 40°C degrees. This was because either most spiders died or the survivors were not hunting and feeding, or the heat killed all the mirids before they could be preyed on by the spiders. Thermal maximum limit for *Nesidiocoris* mirids has been reported at 43-46°C , however, they ceased to function normally well below those temperatures (Hughes *et al.* (2010). Thermal data for *Creontiades* mirids, which were used in this experiment, are not available, however, their absence at the higher temperature would indicate that mirids are likely to be less of a problem during heat waves.

MS 3.3 Plant responses to fruit loss and tipping A3 Experiments C, D & E **- Heimoana**

Every cotton season one of the main topics of discussion is early season fruit retention. The answer to "What is the ideal or minimum retention of fruit that plants need to carry before unacceptable fruit loss – and consequential yield loss – occurs?" is not a magic number. Growers will quote figures from 25 to 90% depending on circumstances with regards to time in the season, plant vigour, radiation, cloudiness, rainfall, temperature, resources such as water and nutrients as well as losses from pests. CCA surveys from 2017-19 indicate that less than 62% retention at first flower will incur unacceptable yield loss. Retention was an important metric when *Helicoverpa* damaged conventional and Ingard® cotton throughout the season and resistance to insecticides was on the increase. Early retention was important as it contributed significantly to yield. While cotton could compensate to some degree by setting fruit higher in the canopy during the later fruiting stage, this could come at the cost of delayed maturity (Bange *et al.,* 2008). With the development of stacked gene varieties (Bollgard II® and Bollgard 3®) giving longer protection from *Helicoverpa*, crops tend to retain bolls set higher up in the canopy and can make up for earlier losses. However, the idea that bolls must be set as low as possible early on has persisted with many growers and every year there are reports of failure to set any bolls below the 10th mainstem node.

Early season damage in emerged transgenic crops is mostly caused by thrips which can tip out plants and cause severe leaf damage, and mirids, which can also cause tip damage or damage to developing squares. Tipping can set back plant development by delaying the onset of fruiting and maturity and may cause yield loss, however, in the long season, central growing areas this is a lesser problem than in short season, southern areas. Previous experiments in long season areas suggest that the risk of suffering yield loss from thrips damage to seedlings is about 1 year in 10 (10%). However, that research was done in non-Bt cotton or Ingard cotton where the plants would have been subject to ongoing fruit loss to *Helicoverpa*. Here, we applied one event of tipping out (i.e. the removal of the shoot tip) between 5 and 7 nodes to assess if this damage reduces yield or delays maturity.

Cotton is a very resilient crop with the capacity to compensate for early losses if growing conditions are suitable. We have previously shown that cotton can recover from leaf damage by artificially reducing leaf area and measuring subsequent plant growth (Wilson *et al.,* 2003). In this project, we simulated fruit loss (squares, flowers, young bolls) from the lower, middle and upper strata of cotton plants to observe plant responses and compensation and answer the following questions:

1. Does tipping cause yield loss and/or maturity delay?
2. How much fruit loss can plants sustain before yield loss occurs?
3. Do plants compensate for fruit loss?

A pilot project in 2017/18 provided us with some data and was the basis for this subsequent 3-year project, which had a sister-project in a short season area at Spring Ridge, NSW, funded by CSD. Experimental treatments at ACRI were co-ordinated with Paul Grundy so experiments could be compared between the different regions.

Experimental Design

The first Experiment, set up in 2018/19 at the Australian Cotton Industry Research Station (ACRI) was hailed out just before Christmas 2019, but we were able to set up a contingency Experiment C at Appletrees, courtesy of AUSCOTT, Narrabri. Experiments D (2019/20) and E (2020/21) were carried out at ACRI. . Since fruit loss does not occur evenly, we included a partial treatment where only every third plant was damaged. This gave us some damage moderation across the crop. Also, we did not count node development but *fruiting branch development*, ignoring the small lower fruiting branches and counting upward from the first well developed fruiting branch.

All experiments were set up and executed in the same design, however, treatments varied between years (Fig.10). The parameters for each experiments were:

- Plant at 20 seeds/m (30 g dipper) and thin back to 12 plants/m (Sicot 746 B3F + Dynasty + Cruiser Extreme +THIMET @ 6 kg/ha))
- 4 randomized complete blocks (8 treatments x 4 reps = 32 plots)
- Plot size 3 rows x 6 m + 2 m buffers
- The full length of 3 central rows in each plot was damaged (=18 m of damage)
- Plot markers were placed in the centre row of the 3 rows (row 2)
- Stringent control of pests – especially mirids was managed across the station

Damage implemented (Tables 4&5)

Tipping Damage (4 plots + Controls) – 2018/19 & 2019/20 only

- Monitor a fortnight to three weeks after planting.
- Growing point of each plant were pinched out using curved tweezers at N5/6.
- 4 x 1 metre of seedlings from buffer rows outside the experiment (row 6) were sampled to check on crop stage.
- Samples were cut off at ground level, plants/m, height and nodes were counted and dry weights recorded.

Fruit removal from fruiting branches 1-6 (8 plots + Controls)

- The lowest 6 fruiting branches were damaged by removing all squares along the branches. This was done for the FB 1-6 treatment as well as for the combined FB 1-6 + FB 7-12 treatment.
- Damage was implemented when plants reached 6 well developed fruiting branches after Christmas and New Year.
- All the fruit taken off from the centre row of each plot were kept, counted and dried (Table 2).
- Squares, candlewicks, yellow, pink and purple flowers were kept, counted and dried.
- Partitioning samples (1 m) were taken from row 1 of the Control plots.

Fruit removal from fruiting branches 7-12 (8 plots + Controls)

- The upper 7-12 fruiting branches were damaged by removing all squares and bolls along the branches. This was done for the FB 7-12 treatment as well as for the combined FB 1-6 + FB 7-12 treatment.
- Damage was implemented when plants reached 12 fruiting branches in mid to late January.
- All the fruit taken off from the centre row of each plot were kept, counted and dried (Table 2).
- Squares, candlewicks, yellow, pink and purple flowers were kept, counted and dried.
- Partitioning samples (1 m) were taken from row 1 of Control plots.

Data collection
Data collected is summarised in Table 6

Yield
Maturity Picks
- Weekly maturity picks of 2 m from the centre row were harvested to estimate the maturity delay and estimate yield
- Maturity picks began as early as possible when bolls began to open
- Bolls were counted during the picking of lint, samples were weighed and pooled where necessary and ginned
- Where available, we also recorded the machine picked harvest of the field (e.g. for 2019/20)

Machine Picks
- Where possible, whole plot rows were picked with a single row picker, a subsample was taken to estimate ginout percentage, and whole plot yield was calculated
-

Stratum Picks
- Stratum picks were carried out over 2m of the centre row in each plot when all bolls had opened and prior to the grower's machine pick.
- During picking, whole bolls were collected into separate paper bags to achieve a segmented pick that would allow us to identify the yield contributions of each stratum (FB 1-6, FB 7-12, FB 13-16, FB 17+) and each boll position (P1, P2, P3). There were no P4 bolls.
- Bags contained all the bolls from a designated position (e.g. FB 1-6, P1) for all the plants in that plot (= 13 bags/plot including a bag for all the bolls from Vegetative branches)
- Bolls were counted, lint was removed and weighed and each sample was ginned separately

Plant Partitioning
After each damage, 1 m of row was taken from Control plots to measure plant height and the no. of nodes to give us a reference of plant stage. This data has not been presented here.

Statistical Analysis
Maturity Pick Data – data were analysed by annual two way-ANOVAs for Treatment by Date interactions using a block design on pre-summarised data that calculated maturity delay and yield in bales/ha. Fisher's Protected Least Significant Difference (LSD) test was used to separate means.

Machine Pick Data - data were analysed by one way-ANOVA for Treatment effects using a block design on pre-summarised data that calculated maturity delay and yield in bales/ha. Fisher's Protected Least Significant Difference (LSD) test was used to separate means.

Segmented Pick Data – data were analysed either by annual one-way ANOVA for Treatment or by two way-ANOVAs for Treatment by Stratum or Treatment by Year interactions using a block design on pre-summarised data that calculated boll weights, boll numbers, maturity and yield in bales/ha. Fisher's Protected Least Significant Difference (LSD) test was used to separate means.

Figure 10: Field Plan 2018/19 (ACRI A3 & Appletrees), 2019/20 (B2) & 2020/21 (A3)

•	**31** Fruit removal @FB 7-12 33%		**32** Fruit Removal @ FB 1-6 & 7-12 33%	
	29 Fruit Removal @ FB 1- 6 100%		**30** Fruit Removal @ FB 7-12 100%	
	27 Control		**28** Tipping @ N5/6	
	25 Fruit removal @ FB 1-6 & 7-12 100%		**26** Fruit Removal @ FB 1 – 6 33%	
	23 Tipping @ N5/6		**24** Fruit removal @FB 7-12 33%	
	21 Fruit Removal @ FB 1 – 6 33%		**22** Control	
	19 Fruit Removal @ FB 1-6 & 7-12 33%		**20** Fruit Removal @ FB 1- 6 100%	
	17 Fruit Removal @ FB 7-12 100%		**18** Fruit removal @ FB 1-6 & 7-12 100%	
	Rep 3		**Rep 4**	
	15 Fruit removal @ FB 1- 6 100%		16 Fruit removal @FB 7-12 33%	
	13 Fruit Removal @ FB 1-6 & 7-12 33%		**14** Fruit Removal @ FB 1 – 6 33%	
	11 Fruit Removal @ FB 7-12 100%		**12** Control	
	9 Fruit removal @ FB 1-6 & 7-12 100%		**10** Tipping @N5/6	
	7 Fruit Removal @ FB 1 – 6 33%		**8** Fruit Removal @ FB 1-6 & 7-12 33%	
	5 Control		**6** Fruit Removal @ FB 7-12 100%	
	3 Fruit removal @FB 7-12 33%		**4** Fruit removal @ FB 1-6 & 7-12 100%	
6 m + 2m buffer	**1** Tipping @ N5/6		**2** Fruit removal @ FB 1- 6 100%	
12 rows Total	**Rep 1**		**Rep 2**	
2 rows buffer	**3 rows**	**2r**	**3 rows**	**2 rows buffer**

NORTH ← **TAIL DRAIN**

Table 4: Summary of fruit removal treatments ACRI & Appletrees, 2018/19 - 2020/21

Treatment	Planting Date ACRI – 03/10/2018 Appletrees – 23/10/2018	Planting Date 06/11/2019	Planting Date 14/10/2020
Variety	Sicot746B3F	Sicot746B3F	Sicot746B3F
Tipping	05/12/2018 (ACRI) 717 DD	16/12/2019 560 DD	No Tipping
Damage to fruiting Branches 1-6 Peak Flower (1300-1400 DD)	Appletrees 33% & 100% - 07/01/2019 1087 DD	33% & 100% - 20/01/2020 1217 DD	33% & 100% - 12/01/2021 1149 DD
Damage to Fruiting Branches 7-12 Green Boll (1572 DD)	33% & 100% - 06/02/2019 1678 DD	Not Done	33% & 100% - 09/02/2021 1554 DD
Combined Damage to fruiting branches 1-12	33% & 100% 07/01/2019 & 06/02/2019 1087 & 1678 DD	Not Done	33% & 100% 12/01/2021 & 09/02/2021 1149 DD & 1554 DD
First Maturity Pick 60% Open Boll (2055 DD)	18/04/2019 (ACRI) 2810 DD 06/3/2019 (Appletrees) 2104 DD	24/03/2020 2066 DD	13/04/2021 2252 DD
Last Maturity Pick End of Season	21/05/2019 (ACRI) 3053 DD 10/04/2019 (Appletrees) 2558 DD 17/04/2019 Last green bolls 2620 DD	19/05/2020 2473 DD	26/05/2021 2494 DD
Strata Pick	Not Done	11/06/2020 2571 DD	01/06/2021 2517 DD
Machine Pick	Not Done Bulk Hand Pick 4m in A3 22/05/2019 3060 DD	20/06/2020 2612 DD	29/06/2021 2600 DD

Table 5: Fruits removed from plants at ACRI & Appletrees in each year (mean/m)

	Squares	Candlewicks	Yellow Flower	Pink & Purple Flower	Green Bolls	Total fruit removed/m
2018/19						
33 % Fruiting Branches 1-6	29.52	1.29	1.13	.83	3.13	35.92
100% Fruiting Branches 1-6	80.75	4.00	2.46	2.08	6.96	96.25
33% Fruiting Branches 7-12	3.75	0.83	1.08	1.33	22.67	29.67
100% Fruiting Branches 7-12	20.04	6.26	3.71	3.88	61.38	95.25
33% Fruiting Branches 1-12	32.29	3.08	2.25	2.96	25.42	66.00
100% Fruiting Branches 1-12	123.25	13.46	6.71	8.37	77.54	229.33
2019/20						
33 % Fruiting Branches 1-6	30.25	1.29	0.25	2.46	5.63	39.88
100% Fruiting Branches 1-6	75.58	2.50	4.25	3.71	14.42	100.46
2020/21						
33 % Fruiting Branches 1-6	54.50	2.17	1.00	1.33	1.50	60.50
100% Fruiting Branches 1-6	150.50	2.50	1.67	3.17	4.83	162.67
33% Fruiting Branches 7-12	100.00	5.50	4.83	8.00	41.67	160.00
100% Fruiting Branches 7-12	206.33	14.83	10.67	23.00	134.83	389.67
33% Fruiting Branches 1-12	163.67	7.00	4.67	867	42.83	226.83
100% Fruiting Branches 1-12	555.67	19.00	16.17	29.50	129.33	749.67

Table 6: Data collected for each experiment at Appletrees and ACRI, 2018/19 - 2020/21

Year	Tip Damage inflicted	Fruit damage at Nodes	No. of plants per metre damaged	Yield measured	Maturity Delay measured	Segmented Pick
2018/19 ACRI Appletrees	Nodes 5-6 (Actual 5.2)	1-6 7-12 1-6 & 7-12	33% 100%	✓	✓	Not done
2019/20 ACRI B2	Nodes 5-6 (Actual 7)	1-6	33% 100%	✓	✓	✓ n.s.
2020/21 ACRI A3	No Tipping	1-6 7-12 1-6 & 7-12	33% 100%	✓	✓	✓

3. Results

Rather than presenting data chronologically, they are presented to answer the questions we asked.

3.1 Does Tipping out reduce Yield?

Tipping damage did not significantly affect yield in the 2018/19 or 2019/20 seasons (Fig. 11). However, yields were lower than average in both years as 2018/19 was an extreme drought year with very hot periods throughout January while in 2019/20 the crop experienced extended wet weather throughout February and both scenarios may have affected fruit retention. Ginouts in both years were 46% and there were no significant differences between boll numbers or boll weights between treatments in each season (Figs. 12-13).

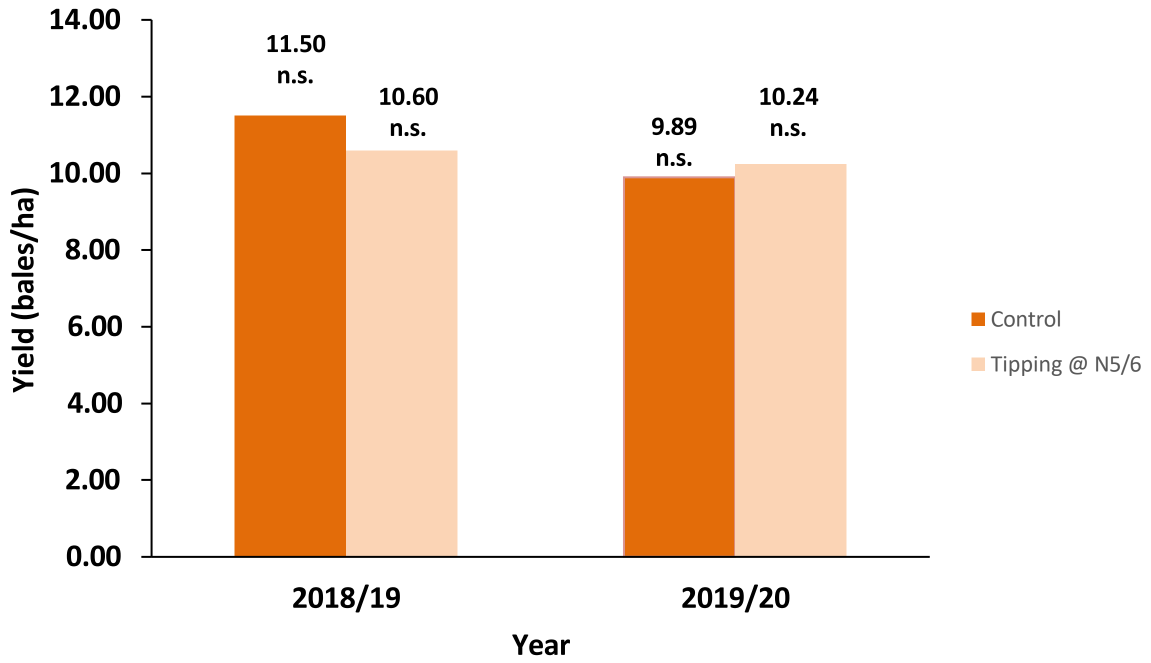

Figure 11: Effects of tipping out below Node 7 on yield at ACRI for each year, 2018/19 to 2019/20. Note that comparisons for significance are between Control and Tipping for each year. Actual Nodes tipped were 2018/19 – Node 5.2, 2020/21 – Node 7. Statistical analyses for 20018/19 – P = 0.244, LSD = n.s., 2019/20 – P = 0.324, LSD = n.s.

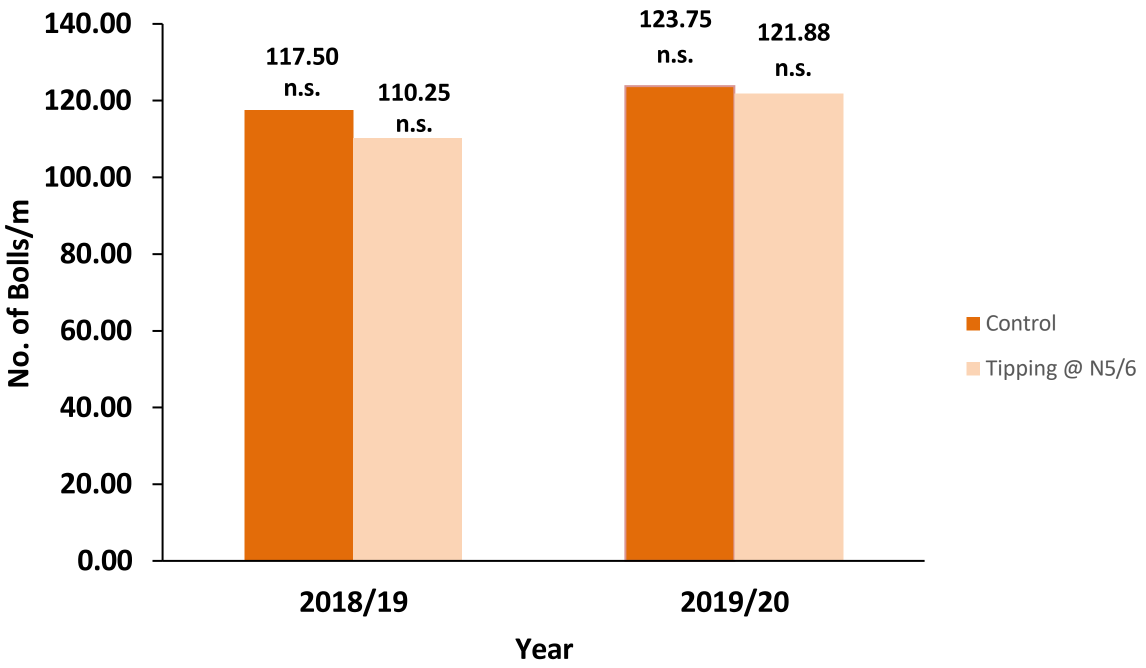

Figure 12: Effects of tipping out below Node 7 on boll numbers at ACRI for each year, 2018/19 to 2019/20. Note that comparisons for significance are between Control and Tipping for each year. Actual Nodes tipped were 2018/19 – Node 5.2, 2020/21 – Node 7. Statistical analyses for 20018/19 – P = 0.137, LSD = n.s., 2019/20 – P = 0.066, LSD = n.s.

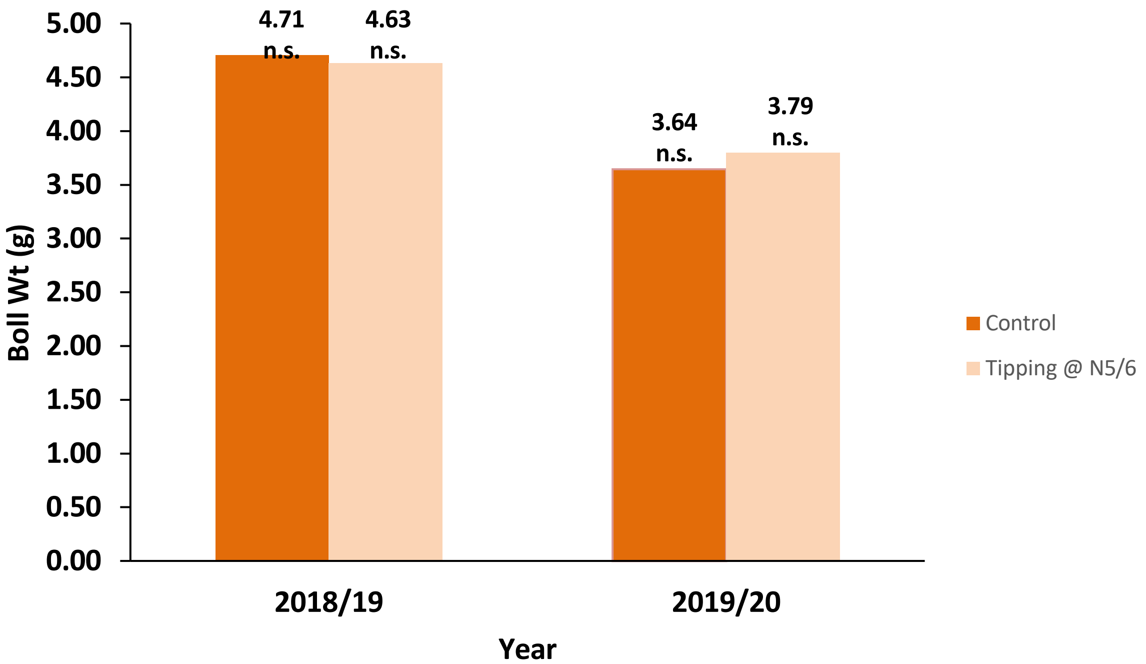

Figure 13: Effects of tipping out below Node 7 on boll weight at ACRI for each year, 2018/19 to 2019/20. Note that comparisons for significance are between Control and Tipping for each year. Actual Nodes tipped were 2018/19 – Node 5.2, 2020/21 – Node 7. Statistical analyses for 20018/19 – P = 0.678, LSD = n.s., 2019/20 – P = 0.517, LSD = n.s.

3.2 Does Tipping out delay Maturity?

Tipping damage did not affect maturity at 60 percent open boll in the 2018/19 or 2019/20 seasons (Fig.14). Tipping plants matured 1-2 days earlier than untipped plants which is of no practical significance.

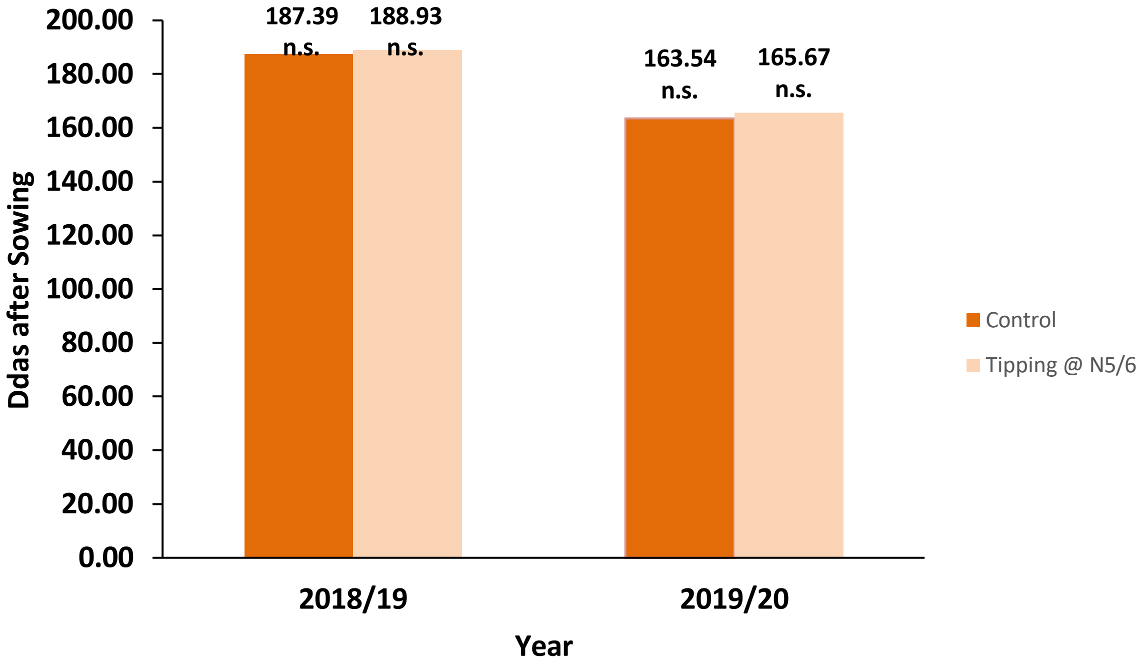

Figure 14: Effects of tipping out below Node 7 on maturity at ACRI for each year, 2018/19 to 2019/20. Note that comparisons for significance are between Control and Tipping for each year. Actual Nodes tipped were 2018/19 – Node 5.2, 2019/20 – Node 7. Statistical analyses for 20018/19 – P = 0.038, LSD = 2.33, 2019/20 – P = 0.64, LSD = n.s.

Tipping Damage Discussion

A one-off tipping event between nodes 5 and 7 had overall no effect on boll number, boll weight and yield showing either a loss or slight compensation of less than 1 bale/ha. Plant responses were unaffected by drought or wet weather. Tipping also had no effect on crop maturity as a one-off tipping damage is relatively minimal and it occurred early in the season when other overriding factors can still have major effects on crop development and yield. The experiments carried out under the current project also only considered tipping but did not simulate the crippling effects on leaves caused by thrips. However, they confirm our previous damage work in this region where season length allows time for crop compensation. Wilson *et al.* (2003) removed extensive amounts of leaf tissue from seedlings below Node 8 and combined that with several tipping events. Even repeated, complete defoliation of mainstem leaves prior to first flower did not affect crop yield. However, such levels of damage did delay crop maturity by 10 days. Three tipping events below node 8 did not affect yield but had a lesser effect on maturity (<5 days). The data was used to develop damage thresholds for thrips for warm or long-season areas which are still in use.

To understand the mechanisms of recovery from thrips damage, Sadras and Wilson (1998) analysed plant growth after recovery and found that it occurred in a biphasic pattern. Initially, plants protected from insect damage with insecticide grew faster than damaged plants until about 40 days after sowing (DAS). After that, leaf area of plants damaged by thrips increased faster than that of undamaged plants but significant differences between treatments were not evident until 60-80 DAS. Lei and Wilson (2004) suggested that leaf growth recovery after damage was driven by the reduced expansion period of the damaged, smaller leaves (which had fewer cells), that allowed for the development and expansion of new healthy leaves above the damage about 1-2.5 nodes sooner than in undamaged plants.

Management of thrips with seed treatments is an insurance policy for good crop establishment that is considered more beneficial-friendly than later applied sprays. As a consequence, seed treatments contribute significantly to the cotton industry's environmental toxicity level (ETL). In cool season areas, and where wireworms are also a problem in stubble planted cotton, seed treatments may well be warranted. However, they may not be categorically needed in warm season cotton growing areas, especially since the effects of seed treatments on thrips are generally not noticeable unless thrips numbers are high. Another consideration is chemical resistance in *Frankliniella occidentalis* which has known resistance to neonicotinoids and may displace *Thrips tabaci* in farming systems.

3.3 Does Fruit Removal from the lower 12 Fruiting branches affect Yield?

Yield

We removed all the fruit from designated fruiting branches on two occasions: as soon as practical once the lowest six proper fruiting branches (FB 1-6) were formed and again when the next six fruiting branched higher up were formed (FB 7-12). For the combined treatment fruit were removed on both dates. Fruit removal occurred at two stress levels: in 33% of plants, to simulate insect damage and in 100% of plants to simulate fruit loss from abiotic factors.

In 2018/19, fruit removal from the lower six fruiting branches resulted in a slightly higher yield than the Control (approx. 1 bale/ha) for both stress levels (Fig. 15). When damage occurred in the mid-canopy later in the season, either as a first damage or an additional damage to the earlier damage, yield was significantly reduced: at the 33% stress level, the reduction was 2.3-2.5 bales/ha while at the 100% level, it was 4.3-4.6 bales/ha. Despite the drought the Control yield was 13.73 bales/ha which contrasts to the Control yield from the Tipping Experiment (11.5 bales/ha). The reason for this is that the experiment was split after the hailstorm: the Tipping damage was carried out at ACRI pre-storm while the post-storm fruit damage was carried out at Appletrees under intensive yield management. We were unable to obtain machine pick data for comparison of overall yield. Ginout percentages for the hand picks ranged from 43% to 46%.

In 2019/20, we only managed to carry out removal of fruit from the lower six fruiting branches due to extended wet weather throughout February. Yields were also lower for that season with Control plots yielding only 9.89 bales/ha. Removing fruit from FB 1-6 of 33 or 100% of plants did not significantly alter yields (less than 1 bale/ha, Fig. 16). Unusually, machine-picked yield (Fig. 17) was higher than hand-picked yield which may indicate good defoliation and a clean pick. Ginout percentages averaged 45% for the hand picks and 42% for the machine pick.

In 2020/21, all treatments were implemented with surprising results for yield from the maturity picks: the Control yield was 17.41 bales/ha (Fig. 18, triple checked!). Removing fruit from the lowest 6 fruiting branches in 33% of plants enhanced yield to 18.56 bales/ha while removal from 100% of plants reduced yield to 16.00 bales/ha. Neither difference was significant. When damage occurred in the mid-canopy later in the season, either as a first damage or an additional damage to the earlier damage, yield compared to the Control was reduced: at the 33% stress level, the reduction was 2.1-2.4 bales/ha which was not statistically significant, while at the 100% level, it was 5.9-7.3 bales/ha which was highly significant. Despite the differences in magnitude between the 2018/19 and 2020/21 yields, the reduction at the 33% stress level was in the same range (2.1-2.5 bales/ha), however, when that damage was imposed to 100% of plants, the damage increased by a factor of 1.5. The machine-picked yields for the treatment plots were not significantly different from one another and were in the 9-10 bales/ha range, except for the FB1-12 x 100% treatment, which yielded only 7.22 bales/ha. (Fig. 19). The strata picks, in which individual boll positions were picked and ginned, resulted in yields somewhat higher than the machine pick and lower than the maturity hand pick. Differences in yield between treatments were not significant and all were lower than the Control by 0.31-2.48 bales/ha with most loss occurring in the later damage treatment x 100% damage levels (Fig.20). The discrepancies between hand, machine and strata picks were likely due to differences in ginout percentages as the gin turnouts for the hand picks and strata picks were much higher than for the machine pick (Table 7). The very high yield in the hand picks was due to high boll numbers in the meters selected for maturity picking where we aim to mark out a representative area of the damaged plot rows but don't have much area to work with.

Table 7: Ginout percentages for Hand and Machine Picks, ACRI A3, 2020/21. Hand and machine picks were ginned on a saw gin while strata picks were ginned on a roller gin.

Treatment	**Hand Pick Ginout%**	**Machine Pick Ginout%**	**Strata Pick Ginout%**
Control	48.49	43.50[a]	47.40
Fruit Removal FB 1-6 33%	47.85	43.37[a]	48.11
Fruit Removal FB 1-6 100%	45.57	43.85[a]	47.34
Fruit Removal 7-12 33%	48.12	42.43[a]	45.54
Fruit Removal FB 7-12 100%	46.65	41.71[b]	45.48
Fruit Removal 1-6 & 7-12 33%	46.47	42.35[a]	45.00
Fruit Removal 1-6 & 7-12 100%	46.40	40.68[b]	44.15
P=0.05	0.570	0.016	0.148
df	(6, 27)	(6, 27)	(6, 27)
LSD	n.s.	1.752	n.s.

The combined data analysis over the three experiments (seasons, Fig. 21) clearly showed three trends:

(i) early loss of fruit from fruiting branches 1-6 did not result in significant yield loss (< 0.4 bale/ha),

(ii) loss of fruit from only one third of the crop did not result in significant yield loss (<0.5 bale/ha), and

(iii) loss of fruit from the lower six fruiting branches in a portion of the crop (33%) could result in a small yield gain of less than 1 bale/ha.

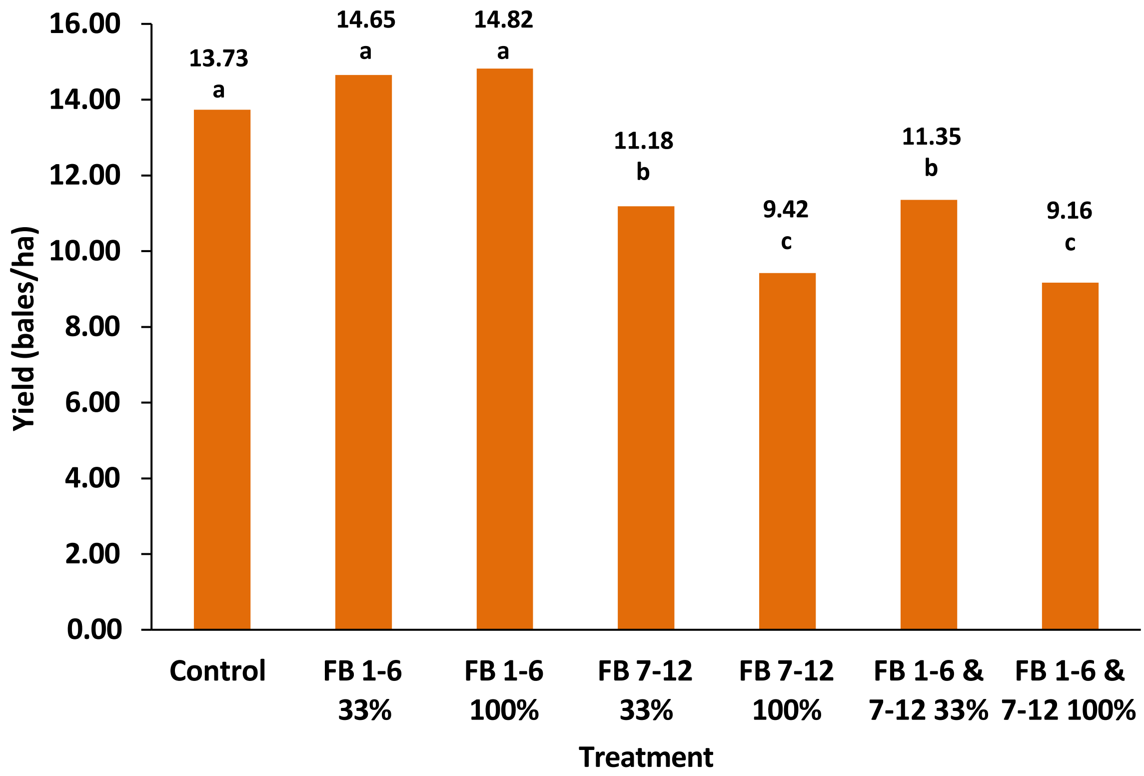

Figure 15: Hand-picked yield at Appletrees 2018/19, P <0.001, df (6, 27), LSD = 1.40

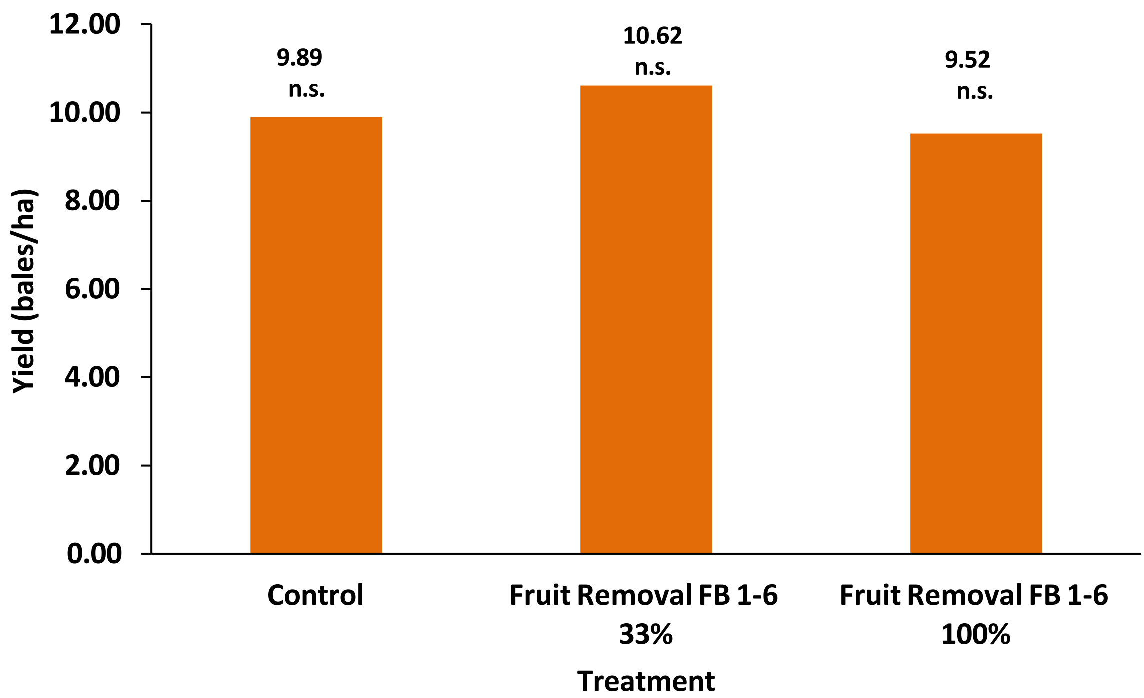

Figure 16: Hand-picked yield at ACRI B2 2019/20, P = 0.324, df (3, 15), LSD = n.s.

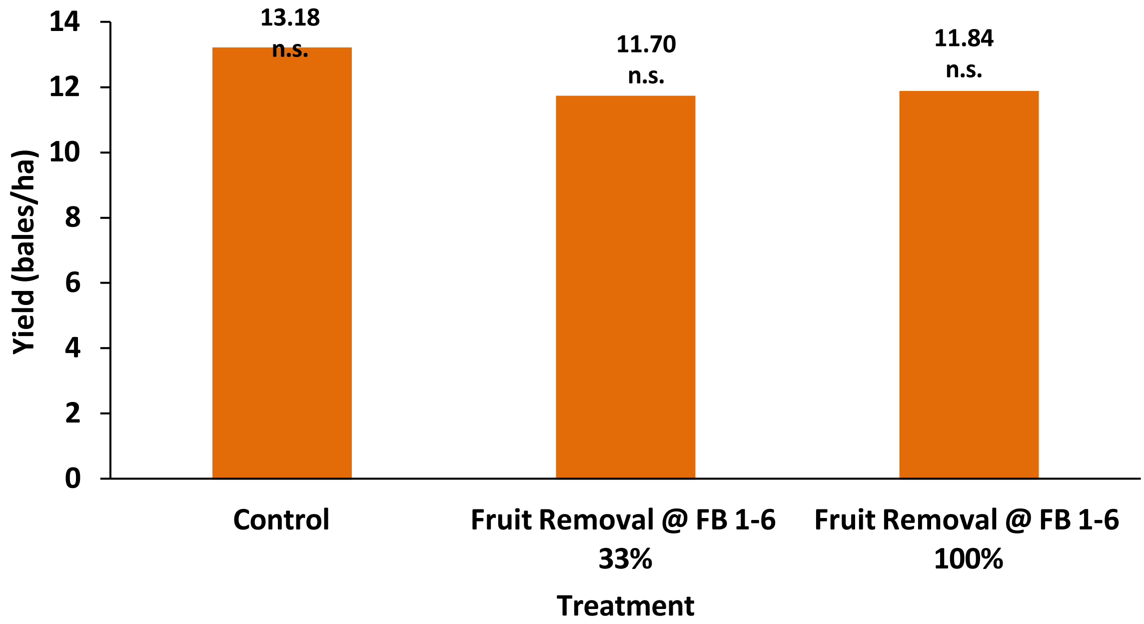

Figure 17: Machine-picked yield at ACRI B2 2019/20, P = 0.118, df (3, 15), LSD = n.s. Mean Ginout % 42.3.

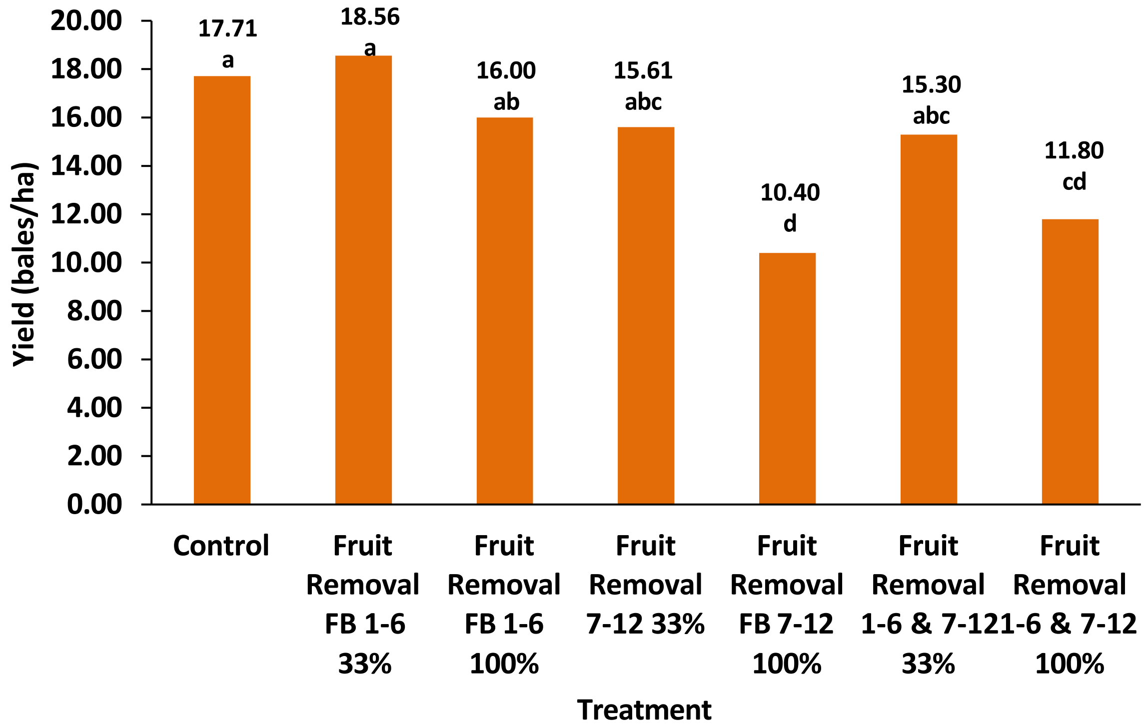

Figure 18: Hand-picked yield at ACRI A3 2020/21, P = 0.001, df (6, 27), LSD = 3.84.

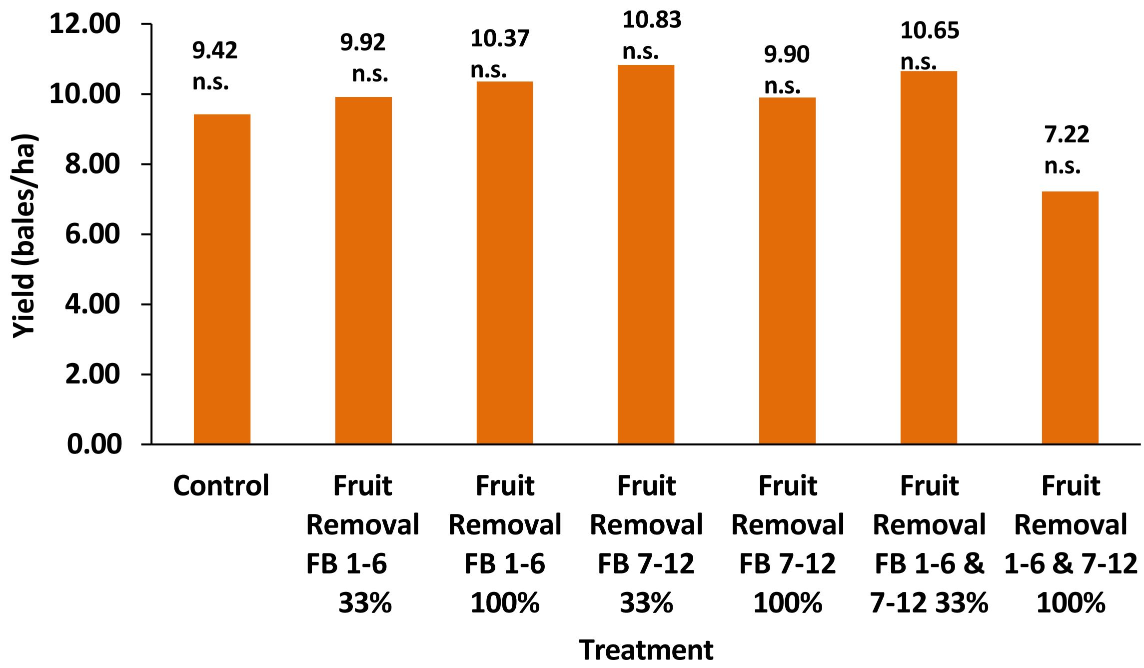

Figure 19: Machine-picked yield at ACRI A3 2020/21, P = 0.516, df (6, 27), LSD = n.s.

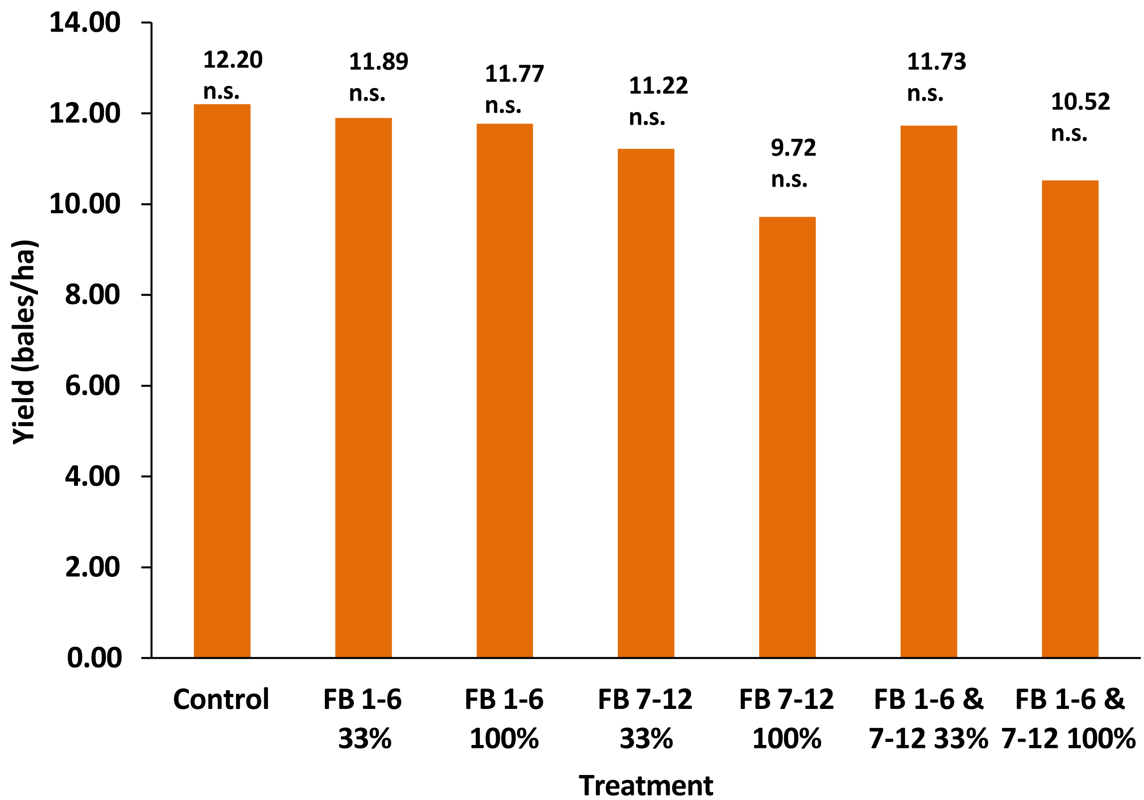

Figure 20: Strata-picked yield at ACRI A3 2020/21, P = 0.230, df (6, 27), LSD = n.s.

Combined Analysis

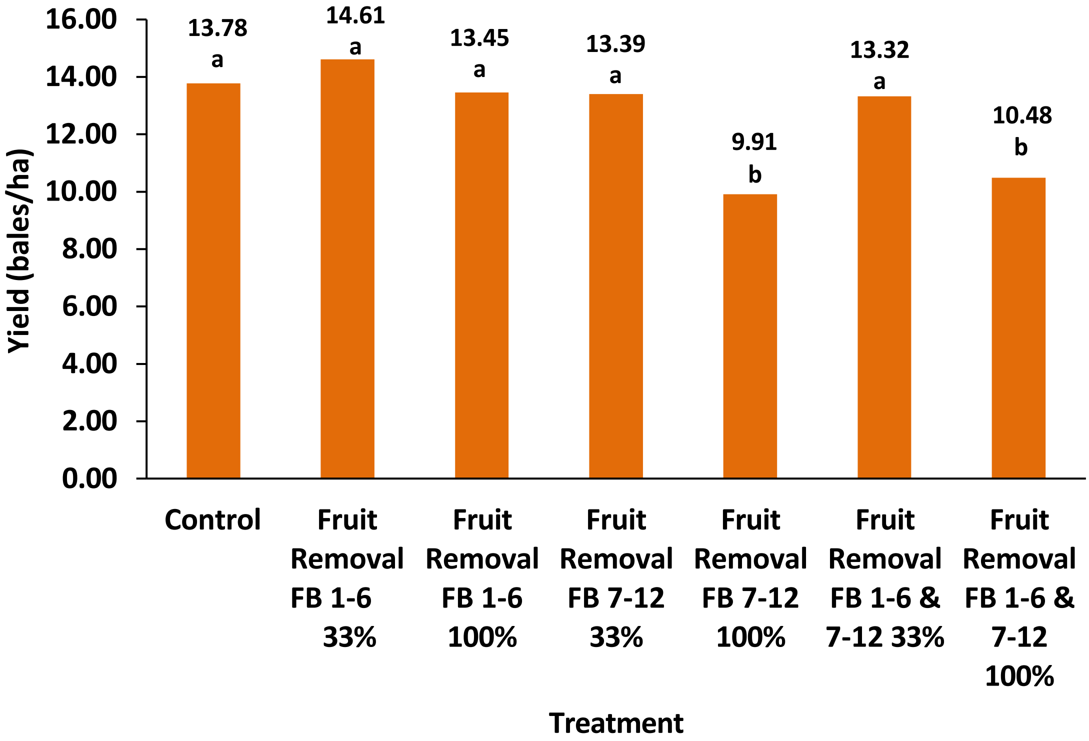

Figure 21: Combined yield analysis for 3 years of hand-picked yield data (2018/19, 2019/20 & 2020/21). P = <0.001,df (6, 16) LSD = 1.647

Boll Numbers

The hand-picked number of bolls harvested per metre was statistically different between treatments in 2018/19 and 2020/21 but not in 2019/20 (Figs 22-24). The patterns reflect the yield differences during those years. It should be noted that the number of bolls harvested in the 2020/21 pick are lower than those picked in 2018/19, yet the yield (bales/ha) was higher in 2020/21. The combined analysis (Fig. 25) reflects the combined yield pattern, which is not surprising given that boll numbers constitute yield.

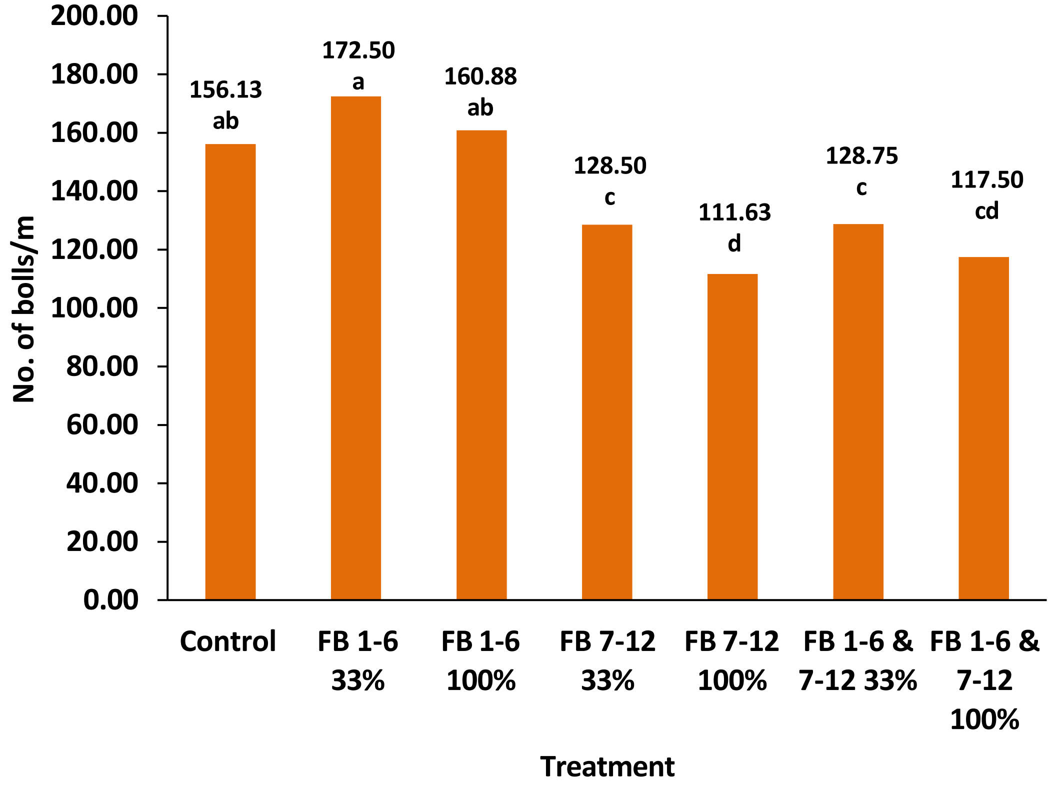

Figure 22: Boll Numbers at Appletrees 2018/19, P = <0.001 df (6,27), LSD = 16.38

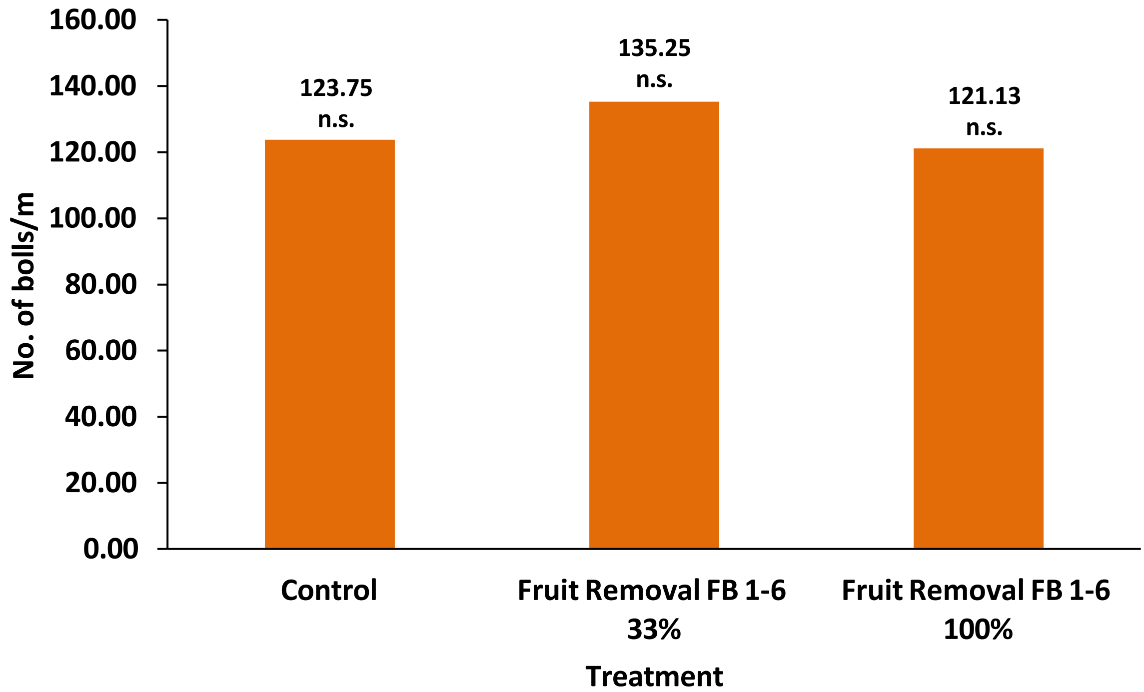

Figure 23: Maturity at ACRI 2019/20, P = 0.066, df (4, 19), LSD = n.s.

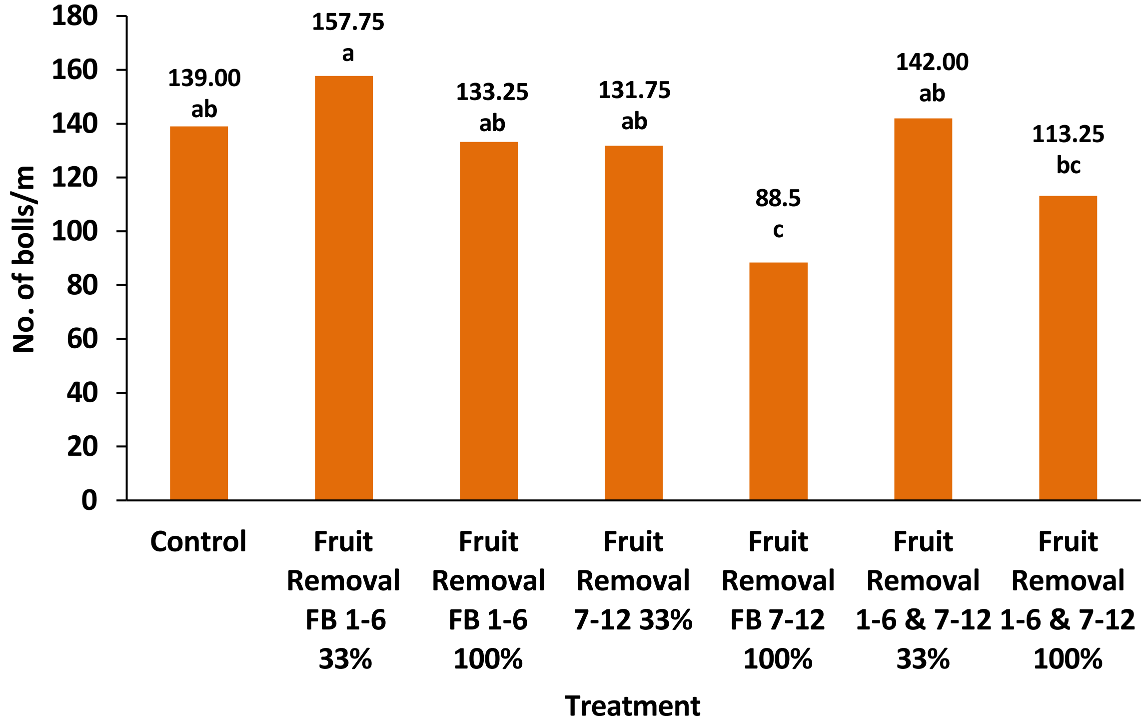

Figure 24: Boll Numbers at ACRI 2020/21, P = 0.006 df (6, 27), LSD = 31.24

Combined Analysis

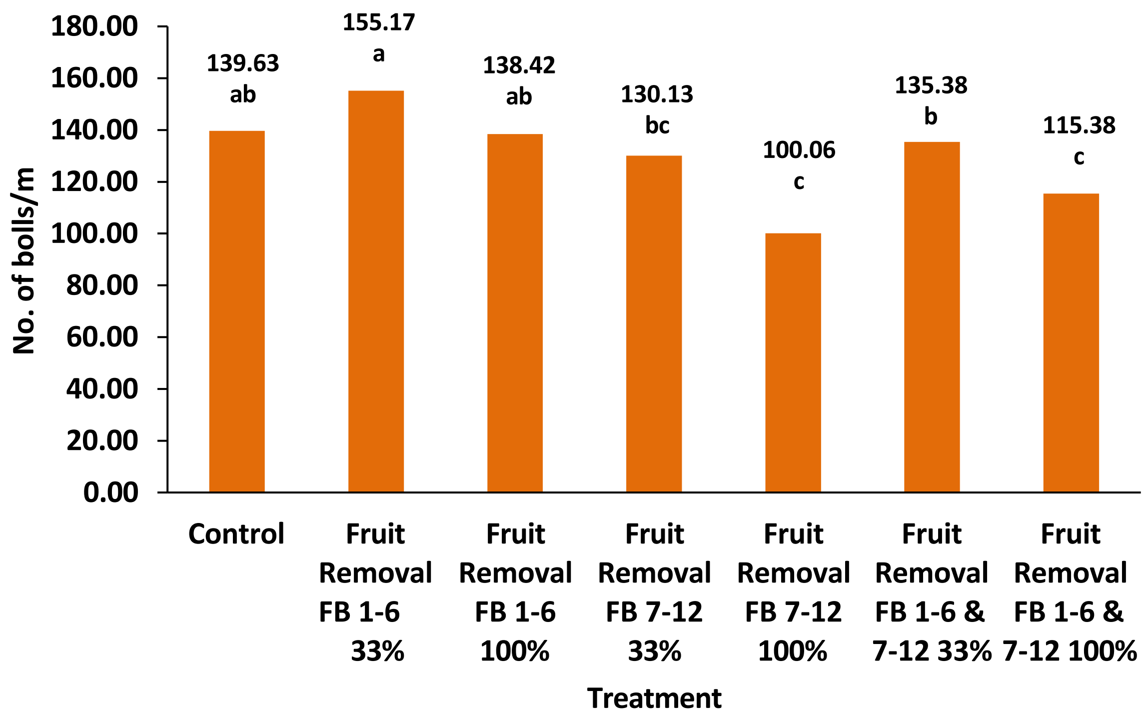

Figure 25: Combined boll number analysis for 3 years of yield data (2018/19, 2019/20 & 2020/21). P = <0.001 df (6, 16), LSD = 17.17

Boll Weight

Boll weights from hand picks in 2018/19 and 2019/20 were not statistically different averaging 3.85 g/boll (Table 7). In 2020/21, however, individual boll weights averaged 5.6 g/boll and together with the higher gin turnout were responsible for the high yield seen in the maturity pick data.

Table 7: Boll weight for Maturity Picks 2018/19-2020-21.

Treatment	Appletrees 2018/19	ACRI B2 2019/20	ACRI A3 2020/21
Control	3.84	3.64	5.70
Fruit Removal @ FB 1-6 33%	3.82	3.91	5.47
Fruit Removal @ FB 1-6 100%	3.76	3.89	5.40
Fruit Removal @ FB 7-12 33%	4.34	---	5.68
Fruit Removal @ FB 7-12 100%	3.83	---	5.76
Fruit Removal @ FB 1-6 & 7-12 33%	3.77	---	5.47
Fruit Removal @ FB 1-6 & 7-12 100%	4.35	---	5.73
P=0.05	0.902	0.517	0.570
df	(6, 27)	(3, 15)	(6, 27)
LSD	n.s.	n.s.	n.s.

Maturity

In 2018/19, there was a significant delay in maturity from damage to 100% of plants. The delay was highest for the FB1-12 treatment (9 days), followed by the FB 1-6 and FB 7-12 treatments (5 and 3.66 days, respectively). When only 33% of plants were damaged, the delay in maturity ranged from half a day to 2.8 days (n.s., Fig. 26). In 2019/20, loss of fruit from FB 1-6 in 33 and 100% of plants caused significant delays of maturity by 2-3 days (Fig. 27). In 2020/21 maturity delays were significant and extended to 19 days for the FB 1-12 x 100% treatment (Fig. 28) and 8 days for the FB 1-6 x 33%, FB 7-12 x 100% and FB 1-12 x 33% treatments. For the FB 1-6 x 100 and FB 7-12 x 33% treatments, maturity was only delayed by 2-3 days, which was not significant.

In the combined analysis of maturity at 60% open boll, maturity delay of 3-4 days was not significant and occurred when fruit was removed from FB 1-6 (33% & 100%) and from FB 7-12 at 33% (Fig. 29). The delay increased significantly to 8-9 days for the FB 7-12 x 100% and FB 1-12 x 33% treatments. For the FB 1-12 x 100% treatment, maturity was delayed by 17 days. The longer delays were driven by the 2020/21 data set.

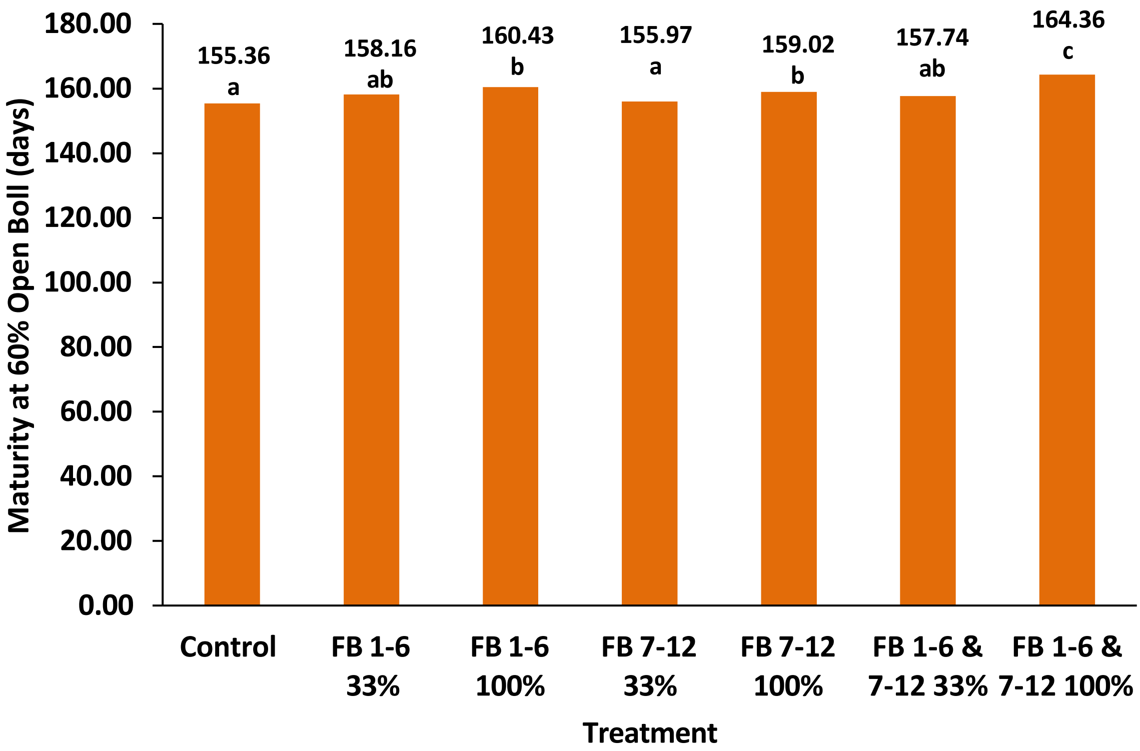

Figure 26: Maturity at Appletrees 2018/19, P = <0.001, df (6, 27), LSD = 3.12

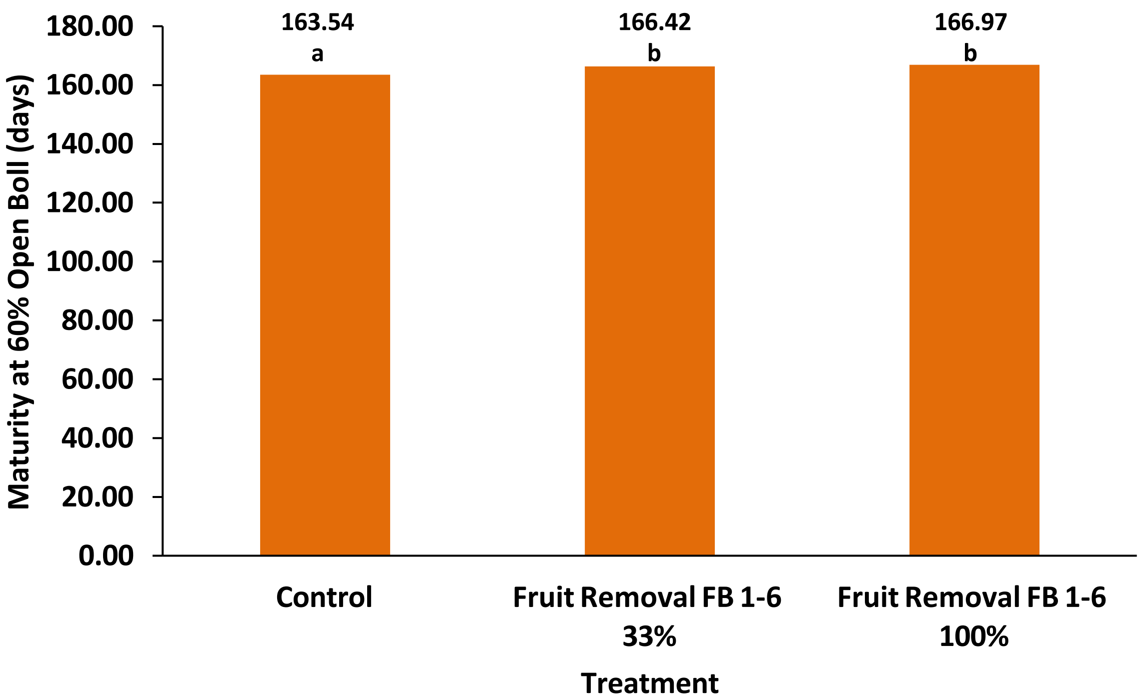

Figure 27: Maturity at ACRI 2019/20, P = 0.038, df (4, 19), LSD = 2.33

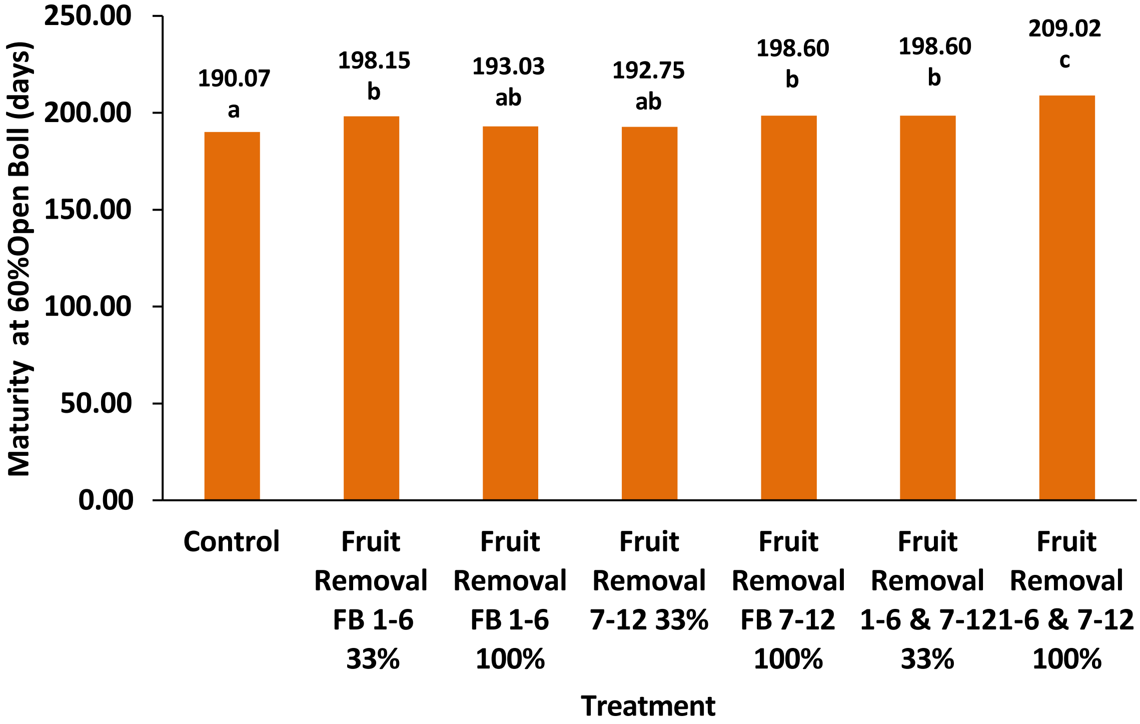

Figure 28: Maturity at ACRI 2020/21, P = <0.001, df (6, 27), LSD = 6.67

Combined Analysis

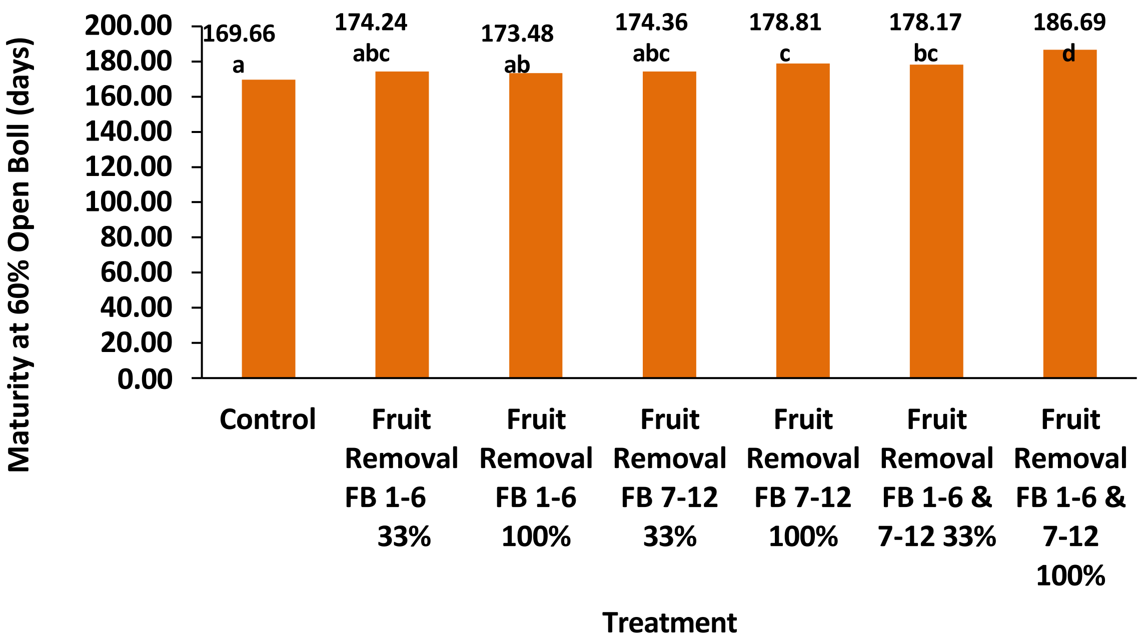

Figure 29: Combined maturity analysis for 3 years of yield data (2018/19, 2019/20 & 2020/21). P = 0.003 df (6, 16), LSD = 4.796

Fruit Removal Discussion

Yield results over three years of experiments were variable and depended on location, season, type of picking and ginning. Yields at Appletrees in 2018/19 were higher than yields at ACRI and were a reflection of a much more intensively managed commercial crop. There were statistically significant yield differences between treatments, especially where fruit was lost from FB 7-12 mid-canopy. Earlier damage to the lower FB 1-6 showed a non-significant trend of compensation which was also indicated in 2019/20 when losses occurred in the lower FB on one third of the crop. Yield differences in this season were not significant and the trend did not reflect in the machine picks. However, there was again indication of it in the 2020/21 hand and machine picks at the lower damage level and across the seasons the difference. Across the three seasons our data shows that early fruit loss in the lower part of the crop does not impact negatively on yield with variations of less than 1 bale/ha. Fruit loss from FB 7-12 and/or a higher proportion of the crop have the potential to incur greater yield loss. Bearing in mind that statistical significance depends on experimental design, real significance is measured in dollar terms and a loss of 2 bales/ha which may not be statistically significant, would have practical significance to a grower. It should be noted that the potential for loss was greater in the higher yielding crops (Appletrees and ACRI Maturity pick 2020/21). Correlation analyses have shown that bolls/m^2 is the major yield determinant (Worley *et al.,* 1974). Boll numbers and boll weights were very variable between years and depended on the season (2019/20 was a drought year), picking mechanism and type of gin used. The intention of the 33% treatment was to simulate insect damage (such as mirid damage) and we may infer from our results that low levels of insect damage could be tolerated without significant yield loss. This would result in fewer spray application to the benefit of the grower in terms of reduced production cost and support of beneficial populations, and to the industry in terms of lower environmental toxicity levels. However, we do not understand the population dynamics of mirids well and leaving mirids unsprayed may well support population build-up to levels that would cause potential damage to squares and bolls on FB 7-12 later in the season. Research into mirid population dynamics in the presence or absence of predators and chemical control would provide knowledge to make better mirid management decisions. While early damage levels may be tolerated, we do not know what level of mirid density and feeding causes this level of damage, hence work in this area could help to improve dynamic thresholds for mirids.

At Appletrees, maturity was delayed by 6-9 days wherever 100% of the crop was damaged irrespective of the amount of fruit removed, and more severe damage caused the longest delay. At 33% damage, delays of 2-3 days were not significant. Yet at ACRI in 2019/20, a 2-3 day delay at low damage levels was significant both in the 33% and 100% treatments. Inexplicably, the FB 1-6 x 33% treatment at ACRI in 2020/21 caused an 8 day delay in maturity but the other lower damage treatments reflected the 2-3 day delay (n.s.) seen in the previous experiments. Practically, the significance of a delay in maturity depends on the weather at the end of the season, defoliation efficiency, rainfall risk and picker/labour availability. Maturity delays for the FB 7-12 x 100% and FB 1-12 treatments exceeded 1 and 2 weeks, respectively, which increases the risk of lint degradation in the field from exposure with subsequent quality loss.

To visually relate the damage we implemented to yield loss, we plotted the number of fruit removed in our treatments against yield data for those plots (Fig. 30). The plot does not include all control treatments but we used a control yield of 13.78 bales/ha which was the average yield from 3 years of experiments. However, from our data in the Namoi, we cannot explain yield reduction (R^2 = 0.022) based on the amount of fruit we removed. In contrast, similar experiments carried out at Spring Ridge over the same time period produced a linear relationship between fruit removal and yield with $R^2 = 0.6$.

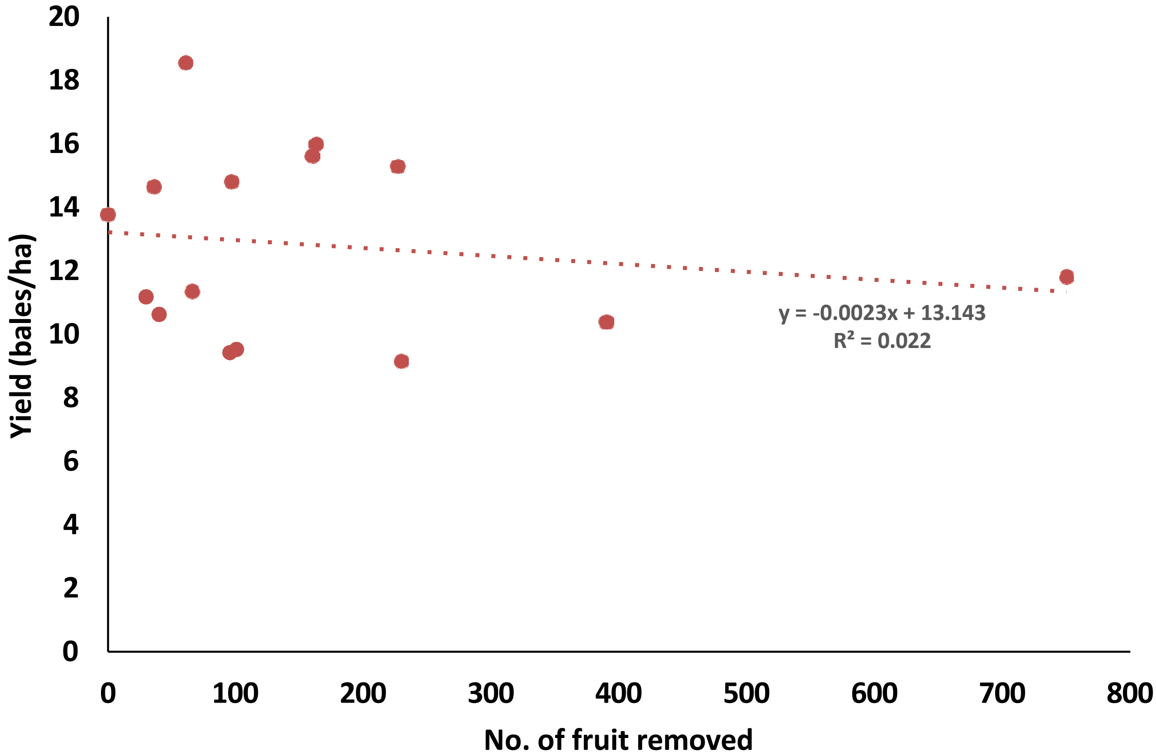

Figure 30: Relationship between fruit loss per metre and yield (bales/ha) Lower Namoi, NSW (2018/19 - 2020/21)

3.4 Does cotton compensate for fruit loss?

Segmented Pick Data 2018/19 & 2019/20

We did not have the opportunity to carry out a time-consuming, segmented pick at Appletrees as it was commercially harvested as quickly as possible after defoliation. Since the results for the 2019/20 pick at ACRI B2 were not significant and compensation did not occur, the segmented pick data was not analysed.

Segmented Pick Data 2020/21

A segmented pick of 2 m per plot was carried out on the 01/06/2021 to determine the stratum and position contribution to total yield. By converting any contributions to percentage of yield, we could determine if compensation occurred and if it did, where on the plant it occurred. We saw significant statistical differences in yield between treatments in the maturity pick, however, these differences disappeared in the machine pick and the segmented pick. We have nevertheless analysed the data set to understand how plants responded to damage and how different plant areas contributed to yield. Data from the segmented picks are presented in diagrams of stylised cotton plants to enable a visual comparison (Figs 31-37). Figures in the plant maps summarise the number of bolls harvested from each stratum and fruiting position. Ginned boll data was converted to yield in bales/ha and represents contribution to total yield.

- Control – The mean yield in Control plots was 12.20 bales/ha. In the vertical profile, Position 1 (P1) bolls contributed 57% while Position 2 (P2) bolls contributed 21%. Only 1% came from P3 bolls (Fig. 31). In the horizontal profile, 23% of yield developed on the lower fruiting branches (FB) 1-6, 43% on FB 7-12 and 10% on FB 13-16. Only 2% of yield was set above the 16th fruiting branch. P1 bolls on FB 7-12 were responsible for just about one third of the yield and together with P2 bolls on FB 7-12 and P1 bolls on FB 1-6 constituted about 60%. Bolls on vegetative branches (VB) made up another 21% of yield.

- FB 1-6 (33%) – The mean yield in this treatment was 11.89 bales/ha. The profile of yield contribution was very similar the Control but the damage imposed was apparent by small losses in yield contribution from FB 1-6 P1 and P2 bolls (which were removed). Any compensation occurred in small amounts over the remaining positions (Fig. 32).

- FB 1-6 (100%) – The mean yield in this treatment was 11.77 bales/ha. Most apparent is the lower contribution by P1 and P2 bolls in the FB 1-6 stratum (8%) showing the loss of 14.8% in yield contribution (Fig. 32). Changes through the FB 7-12 stratum did not make up for this loss, however, there was a higher contribution to yield from vegetative branch bolls, and bolls on FB 13-16. Bolls on vegetative branches contributed more to yield than in the Control treatment (Fig. 33)

- FB 7-12 (33%) – The mean yield in this treatment was 11.22 bales/ha. More fruit were set on FB 1-6 (32%) compared to the control (23%). However, this was not due to P3 bolls. A significant number of bolls was removed in P1 and P2 through FB7-12 resulting in a 12.8% reduction in contribution to yield. Small gains occurred from FB13-16 and VB, however most of the loss was offset on FB 1-6 which had already set by the time the damage to FB 7-12 occurred and was not a consequence of the damage (Fig. 34).

- FB 7-12 (100%) – The mean yield in this treatment was 9.79 bales. Damage caused significant losses through FB 7-12 with a reduction in yield contribution of 27%. Plants compensated by setting more fruit on vegetative branches (38%) and on FB13-16 and 17+ (21%, Fig. 35).

- FB 1-6 & 7-12 (33%) – The mean yield in this treatment was 11.73 bales/ha. Losses in yield contribution through FB1-6 and 7-12 were similar (8% each). Contribution to yield increased through FB 13-16 and FB17+ (Fig, 36).

- FB 1-6 & 7-12 (100%) – The mean yield in this treatment was 10.52 bales/ha. Losses in yield contribution through FB1-6 and 7-12 were significant (19% & 27%). Contribution to yield increased through FB 13-16 (21%) and FB17+ (14%, Fig, 37) as well as on vegetative branches (12%).

Figure 31: Segmented pick, 2020/21 Control (data are means per metre of row). The yield for each stratum and each boll position is summarised in bold black figures. The percentage contributions of each segment (bales/ha) to total yield are signified in red.

Terminal	**Fruiting Position 1**	**Fruiting Position 2**	**Fruiting Position 3**
Fruiting Branch Nodes 17+ 2.00 Bolls **Yield 0.30 bales/ha** **2.42%**	1.88 Bolls Yield 0.20 bales/ha 1.68%	0.13 Bolls Yield 0.09 bales/ha 0.74%	
Fruiting Branch Nodes 13-16 13.75 Bolls **Yield 1.27bales/ha** **10.42%**	10.31 Bolls Yield 1.00 bales/ha 8.21%	2.88 Bolls Yield 0.21 bales/ha 1.69%	0.75 Bolls Yield 0.06 bales/ha 0.53%
Fruiting Branch Nodes 7-12 43.38 Bolls **Yield 5.29 bales/ha** **43.40%**	29.38 Bolls Yield 3.76 bales/ha 30.83%	13.63 Bolls Yield 1.49 bales/ha 12.21%	0.38 Bolls Yield 0.04 bales/ha 0.35%
Fruiting Branch Nodes 1-6 24.50 Bolls **Yield 2.76 bales/ha** **22.62%**	17.38 Bolls Yield 1.98 bales/ha 16.20%	6.63 Bolls Yield 0.74 bales/ha 6.08%	0.50 Bolls Yield 0.04 bales/ha 0.35%
Vegetative Branches and poorly developed fruiting branches without fruit 14.88 VB, 23.88 Bolls **VB Yield = 2.58 bales/ha** **21.14%**			Total Mainstem Bolls = 83.63 Yield 9.62 bales/ha **78.86%** **Total Bolls = 107.50** **Total Yield 12.20 bales/ha** **100%**
Mainstem Nodes **Cotyledonary Nodes**	**Position 1** 58.57 Bolls **Yield 6.94 bales/ha** **56.91%**	**Position 2** 23.25 Bolls **Yield 2.53 bales/ha** **20.72%**	**Position 3** 1.63 Bolls **Yield 0.15 bales/ha** **1.23%**

Figure 32: Segmented pick, 2020/21 FB 1-6 (33%) (data are mean per metre of row). The yield for each stratum and each boll position is summarised in bold black figures. The percentage contributions of each segment (bales/ha) to total yield are signified in red, while the difference for each segment (bales/ha) from the figures in the Control treatment are shown in blue (Fig 22). Where the difference is significant (P=0.05), an asterisks has been placed next to the number of bolls for that segment.

Terminal	Fruiting Position 1	Fruiting Position 2	Fruiting Position 3
Fruiting Branch Nodes 17+ 3.50 Bolls **Yield 0.29 bales/ha** **2.50% +0.08%**	3.13 Bolls Yield 0.26 bales/ha 2.22% +0.54%	0.38 Bolls Yield 0.03 bales/ha 0.28% -0.46%	
Fruiting Branch Nodes 13-16 17.00 Bolls **Yield 1.7 bales/ha*** **14.30% +3.88%**	13.13 Bolls Yield 1.38 bales/ha 11.60% +3.39%	3.13 Bolls Yield 0.25 bales/ha 2.11% +0.43%	0.75 Bolls Yield 0.07 bales/ha 0.58% +0.06%
Fruiting Branch Nodes 7-12 47.00 Bolls **Yield 5.43 bales/ha** **45.63% +2.23%**	30.63 Bolls Yield 3.72 bales/ha 31.26% +0.43%	13.50 Bolls Yield 1.44 bales/ha 12.11% -0.11%	2.88 Bolls Yield 0.27 bales/ha* 2.26% +1.91%
Fruiting Branch Nodes 1-6 19.38 Bolls **Yield 2.37 bales/ha** **19.91% -2.71%**	13.75 Bolls Yield 1.36 bales/ha 11.47% -4.72%	4.38 Bolls Yield 0.52 bales/ha 4.39% -0.11%	1.25 Bolls Yield 0.48 bales/ha 4.04% +1.91%
Vegetative Branches and poorly developed fruiting branches without fruit 16.25 VB, 21.75 Bolls **VB Yield = 2.10 bales/ha** **17.67%** **+3.47%**			Total Mainstem Bolls = 86.88 Yield 9.79 bales/ha **82.33% +3.47%** **Total Bolls = 108.63** **Total Yield 11.89 bales/ha** **-2.50%**
Mainstem Nodes **Cotyledonary Nodes**	**Position 1** 60.63 Bolls **Yield 6.73 bales/ha** **56.55%** **-0.36%**	**Position 2** 21.38 Bolls **Yield 2.25 bales/ha** **18.90%** **-1.83%**	**Position 3** 4.88 Bolls **Yield 0.82 bales/ha** **6.89%** **+5.66%**

Figure 33: Segmented pick, 2020/21 FB 1-6 (100%) (data are mean per metre of row). The yield for each stratum and each boll position is summarised in bold black figures. The percentage contributions of each segment (bales/ha) to total yield are signified in red, while the difference for each segment (bales/ha) from the figures in the Control treatment are shown in blue (Fig 22). Where the difference is significant (P=0.05), an asterisks has been placed next to the number of bolls for that segment.

Terminal	**Fruiting Position 1**	**Fruiting Position 2**	**Fruiting Position 3**
Fruiting Branch Nodes 17+ 4.38 Bolls **Yield 0.33 bales/ha** **2.80%** **+0.38%**	3.50 Bolls Yield 0.26 bal 2.17% +0.49%	0.88 Bolls Yield 0.07 bales/ha 0.62% -0.12%	
Fruiting Branch Nodes 13-16 22.00 Bolls **Yield 2.22 bales/ha*** **18.87%** **+8.45%**	15.63 Bolls Yield 1.62 bales/ha* 13.76% +5.55%	5.5 Bolls Yield 0.54 bales/ha 4.61% +2.92%	0.88 Bolls Yield 0.06 bales/ha* 0.51% -0.02%
Fruiting Branch Nodes 7-12 51.31 Bolls **Yield 4.93 bales/ha** **41.90%** **-1.50%**	30.50 Bolls Yield 3.19 bales/ha 27.11% -3.72%	16.38 Bolls Yield 1.53 bales/ ha 12.97% +0.75%	4.25 Bolls Yield 0.21bales/ha 1.83% +1.47%
Fruiting Branch Nodes 1-6 9.13 Bolls **Yield 0.92 bales/ha** **7.81%** **-14.82%**	5.25 Bolls* Yield 0.53 bales/ha* 4.52% -11.68%	2.88 Bolls Yield 0.31 bales/ ha 2.62% -3.46%	1.00 Bolls Yield 0.08 bales/ha 0.67% +0.32%
Vegetative Branches and poorly developed fruiting branches without fruit 12.88 VB, 39.75 Bolls **VB Yield = 3.37 bales/ha** **28.63%** **+7.49%**			Total Mainstem Bolls = 86.63 Yield =8.40 bales/ha **71.37%** **-7.49%** **Total Bolls = 126.38** **Total Yield 11.77 bales/ha** **-3.52%**
Mainstem Nodes **Cotyledonary Nodes**	**Position 1** 54.88 Bolls **Yield 5.60 bales/ha** **47.56%** **-9.35%**	**Position 2** 25.63 Bolls **Yield 2.45 bales/ha** **20.81%** **+0.09%**	**Position 3** 6.13 Bolls **Yield 0.35 bales/ha** **3.00%** **+1.77%**

Figure 34: Segmented pick, 2020/21 FB 7-12 (33%) (data are mean per metre of row). The yield for each stratum and each boll position is summarised in bold black figures. The percentage contributions of each segment (bales/ha) to total yield are signified in red, while the difference for each segment (bales/ha) from the figures in the Control treatment are shown in blue (Fig 22). Where the difference is significant (P=0.05), an asterisks has been placed next to the number of bolls for that segment.

Terminal	**Fruiting Position 1**	**Fruiting Position 2**	**Fruiting Position 3**
Fruiting Branch Nodes 17+ 4.63 Bolls **Yield 0.18 bales/ha** **1.58% +0.84%**	4.13 Bolls Yield 0.15 bales/ha 1.35% -0.32%	0.50 Bolls Yield 0.06 bales/ha 0.23% -0.51%	
Fruiting Branch Nodes 13-16 24.50 Bolls **Yield 1.43 bales/ha*** **12.79% +2.36%**	17.25 Bolls Yield 1.15 bales/ha* 10.26% +2.06%	6.50 Bolls Yield 0.27 bales/ha 2.44% +0.76%	0.75 Bolls Yield 0.01 bales/ha 0.08% -0.45%
Fruiting Branch Nodes 7-12 35.25 Bolls **Yield 3.44 bales/ha*** **31.65% -12.75%**	24.13 Bolls Yield 2.65 bales/ha* 23.60% -7.23%	9.63 Bolls Yield 0.78 bales/ha* 6.94% -5.28%	1.50 Bolls Yield 0.01 bales/ha 0.12% -0.24%
Fruiting Branch Nodes 1-6 31.25 Bolls **Yield 3.49 bales/ha** **31.09% +8.47%**	20.38 Bolls Yield 2.27 bales/ha 20.26% +4.06%	9.50 Bolls Yield 1.06 bales/ha 9.48% +3.41%	1.38 Bolls Yield 0.15 bales/ha 1.35% +1.00%
Vegetative Branches and poorly developed fruiting branches without fruit 22.38 VB, 35.00 Bolls **VB Yield = 2.68 bales/ha** **23.89%** **+2.75%**			Total Mainstem Bolls = 95.63 Yield 8.54 bales/ha **76.11% -2.75%** **Total Bolls = 130.63** **Total Yield** **11.22 bales/ha** **-8.04%**
Mainstem Nodes **Cotyledonary Nodes**	**Position 1** 65.88 Bolls **Yield 6.22 bales/ha** **55.48%** **-1.43%**	**Position 2** 26.13 Bolls **Yield 2.14 bales/ha** **19.19%** **-1.63%**	**Position 3** 3.63 Bolls **Yield 0.17 bales/ha** **1.54%** **+0.31%**

Figure 35: Segmented pick, 2020/21 FB 7-12 (100%) (data are mean per metre of row). The yield for each stratum and each boll position is summarised in bold black figures. The percentage contributions of each segment (bales/ha) to total yield are signified in red, while the difference for each segment (bales/ha) from the figures in the Control treatment are shown in blue (Fig 22). Where the difference is significant (P=0.05), an asterisks has been placed next to the number of bolls for that segment.

Terminal	**Fruiting Position 1**	**Fruiting Position 2**	**Fruiting Position 3**
Fruiting Branch Nodes 17+ 4.38 Bolls **Yield 0.36 bales/ha** **3.71% +1.29%**	4.13 Bolls Yield 0.34 bales/ha 3.52% +1.84%	0.25 Bolls Yield 0.02 bales/ha 0.19% -0.55%	
Fruiting Branch Nodes 13-16 16.25 Bolls **Yield 1.66 bales/ha*** **16.91% +6.49%**	11.75 Bolls Yield 1.23 bales/ha* 12.56% +4.38%	3.63 Bolls Yield 0.39 bales/ha 3.96% +2.27%	0.88 Bolls Yield 0.04 bales/ha 0.36% -0.17%
Fruiting Branch Nodes 7-12 14.50 Bolls **Yield 1.58 bales/ha** **16.10% -27.30%**	7.88 Bolls* Yield 0.93 bales/ha* 9.52% -21.31%	4.88 Bolls* Yield 0.51 bales/ha* 5.18% -7.04%	1.75 Bolls Yield 0.14 bales/ha 1.40% +1.04%
Fruiting Branch Nodes 1-6 20.50 Bolls **Yield 2.45 bales/ha** **25.06% +2.44%**	12.63 Bolls Yield 1.54 bales/ha 15.70% -0.50%	6.38 Bolls Yield 0.78 bales/ha 7.95% +1.87%	1.50 Bolls Yield 0.14 bales/ha 1.42% +1.07%
Vegetative Branches and poorly developed fruiting branches without fruit 13.50 VB, 33.50 Bolls **VB Yield = 3.74 bales/ha** **38.22%** **+17.08%**			Total Mainstem Bolls = 55.63 Yield 6.05 bales/ha* **61.78% -17.08%** **Total Bolls = 89.13** **Total Yield 9.79 bales/ha** **-19.75%**
Mainstem Nodes **Cotyledonary Nodes**	**Position 1** 36.38 Bolls **Yield 4.05 bales/ha** **41.33%** **-15.58%**	**Position 2** 15.13 Bolls **Yield 1.69 bales/ha*** **17.27%** **-3.45%**	**Position 3** 4.13 Bolls **Yield 0.31 bales/ha** **3.18%** **+1.94%**

Figure 36: Segmented pick, 2020/21 FB 1-6 & 7-12 (33%) (data are mean per metre of row). The yield for each stratum and each boll position is summarised in bold black figures. The percentage contributions of each segment (bales/ha) to total yield are signified in red, while the difference for each segment (bales/ha) from the figures in the Control treatment are shown in blue (Fig 22). Where the difference is significant (P=0.05), an asterisks has been placed next to the number of bolls for that segment.

Terminal	**Fruiting Position 1**	**Fruiting Position 2**	**Fruiting Position 3**
Fruiting Branch Nodes 17+ 8.00 Bolls **Yield 0.69 bales/ha** **5.85%** **+3.43%**	6.63 Bolls Yield 0.60 bales/ha 5.11% +3.45%	1.38 Bolls Yield 0.09 bales/ha 0.73% -0.01%	
Fruiting Branch Nodes 13-16 23.38 Bolls **Yield 2.43 bales/ha*** **20.69%** **+10.27%**	15.00 Bolls Yield 1.63 bales/ha* 13.94% +5.73%	7.50 Bolls Yield 0.74 bales/ha 6.27% +4.58%	0.88 Bolls Yield 0.06 bales/ha 0.49% -0.04%
Fruiting Branch Nodes 7-12 36.88 Bolls **Yield 4.16 bales/ha** **35.50%** **-7.90%**	21.63 Bolls Yield 2.59 bales/ha* 22.12% -8.71%	12.75 Bolls Yield 1.36 bales/ ha 11.58% -0.63%	2.50 Bolls Yield 0.21 bales/ha 1.80% +1.44%
Fruiting Branch Nodes 1-6 15.31 Bolls **Yield 1.75 bales/ha** **14.94%** **-7.68%**	9.50 Bolls Yield1.16 bales/ha 9.89% -6.31%	4.88 Bolls Yield 0.51 bales/ ha 4.31% -1.77%	0.75 Bolls Yield 0.09 bales/ha 0.74% +0.39%
Vegetative Branches and poorly developed fruiting branches without fruit 17.00 VB, 26.88 Bolls **VB Yield = 2.70 bales/ha** **23.02%** **+1.88%**			Total Mainstem Bolls = 83.38 Yield 9.03 bales/ha **76.98%** **-1.88%** **Total Bolls =110.25** **Total Yield 11.73 bales/ha** **-3.87%**
Mainstem Nodes **Cotyledonary Nodes**	**Position 1** 52.75 Bolls **Yield 5.99 bales/ha** **51.08%** **-5.83%**	**Position 2** 26.50 Bolls **Yield 2.68 bales/ha*** **22.89%** **+2.16%**	**Position 3** 4.13 Bolls **Yield 0.35 bales/ha** **3.02%** **+1.79%**

Figure 37: Segmented pick, 2020/21 FB 1-6 & 7-12 (100%) (data are mean per metre of row). The yield for each stratum and each boll position is summarised in bold black figures. The percentage contributions of each segment (bales/ha) to total yield are signified in red, while the difference for each segment (bales/ha) from the figures in the Control treatment are shown in blue (Fig 22). Where the difference is significant (P=0.05), an asterisks has been placed next to the number of bolls for that segment.

Terminal	**Fruiting Position 1**	**Fruiting Position 2**	**Fruiting Position 3**
Fruiting Branch Nodes 17+ 16.88 Bolls **Yield 1.71 bales/ha*** **16.31% +13.88%**	12.25 Bolls* Yield 1.34 bal ha* 12.73% +11.05%	3.63 Bolls* Yield 0.32 bales/ha* 3.03% +2.29%	1.00 Bolls* Yield 0.06 bales/ha* 0.55% +0.55%
Fruiting Branch Nodes 13-16 21.38 Bolls **Yield 3.27 bales/ha*** **31.11% +20.69%**	10.13 Bolls* Yield 1.94 bales/ha 18.42% +10.21%	7.88 Bolls* Yield 1.06 bales/ha* 10.06% +8.37%	3.38 Bolls Yield 0.28 bales/ha* 2.64% +2.11%
Fruiting Branch Nodes 7-12 12.25 Bolls **Yield b1.69ales/ha*** **16.05% -27.34%**	5.13 Bolls Yield 0.84 bales/ha* 7.99% -22.84%	3.88 Bolls Yield 0.52 bales/ ha* 4.96% -7.25%	3.25 Bolls Yield 0.33 bales/ha 3.11% +2.75%
Fruiting Branch Nodes 1-6 3.75 Bolls **Yield 0.40 bales/ha** **3.79% -18.83%**	2.13 Bolls* Yield 0.26 bales/ha* 2.46% -13.73%	1.00 Bolls* Yield 0.08 bales/ ha* 0.74% -5.34%	0.63 Bolls* Yield 0.06 bales/ha* 0.59% -0.24%
Vegetative Branches and poorly developed fruiting branches without fruit 17.63 VB, 25.13 Bolls **VB Yield = 3.44 bales/ha** **32.74%** **+11.60%**			Total Mainstem Bolls = 54.25 Yield 7.07 bales/ha* **67.26% -11.60%** **Total Bolls = 79.38** **Total Yield 10.52 bales/ha** **-13.79%**
Mainstem Nodes **Cotyledonary Nodes**	**Position 1** 29.63 Bolls **Yield 4.38 bales/ha** **41.60%** **-15.31%**	**Position 2** 16.38 Bolls **Yield 1.98 bales/ha** **18.79%** **-1.94%**	**Position 3** 8.25 Bolls **Yield 0.72 bales/ha** **6.87%** **+5.46%**

Compensation Discussion

As expected, in undamaged plants Position 1 and 2 bolls of the lower 12 Fruiting branches constituted the core of the plant and were the main contributors to yield (Table 8). The next largest contribution was from bolls on vegetative branches and the remainder of yield was contributed by Position 3 bolls and bolls from FB 13 upwards. The summary in Table 8 shows how severity and timing of damage changes fruit development and contribution to yield, irrespective of the actual yield.

Table 8: Summary of yield contribution by different areas of cotton plants, ACRI, 2020/21

Treatment	Mainstem FB 1-12 P1&2	Vegetative Branches	Mainstem FB13+ P1,2 & 3
Control	65.32%	21.14%	13.55%
Fruit Removal @ FB 1-6 33%	59.23%	17.67%	23.09%
Fruit Removal @ FB 1-6 100%	47.22%	28.63%	24.17%
Fruit Removal @ FB 7-12 33%	60.28%	23.89%	13.83%
Fruit Removal @ FB 7-12 100%	38.35%	38.22%	23.45%
Fruit Removal @ FB 1-6 & 7-12 33%	47.90%	23.02%	29.08%
Fruit Removal @ FB 1-6 & 7-12 100%	16.15%	32.74%	51.13%

Irregular and early fruit loss (FB 1-6 @ 33%) does not markedly alter the within plant compensation across the three zones shown in Table 8. However, as the damage becomes more widespread (FB 1-6@100%), fruit loss from the core of the plant allows for more fruit to be formed on vegetative branches. Contribution to yield from a low level of insect damage through the mid-canopy later in the season (Fb 7-12@33%) was also similar to the Controls. On a larger scale again (FB 7-12@100%), fruit lost from the core of the plant resulted in more fruit on vegetative branches. At the lower level of extreme damage FB1-6 & 7-12@ 33%), plants responded in a similar manner as they did under a higher level of earlier damage (FB 1-6@100%) though less fruit was set on vegetative branches while more developed in the upper canopy. At the higher level of extreme damage (FB 1-6&7-12@100%), the core of the plant contributed a mere 16% to yield while the upper canopy and P3 fruit contributed 51% and vegetative branches the remaining 33%.

Insect damage is rarely a uniform occurrence throughout crops and mostly affects individual plants, however, compensation may occur at the plant or crop level (Wilson *et al.*, 2009). At the plant level, the alteration in plant architecture, growth dynamics and resource allocation pattern may allow plants to recover from damage. Because plants that lose fruit can invest more energy into leaf development, they should subsequently have advantages in light interception and soil resource acquisition. At the crop level, the differences in damage levels between plants affect plant-to-plant interactions and, concerning fruit loss, Sadras (1997) found that fruit numbers in plants damaged at 85 days after sowing could recover to the level of those in undamaged plants. Boll weight, however, was significantly reduced due to the limited time left in the growing season for recovery.

In our series of experiments we did not see significant compensation at the low damage levels that aimed to simulate insect damage but also did not see significant losses, hence, a small degree of early fruit loss can be tolerated. The question is one of risk as to how favourable the season may be with regards to additional abiotic stresses that cause fruit loss and hamper compensation at the higher levels of damage later in the season. Understanding compensatory responses and plant damage thresholds helps us to refine economic pest thresholds.

Milestone 4. Impact and IPM fit of various chemicals for SLW management

***MS 4.1 – Understanding and comparing the properties and efficacies of various registered chemicals for the control of SLW* - Heimoana**

At the time we began these experiments, the cotton industry was very familiar with the modes of action and efficacies of Admiral (Pyriproxifen) and Pegasus (Diafenthiuron) for SLW control. Other chemicals recommended for whitefly management in the CPMG were not used frequently, primarily due to a lack of experience with the chemicals by growers/consultants. Price differences also played a part. Our experiments aimed to better understand the activities of these chemicals so that industry would have the full benefit of a wider range of IPM suitable products.

Whitefly management has become more difficult with the increasing resistance to pyriproxifen in some regions and the increasingly harsher management of early-season pests such as thrips, cutworm, wireworm and mirids. The use of pesticides at planting, compounded by several applications of low rate (+ salt) "soft" sprays are likely to affecting the build-up of effective predator populations. Resistance in SLW against pyriproxyfen is also on the increase. In this experiment we wanted to apply season insecticides such as Regent (Fipronil) for mirids to see how this affects beneficials and the related whitefly population increase (we were trying to increase whitefly populations to a spray threshold) hence the crop was monitored closely around flowering for mirids. We also used a range of insecticides for whitefly management, ideally applied in optimum conditions, i.e. based on thresholds and pest developmental stages. We expected crop penetration of chemicals to be an important issue later in the season.

Experiments F (2018/19), G (2019/20) and H (2020/21)

Materials and Methods
The experiments were set up in four randomised complete blocks (6 trts x 4 reps = 24 plots) with plot size of 8 rows x 15 m + 2 m buffer. At the beginning of January, experiments were artificially infested with Silverleaf whitefly. Populations were monitored for spraying once insect numbers had reached threshold.

Treatments
Commonly used insecticides for SLW control include Pyriproxifen (Admiral, Lascar) and Diafenthiuron (Pegasus). Due to space restrictions, we omitted Admiral in the experiment as its mode of action and efficacy are well known. Instead, we included another hormone-based spray, buprofezin (Applaud). Chemicals tested in these experiments are listed in Table 9. Sprays were applied with a Spraying Mantis 8-line rig calibrated to 3 bar, groundspeed of 5.0 km/hr, using Spraying Systems hollow cone TX4 nozzles at 2 nozzles/m.

Measurements taken included:

- Score for adult SLW on 15 leaves for node/leaf 11 (from the top) in centre rows alternating between (Rows 3& 4 & Rows 5 & 6) weekly.
- Assess leaf 11 for SLW nymphs in lab & record

- Collect 15 x Leaf 4 and wash for mites/thrips/aphids
- 1 Beat sheet per plot alternating weekly between rows 3 & 6. Beat sheet from opposite rows that leaves were collected in that week.
- Machine pick rows 4&5

Table 9: Chemicals (active ingredient g/ha) and product rates included in the Whitefly x Chemistry Experiments 2018/19 to 2020/21

Product	2018/19	2019/20	2020/21
Admiral (Pyriproxifen)			50 g ai/ha 500 ml/ha
Applaud (Buprofezin)	440 g ai/ha 1L/ha	440 g ai/ha	440 g ai/ha
BioPest Oil	815 g ai/ha 2L/ha	815 g ai/ha	815 g ai/ha
Exirel & Hasten (Cyantraniliprole)	60 g ai/ha 600 ml/ha (500 ml/100L)	100 g ai/ha 600 ml/ha (500 ml/100L)	100 g ai/ha 600 ml/ha (500 ml/100L)
Exirel & Pulse			60 g ai/ha 600 ml/ha (@ 2%)
Mainman (Flonicamid)	70 g ai/ha 140 g/ha	70 g ai/ha	70 g ai/ha
Movento & Hasten (Spirotetramat)	27 g ai/ha 300 ml/ha (200 ml/100L)	27 g ai/ha 300 ml/ha (200 ml/100L)	27 g ai/ha 300 ml/ha (200 ml/100L)
Movento & Pulse			27 g ai/ha 300 ml/ha (@ 2%)
Pegasus (Diafenthiuron)	300 g ai/ha 600 ml/ha	300 g ai/ha 600 ml/ha	300 g ai/ha 600 ml/ha
Starkle (Dinotefuran)	50 g ai/ha 250 g/ha	50 g ai/ha 250 g/ha	50 g ai/ha 250 g/ha
Sero X (*Clitoria ternatea*)		800 g ai/ha 2 L/ha	800 g ai/ha 2 L/ha
Seasonal conditions and Sprays against beneficials	Hailstorm destroyed crop in December, no opportunity to re-plant, re-used ES experiment (prior effects), waited for numbers to build, then rain and cool nights dropped numbers. Predator control: Fipronil x 2	Re-plant, severe drought impacted on rearing SLW, eventually got numbers, then rain and cold. Predator control: Fipronil x 2	Re-plant, Expt rained out, high predator numbers , parasitoids uncontrollable. Predator control: Fipronil x 2 Propargite x1 Amitraz x 1 Spinetoram x 1

Results

Our biggest challenge over the three years of executing this experiment was the successful infestation of the field with high SLW populations, on which any sprays and observations relied. Despite artificial infestations with glasshouse reared SLW, control of beneficials with harsh chemicals, slashing of nearby infested fields and reinfestation, we could not generate large enough infestations to be confident about differences (or lack of differences) between treatments. The annual build-up of SLW numbers is illustrated in Figures 38-40. Whitefly numbers were decreasing through consecutive years from 10-20/leaf in 2018/19 to fewer than 1.5/leaf in 2020/21 despite the increasing spray regime against beneficials (Table 9 bottom). In both years where the scheduled insecticide sprays were applied, differences between them were generally not significant with respect to SLW control. However, Starkle had significant negative effects on jassids, mirids, ADB and total Hemiptera Pests while Pegasus and

Applaud had significant negative effects on jassids, total Hemiptera Pests and other Ladybird beetles (LB, Fig. 41). Starkle also impacted negatively on total beneficial numbers compared to the Control, Applaud and Movento (Table 10). Most noticeable is the graph for 2020/21 which, if drawn out to the right would show nearly flat lines with SLW not exceeding 1.5 SLW/leaf. Unsprayed control treatments follow the same trend as sprayed plots, indicating that seasonal conditions coupled with high beneficial numbers have greater effects than chemical sprays.

Beneficials collected from beat sheets included Apple Dimpling bugs, Big-eye bugs, Pirate bugs, Damsel bugs and other predatory Hemiptera, Red and blue beetles and Coccinellids, lacewings, ants and spiders. Total beneficial numbers recorded are shown in Figures 42-44. For the first two seasons, beneficial numbers averaged 10-25 per metre (not including parasitoids in SLW nymphs a parasitism was low) despite 2 sprays of Fipronil (Regent) to suppress them. Starkle significantly reduced total beneficial numbers in 2018/19 (Table 10), while Movento, Applaud and the Control had the least effects. During 2020/21, beneficial numbers included parasitoids in SLW nymphs and increased throughout the season to up to 35 per metre, despite 5 applications of harsh insecticides, including spinetoram which is hard on wasps (sprayed 08/03/2021). These applications, however, appeared to have minimal effects on beneficials including Coccinellids, Red & blue beetles and spiders (Fig. 45).

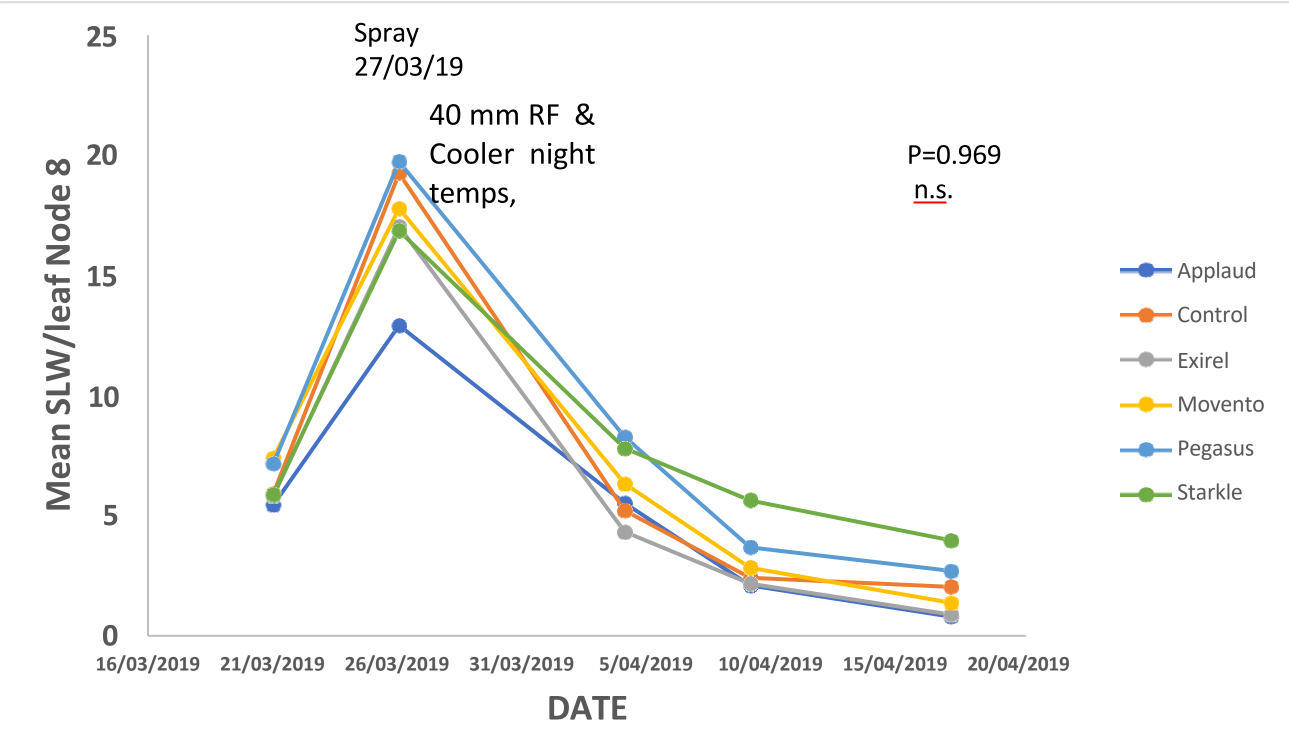

Figure 38: Effect of various chemicals on SLW infestation (adults & nymphs), ACRI 2018/19

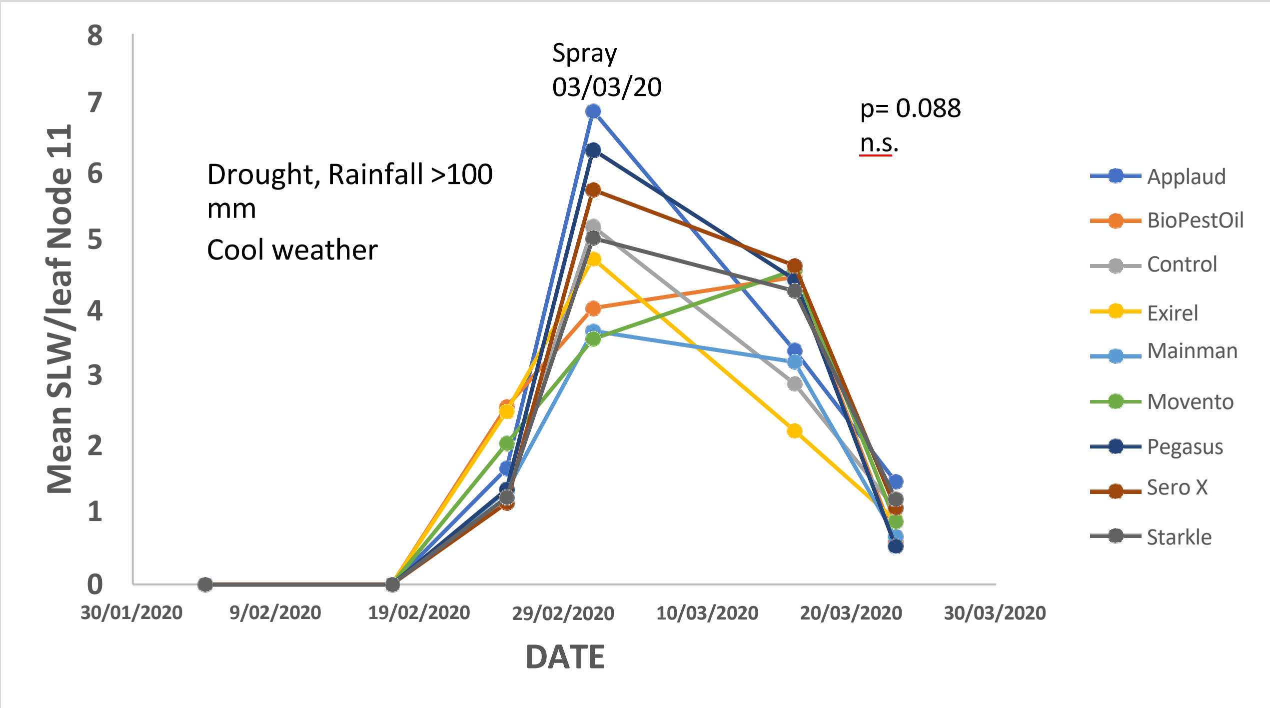

Figure 39: Effect of various chemicals on SLW infestation (adults & nymphs), ACRI 2019/20

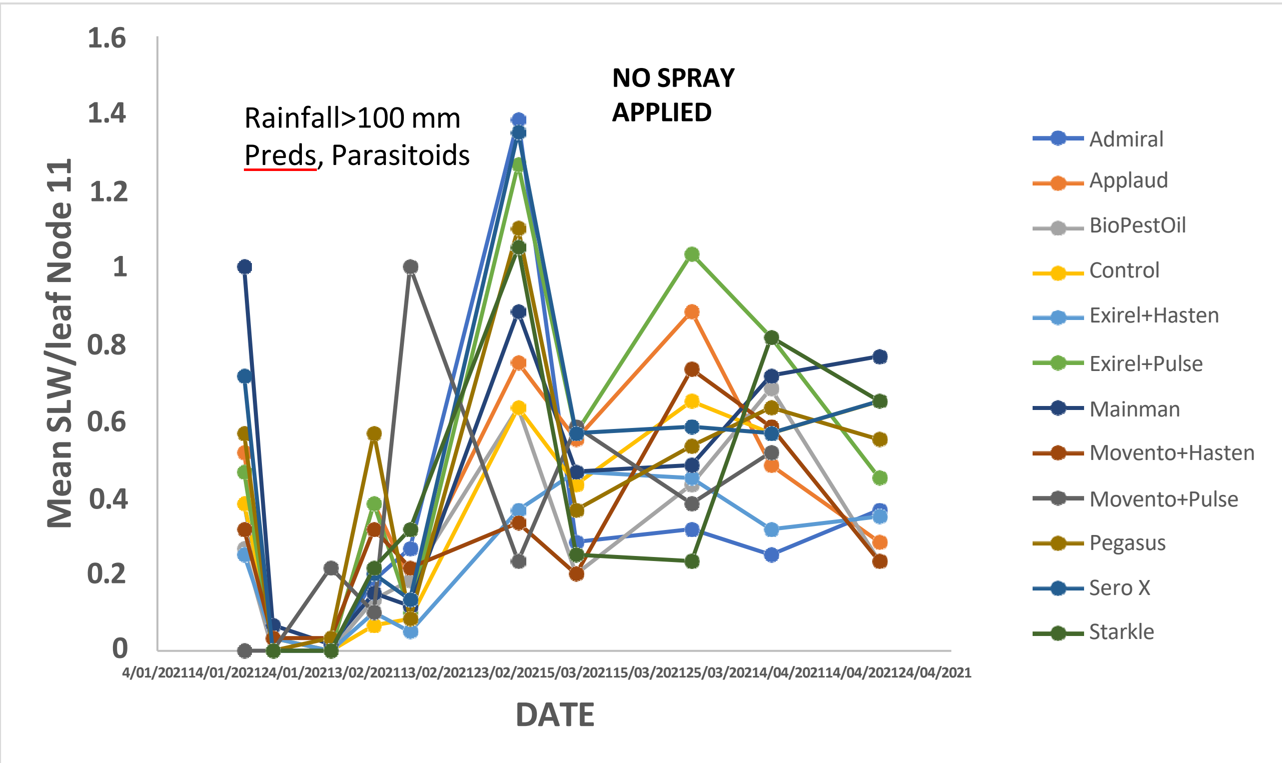

Figure 40: Effect of various chemicals on SLW infestation (adults & nymphs), ACRI 2020/21

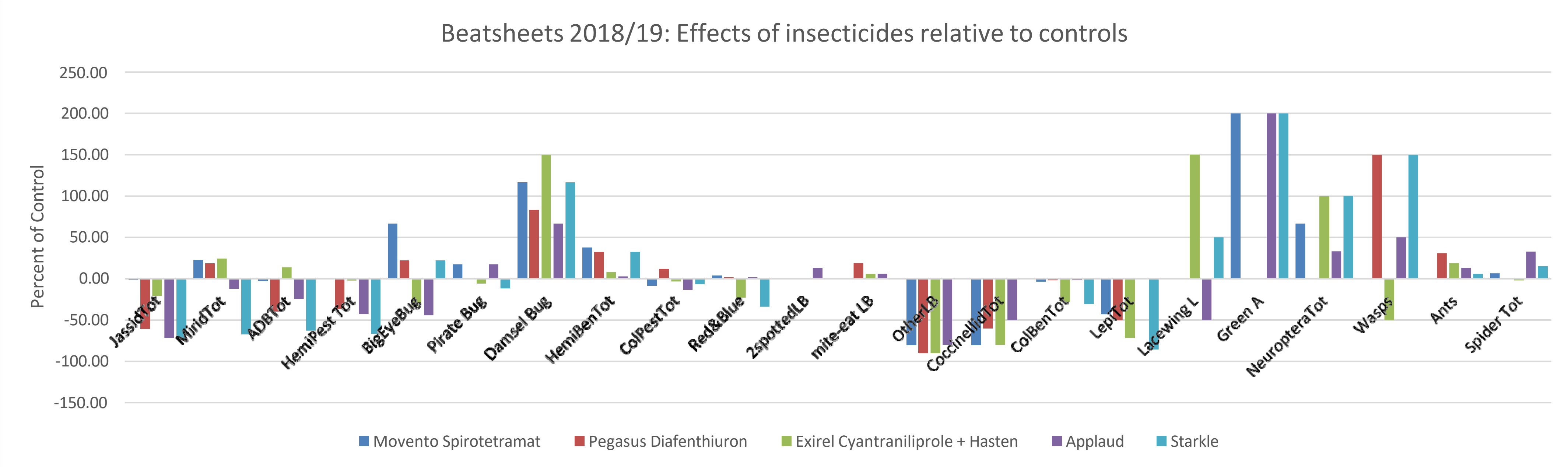

Figure 41: Effects of insecticides relative to controls. Starkle had significant negative effects on jassids, mirids, ADB and total Hemiptera Pests. Pegasus and Applaud had significant negative effects on jassids, total Hemiptera Pests and other Ladybird beetles (LB).

Table 10: Effect of insecticides on total beneficial numbers 26/03/2019 to 17/04/2019

	Control	Applaud	Exirel + Hasten	Movento	Pegasus	Starkle
Total mean Beneficials/m	18.00	17.81	17.19	18.81	17.00	14.06*
P (0.05)	<0.001					
df	(5, 95)					
LSD	3.20					

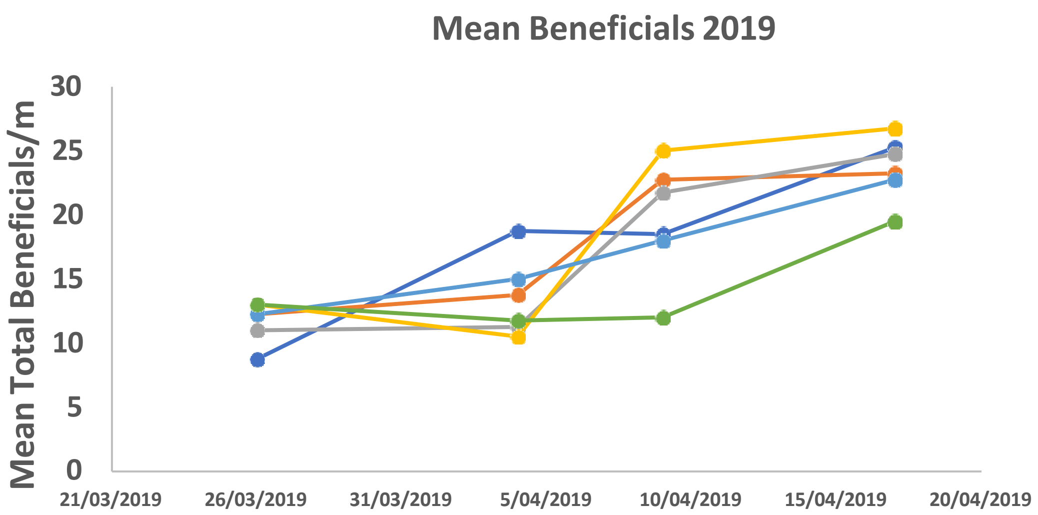

Figure 42: Mean beneficial numbers ACRI, 2018/19

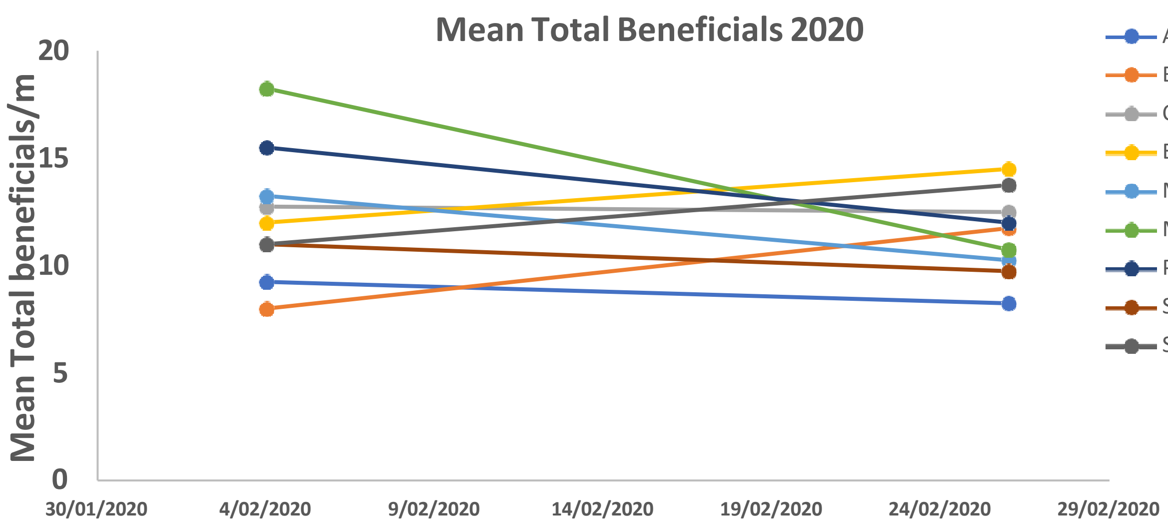

Figure 43: Mean beneficial numbers ACRI, 2019/20

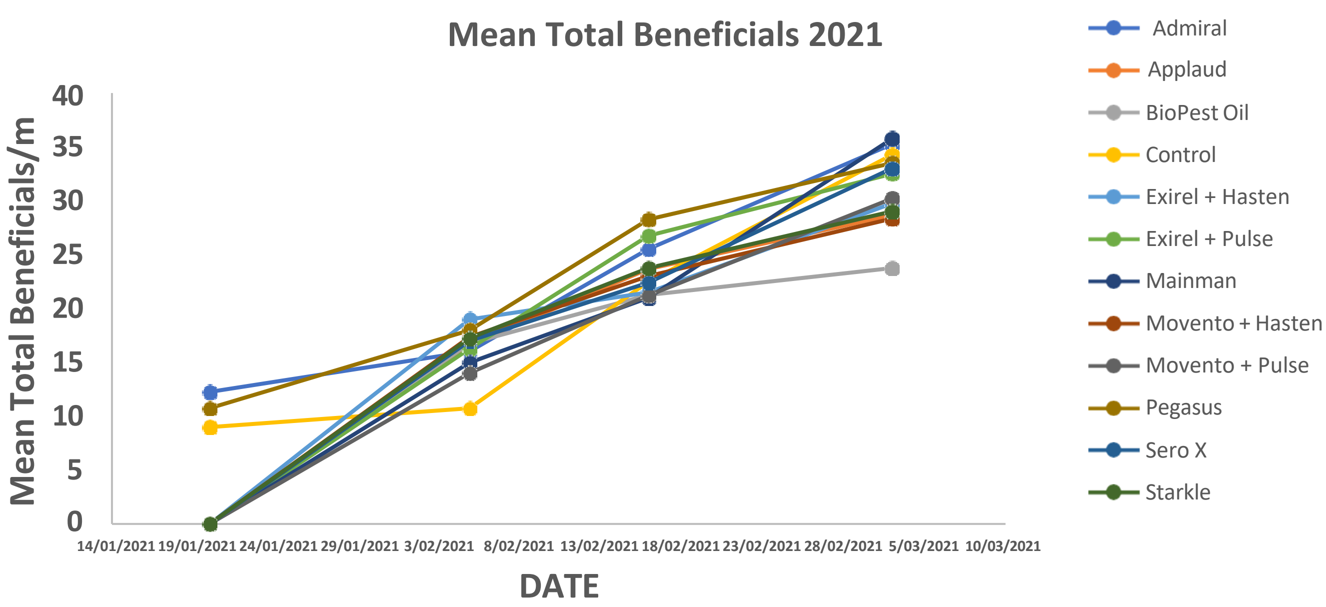

Figure 44: Mean beneficial numbers ACRI, 20120/21

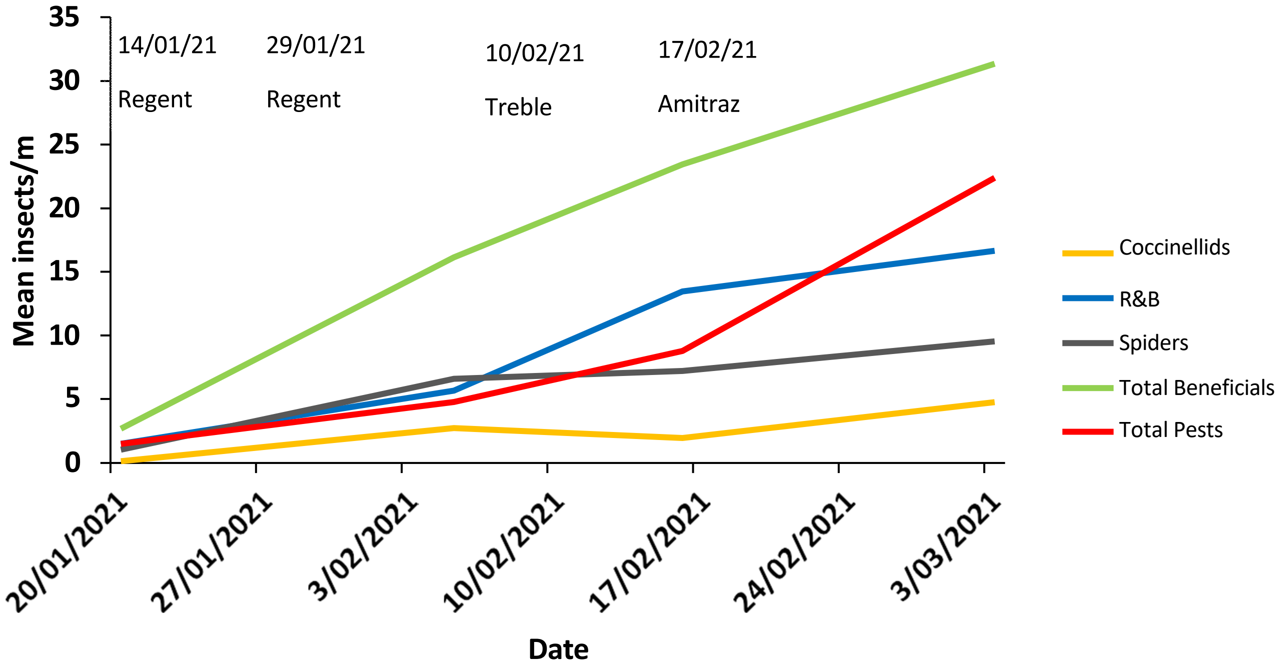

Figure 45: Effect of Regent, Treble and Amitraz on Coccinellids, Red & Blue beetles and spiders. These sprays were applied to reduce predators and parasitoids to enable SLW to establish.

Summary Discussion

In both years where sprays were applied, differences between insecticides were not significantly different from each other or the unsprayed control. Our trial did show that the naturally occurring predators and parasitoids, if not interfered with, are able to control pest numbers. Our experimental blocks are located along the river where native vegetation provides good habitat for beneficials which can move in and out of our field. We see this as an advantage even though river blocks along the Gwydir River reportedly suffer from significant stink bug infestations. This may be due to the presence of African boxthorn (*Lycium ferocissimum*) along the banks, which are preferred breeding hosts of several shield bugs. We do not have this problem along our stretch of the Namoi River. Secondly, we plant sunflowers as buffer rows throughout our experiments which act as refuges and sources of beneficials early in the season. Once past flowering, sunflowers, however, are also good hosts of mites hence are not suitable in a commercial situation. Thirdly, most of the block does not get sprayed. Only certain experiments require selective spraying of small areas, so most of the field acts as a refuge for beneficials. In two out of three experiments, lower night temperatures were not conducive to SLW development and such effects should be considered for late plantings.

High beneficial numbers alone cannot be the only reason why it is now harder to artificially infest fields with SLW using tried and tested methods that have worked well before 2019/20. We have now carried out SLW research at ACRI for the past 12 years. During this time Bollgard 3 was introduced in 2016/17. Two years later, we have difficulties infesting and growing SLW in the field. The same scenario happened with our aphid research which was very successful due to our ability to mass rear aphids in the field. We studied aphids intensively in the field between 1998/99 and 2005/06, when in 2003/04 Bollgard II was introduced. In 2004/05 we had trouble getting field infestations established and by 2005/06 they were impossible as aphids were eaten as soon as they were placed in the field. What this highlights is the importance of landscape factors and IPM tools (GM cotton), and this knowledge should play a major part in the development of better pest management strategies.

Experiment I: Silverleaf Whitefly App Testing 2019-20

Good management of SLW depends on regular and reliable monitoring, which is labour intensive. For each 25 ha of cotton, 20-30 leaves must be assessed visually to estimate SLW nymph numbers and anticipate population changes. For agronomists this results in hundreds of leaves each week. To assist with this task, USQ and Queensland DPI have developed an app that uses image analysis to detect SLW nymphs on the underside of cotton leaves. Such models are normally based on standardised images and do not consider image capture under field conditions. We were requested by USQ to test the app in the field and provide feedback on accuracy by comparing manual nymph counts to numbers produced by the app. Preliminary image analysis from smartphone images demonstrated ability to achieve up to 75% detection rate of silverleaf whitefly nymphs on the underside of cotton leaves.

Methods

We collected 100 leaves from the lower canopy of our SLW x Chemistry experiment on two dates and estimated nymph numbers using the app. We then counted the actual number of nymphs on each leaf and analysed the data.

Results and Discussion

Between the 19/02/20 and the 27/02/20, nymph numbers reduced significantly in actual and App counts. Actual counts reduced from 10.01 nymph/leaf to 5.45 nymphs/leaf ($P=0.002$, df (1,198) while App counts reduced from 4.77 nymphs/leaf to 1.25 nymphs/leaf ($P<0.001$, df (1, 498). Regression of actual against estimated nymph counts gave an R^2 of 0.517 (Fig. x) which means that the App only captured about 51% of the nymphs on leaves. Some of the reasons for the poor performance of the App were probably picture quality which can be influenced by light and angle of photograph, imperfections on the leaf that may be mistaken by the App for whitefly and counting of other pests such as aphids. We provided feedback to USQ for improvement of image capture.

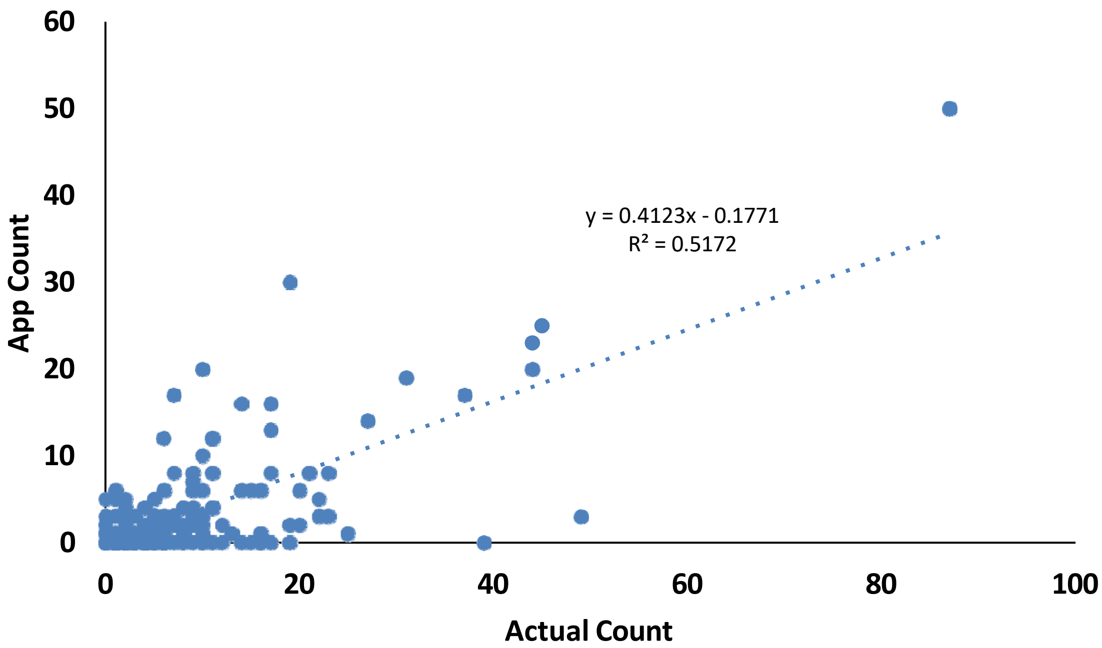

Figure 46: Comparison between Silverleaf whitefly nymph visual counts and nymph numbers detected by the App.

Milestone 5: Support new IPM tactics and enhance IPM best practise

MS 5.1 Comparing profit/ha - **Whitehouse**

NOTE: The actual survey was not conducted and the development of the survey was the output for this milestone. The milestone was changed in the variation document.

Our incentive-based approach to enhance IPM best practice focussed on exploring the economic benefits of IPM to individual growers, especially long term; and encouraging realistic expectations of yield based on seasonal constraints. In consultation with Mr Ben Simpson (CRDC) and Ms Janine Powell (AgEcon) we developed a survey instrument to identify whether an IPM approach to growing cotton is costly (or whether there is no correlation in cost). We sought an ethics approval to conduct this research and one was granted internally within CSIRO. However, due to the departure of Mary Whitehouse from CSIRO the survey was never conducted. Substantial time was invested to develop the approach and questionnaire, the details of which are provided below.

The survey was developed in the context of it being an IPM Profitability case study (see Appendix C for the questionnaire). The aim of the case study was to identify if there is a direct cost or economic benefit to growers using IPM strategies to grow Bt cotton at the farm level, focusing on the 2019/20 season.

The case study first part aimed to clarify a grower's perspective on IPM approaches to cotton pest management. We aimed to target grower's that were spread along a spectrum of being more likely to less likely to use an IPM approach.

The second part records the inputs involved with growing cotton. All input costs would be calculated from AgEcon's estimation of the Cotton Industry Gross Margins standard rates (to remove the effect of particularly good or bad deals individual growers may have obtained). So it would not necessarily reflect the grower's actual costs, but their choices. Likewise, the income from the cotton produced would be calculated using the spot price Base Grade price for the month the cotton was harvested. This removes the effect of forwards selling.

We would then use a regression analysis of the combined data from all participants to compare the calculated costs and benefits (gross margin/ha) with the calculated IPM affinity (see questionnaire for the affinity scores), to gauge if following an IPM strategy was more or less costly in the 2019/20 season.

Consequently, the results that would be calculated from the information provided would not be personalized cost and benefits, but would allow us to compare, on an even playing field, standardized costs and benefits of different IPM approaches. All data would be aggregated for reporting purposes to ensure you remain de-identifiable.

The intent was to ask several growers to fill out the questionnaire as part of a 60-minute face to face interview. The 30 participants would be strategically sampled from the project teams existing professional network which include growers who have voluntarily participated in prior CSIRO research in the past, and some people who have links to Area-Wide Management groups.

Results and discussion

To maintain a sustainable approach to growing cotton, the industry encourages the use of Integrated Pest Management (IPM) to control pests. However, there is a perception that an IPM approach costs more. If the industry wants growers to be sustainable, it needs to know if an IPM approach is costly. If it is more costly, then the industry can add incentives to encourage IPM. The approach and questionnaire developed within this study would enable an estimate to be placed on this key farming practise.

Milestone 6: Support the continued development of existing industry education initiatives

This work was detailed in a report provided to CRDC in November 2021. The report by Trudy Staines CSP1905 “Developing Capability to Service the Cotton Industry”. Staines and her collaborative partners conducted a series of activities including:

- EnviroStories Readers
- The graduate forum
- Promotion at Career Expos
- School Visits and workshops
- STEM professional events
- Industry Tours
- Student Work Experience and Placements
- Presentations on a range of topics

This has helped to create cotton industry advocates that are well informed as well as a more scientifically aware community. This project has had an impact on attracting, retaining, and developing highly educated, qualified, and skilled employees, increasing our competitive advantage, and making the cotton industry an employer of choice.

Acknowledgements

Mary Whitehouse:

Thanks to Trudy Staines, Karen Stanford, Abbey Johnston and Jade Williams for technical support; Sharon Downes for comments on the report; CRDC and CSIRO for funding the work, and Kieran O’Keeffe and IREC for logistical support at Griffith and the use of the IREC Field Station.

Simone Heimoana:

I would like to thank CRDC for funding this project and CSIRO for its co-investment and support through two very difficult years, due to COVID-19 and deep personal stresses. My sincere thanks to my team – Tanya Smith, Ammie Foster, Dee Hamilton and Tianne Parker – for all their support, understanding and carrying on with the jobs at hand. I also thank Dr. Sharon Downes and Sarina Macfadyen for their consistent support and assistance in finalising this project report. I appreciate the help from our seasonal technical support staff Shoobie Hamilton and Casey Van Drie.

We are also grateful to Auscott for providing space for our experiments after the hailstorm and the CSIIRO Breeding team for helping with planting and harvesting. Thanks to NSW DPI farm management for routine field preparation and maintenance and irrigation.

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Part 4 – Summary for public release

Project title:	*Error! Reference source not found.*	
Project details:	CRDC project ID:	***Error! Reference source not found.***
	CRDC goal:	*1. Increase productivity and profitability on cotton farms*
	CRDC key focus area:	*1.3 Protection from biotic threats and environmental stresses*
	Principal researcher:	*Simone Heimoana*
	Organisation:	***Error! Reference source not found.***
	Start date:	*01/07/2018*
	End date:	*30/06/2021*
Objectives	The main objective of this project was to generate new scientific knowledge to support Integrated Pest Management (IPM) practice and continued adoption, and to update IPM tools. Experiments were designed to improve understanding of pest x beneficial x plant x environment /climate interactions. Objectives for Part one were: • To investigate the impact of novel insecticides on target pests and beneficials. • To understand the effects of pesticides on invertebrate communities in the cotton production system • To measure the impact of physiological stress/pest damage interactions and understand when and how plants compensate for damage. • To develop an incentive-based approach to enhance IPM best practice A second objective related to the attraction, retention and development of educated and highly qualified workers to support the cotton industry. This part of the project was detailed in a report CSP1905 "Developing Capability to Service the Cotton Industry". Objectives for Part 2 were: • To inspire and educate children about popular topics in agriculture as a pathway to future careers in the cotton industry via IPM training activities • To support and mentor students that are at an early phase in their career and link them with agricultural investments in education and business.	
Background	The use of *Bt* varieties has drastically reduced insecticide sprays for the primary pest on cotton farms improving yield and profitability. Research in this project focused on complex interactions between secondary pests and abiotic factors unique to each season. Adding new knowledge in this area aimed to help maintain and improve IPM practices and encourage adoption.	
Research activities	Research activities included on-station and on-farm replicated experiments to manipulate real pest species and simulate pest damage, on-station experiments to assess novel insecticide impacts on beneficials, and on-farm surveys of invertebrate communities. We developed a survey tool to assess attitudes towards IPM, and we made significant contributions to industry responses and plans for exotic pest threats.	
Outputs	Research outputs involved the creation of new knowledge that will contribute to the better management of complex scenarios. They included: • Evaluation of the effects of new pesticide compounds on non-target species (predators and parasitoids) and ranking them according to a standardised system (Cotton Pest Management Guide Table 4). • Comparing the effects of insecticides specifically aimed at controlling silverleaf whitefly (SLW) given the risk of resistance to some commonly used products. Low SLW numbers in the field largely hampered comparisons between chemicals, however, we gained insights into the important role that beneficials play in the build-up of SLW populations, and we can infer that the preservation of predator and parasitoid populations is an important part of preventing SWF outbreaks as is the proximity of non-crop areas for replenishment.	

	• Testing an app that assessed SLW nymphs on leaves to make SLW monitoring more time efficient. The app captured about 51% of the variance of the nymphs on leaves. However, with refinement, these types of tools will become increasingly important for monitoring pest populations. • Conducting experiments that assessed plant responses of BG3 Cotton to tipping damage and fruit loss. A one-off tipping event between nodes 5 and 7 had overall no effect on maturity, boll number, boll weight and yield showing either a loss or slight compensation of less than 1 bale/ha. Across three seasons our data shows that early fruit loss in the lower part of the crop does not impact negatively on yield with variations of less than 1 bale/ha suggesting that a low level of insect damage can be tolerated. Maturity delays were not significant. Fruit loss from FB 7-12 and/or a higher proportion of the crop reduced yield and extended maturity significantly and has the potential to incur greater loss, especially in high yielding crops. In undamaged plants, Position 1 and 2 bolls of the lower 12 Fruiting branches were the main contributors to yield followed by bolls on vegetative branches and then Position 3 bolls and bolls from FB 13 upwards. Severity and timing of damage changes fruit development and contribution to yield, irrespective of the actual yield. • Testing the effect of simulated cloudiness and mirid damage on cotton yield. Plants can compensate for both factors in a controlled environment without yield reduction • Contributing to the Australia-wide response of the arrival of exotic fall armyworm and to cotton industry plans to respond to future threats like blue disease. • Developing a survey to explore the economic benefits of IPM to growers.
Impacts	Our work from this project gives further evidence that growers' pest management decisions early season can greatly impact outcomes at the end of the season. Considering that plants can compensate for low levels of insect and/or abiotic damage, some pest thresholds (e.g. mirids) may be reconsidered, given there was a better understanding of their population dynamics and damage pattern, which would warrant focused research. We added three more products to Table 4 in the Cotton Pest Management Guide increasing options to chose IPM friendly pesticides. Coincidentally we showed that SLW management can be greatly enhanced by building and maintaining high predator and parasitoid populations throughout the season. We supported further development of the SLW app to improve monitoring in the field. Our activities in the biosecurity field continue to represent and support the cotton industry. We prepared a survey to identify whether an IPM approach to growing cotton is costly, that is ready to be implemented if industry interest exists.
Key publications	Heimoana, S.; Wilson, L.J. *et al.* (2018-2021). Impact of insecticides and miticides on predators, parasitoids and bees in cotton. In: The Australian Cotton Industry CottonInfo Team (eds) Cotton Pest Management Guide 2019-20 (also 2020-21). Cotton Research and Development Corporation, pp 10-11. Whitehouse, M.E.A. 2019. The mirid Challenge – Does cloudiness affect mirid damage in the Murrumbidgee? IREC Farmer's Newsletter no. 202:9-11. Sequeira, R., Whitehouse, M.E.A., Williams, S., Maas, S. 2018. Revised mirid spray thresholds – what they mean and how to use them. *The Australian Cottongrower* 39(3): 42-45. Thomas, A., Williams, S., Whitehouse, M., Dickinson, S., Twine, A. 2018. Does high mirid pressure at early squaring have an effect on yield? *The Australian Cottongrower* 39(4): 28-31. Downes, S*., et al*.. 2018. Terminating the mega-pest. Biosecurity a key to effective Integrated Pest Management. *The Australian Cottongrower* 39(4): 14-17.

APPENDIX A: Table 4 Impact of insecticides and miticides on predators, parasitoids and bees in cotton

Appendix B

Table B1: Canopy invertebrates sampled, including common name, scientific name, and shortened name used in ordination figures. Their roll within the cotton community (as "pest" "beneficial" or "other" is also identified.

Pest/ Other/ Benefical	Common name	Scientific classification	Short Name
P	helicoverpa Larvae	Insecta: Lepidoptera:Helicoverpa	HeliLar
P	helicoverpa moth	Insecta: Lepidoptera:Helicoverpa	HeliMoth
P	other caterpillars	Insecta: Lepidoptera: other	OthrCat
P	Other Moths	Insecta: Lepidoptera: other	OthrMoth
P	Mirids adults	Insecta: Hemiptera: Creontiades	MiridAdul
P	Mirid nymphs	Insecta: Hemiptera: Creontiades	MiridNymp
P/B	Apple Dimpling Bug	Insecta: Hemiptera:Campylomma	ADB
P	broken back bug	Insecta: Hemiptera:Taylorilygus	BBB
P	cotton seed bug	Insecta: Hemiptera:Osycarenus	CotSeeBg
P	Cricket	Insecta: Orthoptera:Ensifera:Gryllidea:Gryllidae	Cricket
P	Flea beetle	Insecta: Coleoptera:Chrysomelidae:Alticini	FleaBeet
P	Green Veggie Bug	Insecta: Hemiptera:Pentatomidae	GVB
P	Jassids	Insecta: Hemiptera:Cicadelliae	Jassids
O	Pollen/Flower Beetle	Insecta: Coleoptera:Nitidulidae	PollBeet
P	Red banded shield bug	Insecta: Hemiptera:Pentatomidae	FlwrBeet
P	Rutherglenbug	Insecta: Hemiptera:Lydaeidae:Nysius	Ruthergl
P	Shiny Beetle	Insecta: Coleoptera	ShinyBeet
P	Thrips	Insecta: Thysanoptera: Thripidae	Thrips
P	Weevils	Insecta: Coleoptera:Curculionidea	Weevils
P/B	others	Insecta	others
B	Common Spotted ladybug	Insecta: Coleoptera:Coccinellidae	ComLV
B	Hippo Ladybug	Insecta: Coleoptera:Coccinellidae	HippoLB
B	Stethorus Ladybug	Insecta: Coleoptera:Coccinellidae:stethorus	StethLD
B	Striped Ladybug	Insecta: Coleoptera:Coccinellidae	StrpdLB
B	3-Banded Ladybug	Insecta: Coleoptera:Coccinellidae	3-BandLB
B	Transverse Ladybug	Insecta: Coleoptera:Coccinellidae	Transver
B	Variable ladybug	Insecta: Coleoptera:Coccinellidae	VarLB
B	Diomus ladybug	Insecta: Coleoptera:Coccinellidae	Diomus
B	Ladybird larvae	Insecta: Coleoptera:Coccinellidae	Lblar
B	Big Eyed bug	Insecta: Hemiptera:Geocoridae:Geocoris	BEB
B	brown smudge	Insecta: Hemiptera:Deraeocoris	BrownSm
B	Damsel bug	Insecta:Hemiptera:Nabidae	nabis
B	glossy shield	Insecta: Hemiptera:Pentatomidae:Cermatulus	GlosShld
B	pirate bug	Insecta: Hemiptera:Orius	Piratebug
B	predatory shield	Insecta: Hemiptera:Pentatomidae	PredShield
B	Red & Blue beetle	Insecta: Coleoptera:Melyrdae:Dicranolaius	red/blue
P/B/0	other beetles	Insecta: Coleoptera	OthrBeet
P	other bugs	Insecta: Hemiptera:	OthrBug
B	lacewing egg	Insecta: Neuroptera:	LacewgEgg
B	lacewing larvae	Insecta: Neuroptera:	LacewgLar
B	Brown Lacewing	Insecta: Neuroptera:Hemerobiidae	Blacew
B	Green Lacewing	Insecta: Neuroptera:Chrysopoidea:Mallada	GLacew
P/B	ants <2mm	Insecta: Hymenoptera:Formicidae	ants<2mm
P/B	ants 3-4mm	Insecta: Hymenoptera:Formicidae	ants3-4mm
P/B	other ants	Insecta: Hymenoptera:Formicidae	othr ants
B	Hoverfly larvae	Insecta:Diptera:Syrphidae	Hoverfly
B	Orb weaver	Arachnida:Araneae:Araneidae/Tetragnathidae	OrbWeav
B	Yellow night stalker	Arachnida:Araneae:Clubionidae	ClbNigSt
B	Wolf spider	Arachnida:Araneae:Lycosidae	WolfSpid
B	Lynx spider	Arachnida:Araneae:Oxyopidae	OxyoSpid
B	Jumping spider	Arachnida:Araneae:Salticidae	SaltSpid
B	Tangle web spider	Arachnida:Araneae:Theridiidae/Linyphiidae	TherSpid
B	Crab spider	Arachnida:Araneae: Tomisidae	TomSpid
B	Other spiders	Arachnida:Araneae:	otherSpid
B	Jumping spiders	Arachnida:Araneae:Salticidae	SaltSpid
B	Parasitoids	Insecta: Hymenoptera:	Parasito
B	Other wasps	Insecta: Hymenoptera:Other	OthrWasp
P	Flies	Insecta:Diptera	Diptera

Table B2: Pitfall trap invertebrates sampled, including common name, scientific name, and shortened name used in ordination figures.

Common name	Scientific classification (Usually class: Order: family: Genus)	Short Name
Pseudoscorpion	Arachnida:Pseudoscorpiones	AracPSco
Scorpion	Arachnida:Scorpiones	AracScor
Mite/Tick	Arachnida:Acari	AracAcari
Wolfspider	Arachnida:Araneae:Lycosidae: Hogna Crispipes	LHogCris
Wolfspider	Arachnida:Araneae:Lycosidae: Hogna Kuyani	LHogKuya
Wolfspider	Arachnida:Araneae:Lycosidae: Hogna SP	LHognaSP
Wolfspider	Arachnida:Araneae:Lycosidae: Venatrix Konei	LVenKone
Wolfspider	Arachnida:Araneae:Lycosidae: Venatrix Fontis	LVenFont
Wolfspider	Arachnida:Araneae:Lycosidae: Venatrix SP	LVenatSP
Large wolfspider	Arachnida:Araneae:Lycosidae: Tasmanicos Leuckarti	LTasLeuc
Smaller Wolfspider	Arachnida:Araneae:Lycosidae: Artoria SP	LArtorSP
Smaller Wolfspider	Arachnida:Araneae:Lycosidae: Artoriopsis SP	LArtopSP
Smaller Wolfspider	Arachnida:Araneae:Lycosidae: Anomalosa SP	LAnomaSP
Wolfspider	Arachnida:Araneae:Lycosidae: UNKNOWN	LycoUNKN
Jumping spider	Arachnida:Araneae:Salticdae	Salticid
Lynx spider	Arachnida:Araneae:Oxyopidae	Oxyopid
Black ground running spider	Arachnida:Araneae:Zodariidae	Zodariid
White-tailed spider	Arachnida:Araneae:Lamponae	Lampona
Orb web spider	Arachnida:Araneae:Araneidae	Araneid
Ground running spider	Arachnida:Araneae:Gnaphosidae	Gnaphosid
Mesh-webbed spider	Arachnida:Araneae:Dictynidae	Dictynid
Unknown spider	Araneae Unknown	AraneaUN
Cockroach	Insecta: Blattodea:Cockroach	Blattode
Termite	Insecta: Blattodea:Termitoidae	BlatTerm
Ant-like flower beetles	Insecta: Coleoptera:Anthicidae:Anthicus	CAnthici
Auger beetles	Insecta: Coleoptera:Bostrichidae	CBostric
Carab beetles	Insecta: Coleoptera:Carabidae:Other	CCarabid
Ant Nest Beetle	Insecta: Coleoptera:Carabidae:Arthropterus	CCarArth
Green carab beetle	Insecta: Coleoptera:Carabidae:Calosoma	CCarCalo
Big shiny green carab beetle	Insecta: Coleoptera:Carabidae:Carenum	CCarCare
Green-lined beetle	Insecta: Coleoptera:Carabidae:Catadromus	CCarCata
Half-Green carab beetle	Insecta: Coleoptera:Carabidae:Chlaenius	CCarChla
Waisted carab beetle	Insecta: Coleoptera:Carabidae:Clivina	CCarCliv
Bulky carab beetle	Insecta: Coleoptera:Carabidae:Geoscaptus	CCarGeos
Long carab beetle	Insecta: Coleoptera:Carabidae:Gigadema	CCarGiga
Harp beetle	Insecta: Coleoptera:Carabidae:Harpalus	CCarHarp
Rhytisternus Carab beetle	Insecta: Coleoptera:Carabidae:Rhytisternus	CCarRhyt
Dull green carab beetle	Insecta: Coleoptera:Carabidae:Platycoelus	CCarPlat
Tank-like carab beetle	Insecta: Coleoptera:Carabidae:Philoscaphus	CCarPhil
Large carab beetle	Insecta: Coleoptera:Carabidae:Helluo	CCarHell
Microlestes carab beetle	Insecta: Coleoptera:Carabadae:Microlestes	CCarMicr
Bombarder Beetle	Insecta: Coleoptera:Carabadae:Pheropsophus	CCarPher
Starticus carab beetle	Insecta: Coleoptera:Carabidae:Sarticus	CCarSart
Long horned beetle	Insecta: Coleoptera:Cerambycidae	CCeramb
Flat Faced Long horned beetle	Insecta: Coleoptera:Cerambycidae:Parmenini	CCerParm
Flea beetle	Insecta: Coleoptera:Chrysomelidae:Alticini	CChrAlti
3-Lined Potato Beetle	Insecta: Coleoptera:Chrysomelidae:Lema	CChrLemm
Lady Beetle	Insecta: Coleoptera:Coccinellidae	CCoccine
Mite eating Lady beetle	Insecta: Coleoptera:Coccinellidae:Ladybird:Stethorus	CCocStet
Minute Fungus Beetles	Insecta: Coleoptera:Corylophidae&Sericoderine	CCorSeri
Amycterus weevil	Insecta: Coleoptera:Curculionidae:Amycterus	CCurAmyc
Cryptorhynchinae weevil	Insecta: Coleoptera:Curculionidea:Cryptorhynchinae weevil	CCurCryp
True weevils	Insecta: Coleoptera:Curculionidea	CCurculi
Wireworm	Insecta: Coleoptera:Elateridae:wireworm	CElateri
Pleasing fungus beetle	Insecta: Coleoptera:Erotylidae (Languariidae):Cryptophilus	CEroCryp
Fungus beetle	Insecta: Coleoptera:Erotylidae(Languariidae)	CErotyli.
Lined flat bark beetles	Insecta: Coleoptera:Laemophloeidae:Cryptolestes	CLaeCryp
Minute brown scavenger beetles	Insecta: Coleoptera:Latridiidae: Corticaria	CLatCort
Minute mould beetle	Insecta: Coleoptera:Latridiidae:Aridius	CLatArid
Red and blue beetle	Insecta: Coleoptera:Melyrdae:Dicranolaius:R&B	CMelDicr
Hairy Fungus beetle	Insecta: Coleoptera:Mycetophagidae	CMycetop
Pollen/Flower Beetle	Insecta: Coleoptera:Nitidulidae	CNitidul
Spider beetle	Insecta: Coleoptera:Ptinidae	CPtinida.
False flower beetle	Insecta: Coleoptera:Scraptiinae	CScrapti
Scarab beetle	Insecta: Coleoptera:Scarbaeidae:Melolonthinae	CScaMelo
Dung beetles	Insecta: Coleoptera:Scarbaeidae	CScaDung

Common name	Scientific classification (Usually Class: Order: family: Genus)	Short Name
Ctenicellus Rove beetles	Insecta: Coleoptera:Staphylinidae:Ctenicellus	CStaphCt
Euconnus Rove beetles	Insecta: Coleoptera:Staphylinidae:Euconnus	CStaphEu
Gonocephalum rove beetles	Insecta: Coleoptera:Staphylinidae:Gonocephalum	CStaphGo
Other Rove beetles	Insecta: Coleoptera:Staphylinidae:other	CStaphylin
Adelium darkling beetles	Insecta: Coleoptera:Tenebrionidae:Adelium	CTeneAde
Gonocephalum darkling beetles	Insecta: Coleoptera:Tenebrionidae:Gonocephalum	CTeneGon
Click beetle/mealworm	Insecta: Coleoptera:Tenebrionidae:Elaterdae	CTeneEla
Hide Beetle	Insecta: Coleoptera:Trogidae:Omorgus	CTroOmo
Beetle other	Insecta: Coleoptera: other	Coleopto
Springtail	Insecta: Collembola	Collembl
Dermaptera: Earwig	Insecta: Dermaptera:Labiduridae	Dermapte
Flies	Insecta: Diptera	Diptera
Bean Bug	Insecta: Hemiptera:Alydidae	HemiAlyd
Pirate Bug	Insecta: Hemiptera:Anthocoridae	HemiAnth
Stilt Bug	Insecta: Hemiptera:Berytidae:	HemiBery
Piglet bugs	Insecta: Hemiptera:Caliscelidae	HemiCali
Jassid	Insecta: Hemiptera:Cicadelliae	HemiCica
Spurred Planthopper	Insecta: Hemiptera:Delphacidae	HemiDeph
Gnat Bugs	Insecta: Hemiptera:Enicocephalidae	HemiEnic
Big Eyed Bug	Insecta: Hemiptera:Geocoridae:Geocoris	HemiGeoc
Rutherglen bug	Insecta: Hemiptera:Lydaeidae:Nysius	HemiLyda
Fulgoromorph Planthopper	Insecta: Hemiptera:Meenoplidae:Phaconeura	HemiMeen
Apple Dimpling Bug	Insecta: Hemiptera:Miridae:Campylomma	HemiCamp
Mirid	Insecta: Hemiptera:Miridae:Creontiades	HemiCreo
Broken Back Bug	Insecta: Hemiptera:Miridae:Taylorilygus	HemiTayl
Packy Bug	Insecta: Hemiptera:Pachygronthidae	HemiPach
Mealybugs	Insecta: Hemiptera:Pseudococcidae	HemiPseu
Green Veggie Bug	Insecta: Hemiptera:Pentatomidae	HemiPent
Jumping Plant lice	Insecta: Hemiptera:Psyllidae	HemiPsyl
Assasin bug	Insecta: Hemiptera:Redubviidae:Oncocephalus	HemiRedu
Dirt Coloured Seed bug	Insecta: Hemiptera:Rhyparochromidae	HemiRhyp
Lace bug	Insecta: Hemiptera:Tingidae	HemiTing
Aphids	Insecta: Hemiptera:Aphidae	HemiAphi
Predatory hemiptera	Insecta: Hemiptera:Predator	HemiPred
Plant hermiptera	Insecta: Hemiptera:Plant feeder	HemiPlant
Other Wasps	Insecta: Hymenoptera:Other	HymeOthe
Green head ants	Insecta: Hymenoptera:Formicidae:Rhytidoponerae	HyForRhy
Sugar ants	Insecta: Hymenoptera:Formicidae:Camponotus	HyForCam
Big headed ants	Insecta: Hymenoptera:Formicidae:Pheidole	HyForPhe
Furnace ants	Insecta: Hymenoptera:Formicidae:Melophorus	HyForMel
Flower ants	Insecta: Hymenoptera:Formicidae:Monoomorium	HyForMon
Meat ants/Tyrant ants	Insecta: Hymenoptera:Formicidae:Iridomyrmex	HyForIri
Panther ant	Insecta: Hymenoptera:Formicidae:Pachycondyla	HyForPac
Green tree ants	Insecta: Hymenoptera:Formicidae:Oecophylla	HyForOec
Stinging ant	Insecta: Hymenoptera:Formicidae:Hypoponera	HyForHyp
Ant unknown	Insecta: Hymenoptera:Formicidae:UNKNOWN	HyForUNK
Ant Stereomyrmex	Insecta: Hymenoptera:Formicidae:Stereomyrmex	HyForSte
Moths	Insecta: Lepidoptera	Lepidopt
Praying Mantis	Insecta: Mantodea	Mantode
Green Lacewing	Insecta: Neuroptera:Chrysopidae:Mallada	NeurChry
Dustywings	Insecta: Neuroptera:Coniopterygidae	NeurConi
Ant Lion	Insecta: Neuroptera:Myrmeleontidae	NeurMyrm
Grasshopper other	Insecta: Orthoptera:Caelifera:	OrthCael
Tower grasshoppers	Insecta: Orthoptera:Caelifera:Pyrgomorphidae	OrthPyrg
Mole cricket	Insecta: Orthoptera:Ensifera:Gryllidea:Gryllotalpidae	OrthGryo
Cricket	Insecta: Orthoptera:Ensifera:Gryllidea:Gryllidae	OrthGryl
Raspy cricket	Insecta: Orthoptera:Ensifera:Stenopelmatoidea:Gryllacrididae	OrthSten
Barklice	Insecta: Psocoptera	Psocopte
Thrip	Insecta: Thysanoptera: Thripidae	Thysanop
House centipedes	Myriapoda:Chilopoda:Scutigeridae	MyriScut
Centipede Other	Myriapoda:Chilopoda	MyriChil
Millipede	Myriapoda:Diplopoda:	MyriDipl
Nematodes	Nematoda	Nematode
Silverfish	Zygentima:Lepismatidae	Zygentim
Wood louse	Crustacea:Isopoda	Isopoda
Unknown	Unknown	Unknown

IPM Impacts to Production and Profit Survey

Introduction:

Thank you for taking part in IPM Profitability case study. We appreciate your time and effort. The aim of this case study is to identify if there is a direct cost or economic benefit to growers using IPM strategies to grow Bt cotton at the farm level, focusing on the 2019/20 season.

This case study first part aims to clarify your perspective on IPM approaches to cotton pest management. The aim is to quantify peoples' responses so that they are spread along a spectrum of growers who are more likely to less likely to use an IPM approach.

The second part records the inputs involved with growing cotton. All input costs will be calculated from industry standard rates (to remove the effect of particularly good or bad deals individual growers may have obtained). So it won't reflect the grower's actual costs, but their choices. Likewise, the income from the cotton produced will be calculated using the spot price Base Grade price for the month the cotton was harvested. This removes the effect of forwards selling.

We will then compare the calculated costs and benefits with the calculated IPM affinity, to gauge if following an IPM strategy was more or less costly in the 2019/20 season. Consequently, the results that are calculated from the information you provide will not be your cost and benefits, but will allow us to compare, on an even playing field, standardized costs and benefits of different IPM approaches.

Your responses are kept confidential and remain anonymous. All data will be aggregated for reporting purposes to ensure you remain de-identifiable.

For a confidential discussion about this survey please contact Mary Whitehouse, CSIRO Principal Research Scientist & Team Leader, on (02) 6799 1538 /0428 424 205 or email mary.whitehouse@csiro.au. Results will be provided to you following the completion of the report in the second half of 2021.

Part I. IPM affinity

(red text is the scale as assessed by the researcher and will not be provided to the grower)

1. Do you think that beneficial insects are useful in controlling pests?

1	2	3	4	5
Not at all useful	Somewhat useful	Useful	Very useful	Extremely useful
5	**4**	**3**	**2**	**1**

2. In your bug check in early flowering, you find a pest in very low numbers (well below threshold) but the weather is poor so retention is low. (There are no plans to put on a herbicide). How likely is that you would you consider applying a pre-emptive insecticide spray?

1	2	3	4	5
Not at all likely	Somewhat likely	Likely	Very likely	Extremely likely
1	**2**	**3**	**4**	**5**

3. You detect high numbers of a pest in your pre-squaring cotton but they are unlikely to destroy the plant, the crop has time to overcome any developmental delay, and your beneficial numbers are good. How likely is that your first consideration would be to control the pest by spraying?

1	2	3	4	5
Not at all likely	Somewhat likely	Likely	Very likely	Extremely likely
1	**2**	**3**	**4**	**5**

4. Deciding on a suitable product to spray is determined by several factors. Tick the 3 factors that you consider **most** important when choosing a product:

6	☐ Crop stage
4	☐ Pesticide attributes (persistence, mode-of-action, translocation, etc.)
2	☐ Cost
9	☐ Impact on beneficials
8	☐ Impact on environment
5	☐ Efficacy to control pest
3	☐ Application method
7	☐ Resistance management
1	☐ Other

Divide total by 4 -scores range from 1.5-6

5. How likely is it that you would consider planting trees on your farm to support pest management?

1	2	3	4	5
Not at all likely	Somewhat likely	Likely	Very likely	Extremely likely
5	**4**	**3**	**2**	**1**

6. How likely is it that you would consider releasing beneficials into your cotton to contribute to pest control?

1	2	3	4	5
Not at all likely	Somewhat likely	Likely	Very likely	Extremely likely
5	**4**	**3**	**2**	**1**

7. How effective do you believe managing pests only within the crop is for pest control?

1	2	3	4	5
Not at all effective	Somewhat effective	Effective	Very effective	Extremely effective
1	**2**	**3**	**4**	**5**

8. How likely is it that you would consider maintaining un-grazed native vegetation on your farm to support pest management?

1	2	3	4	5
Not at all likely	Somewhat likely	Likely	Very likely	Extremely likely
5	**4**	**3**	**2**	**1**

9. As part of your farming business goal (given that your cotton is Base Grade or above) do you aim to:

1	2	3	4	5
Maximise yield every year	Somewhat maximise yield each year	Somewhat maximise yields over 5 years	Maximise yields over 5 or more years	The focus is not on yield maximisation
1	**2**	**3**	**4**	**5**

Are there any other comments you wish to record?

…………………………………………………………………………………………………

Part II. Calculating standardized costs and benefits.

Module 1: Farm Profile

First, we would like to ask you a few questions related to your farm. If you have more than one farm, please choose one for this case study. Please be assured that all of the information you provide will be aggregated for reporting so you and other growers are not identifiable.

Q1 Which age category do you belong to?

Under 30	1
31-40	2
41-55	3
56+	4

Q2 What is your role on your farm?

Farm manager	1
Grower: Family member or farm business owner (operational)	2
Other (please specify)	3

Q3 Would you categorize the farm that you choose for this study as:

A family-business run farm	1
Part of a large agribusiness	2

Q4 In which region is your farm located?

Central Queensland (Emerald, Theodore)	1
Southern Queensland (St George, Dirranbandi, Border Rivers, Darling Downs)	2
Northern New South Wales (Bourke, McIntyre, Gwydir, Upper and Lower Namoi, Walgett)	3
Central New South Wales (Lachlan, Macquarie)	4
Southern New South Wales (Murrumbidgee, Murray Valley)	5

Q5 How long have you been growing cotton?

Less than 5 years	1
5 to 14 years	2
15 to 24 years	3
25 years or more	4

Module 2: Farm Output

Q6 What is the total area of your farm (in hectares)

Total farm size (ha):	<100	100-500	500-1000	1000+

Q7 During the 2019-20 cotton growing season, what area was planted in **Bt cotton** (don't include refuge area)?

	Fully irrigated (ha)	Partially irrigated (ha)	Raingrown / Dryland (ha)
Field area planted			
Green area planted			
Green area harvested			

Q8a What were your total yields for the 2019-20 cotton growing season?

	Fully irrigated	Partially irrigated	Raingrown
Total yield (bales /ha)			

Q8b Yields from refuges (if applicable).

Crop	Yield bales/ha	Form of yield (cotton /seed)	Irrigated (I) /raingrown (R)

Q8b Were there any other outputs from growing cotton (eg yields from nursery crops)?

………

Module 3: Farm Inputs for Bt Cotton

Could you please provide estimates of the following farm inputs for growing Bt cotton during the 2019-20 cotton growing season **up to defoliation**. Please use a separate form for **fully irrigated** and **raingrown** cotton.

Q9 Is this breakdown for your:

Fully Irrigated cotton	Rain grown cotton

Variety and Seed treatment

Q10 Please choose the seed variety, the quantity planted, and the seed treatment for the 2019-20 season.

Seed variety	Treatment*	Amount planted (green ha or %)
Sicot 746B3F	VC C CE TP G6	
Sicot 714B3F	VC C CE TP G6	
Sicot 754B3F	VC C CE TP G6	

**Possible seed treatment options:*
Vibrance Complete (VC),
Cruiser (C)
Cruiser Extreme (CE),
TriPlus (TP)
Genero 600 (G6)

Field preparation and in crop cultivation

Q11 Please list the time spent cultivating both before planting and in-crop

(Approx. date)	Pre /post planting	Area cultivated

At planting (in furrow) pesticide applications

Q12 Did you apply any in-furrow pesticides (herbicide /fungicide / insecticide) at planting?

Yes	No

If Yes:

Pesticide	rate	% Bt crop or per ha

Field monitoring

Q14a Consultants /agronomists in the Bt cotton crop -Agronomy

Weeks of Agronomic advice	Visits /week	Agronomic reporting detail*:

**Possible reporting detail:*
Superficial (1)
Thorough (2)
Very Detailed (3)

Q14b Consultants /agronomists in the Bt cotton crop -Bug checking.

Weeks checked for bugs	Average number of checks /week	Average Bug check intensity*	Ha covered by bug checking

**Bug check intensity:*
Key pests only(up to 6 pests identified), no densities given (1)
Key pests and their densities /m (up to 8 pests) (2)
Pests and some beneficials (7-12 invertebrate groups identified) (3)
More than 13 invertebrate groups identified with densities /m (4)

Q15 Sensors: If you use sensors, what type do you use in your Bt cotton fields?

Type of sensor	Quantity	Age

Applied Nutrients

Q16 Please list the rate of applied nutrients during the 2019-20 season (include Band width if relevant).

Nutrient*	Blend**	Form of nutrient***	Amount (kg/ha)	Area treated (ha)	Application method*#
Preseason Nitrogen					
In-season Nitrogen					

**Additional nutrients*: Phosphorus (P)/ Potassium (K)/ Zinc (Zn)/ Sulphur (S).
***Blends*: BAP / Granlock (G)/ MAP / Urea (U) / Anhydrous ammonia (AA)
****Form of nutrient*: soil (S)/ tissue (T)/ Petiole (P).
*#*Application method*: Groundrig (G), Aerial (A)

Herbicides / Diseases

Q17 In relation to herbicides, please select the type and rate of applied chemicals for your Bt cotton during the 2019-20 season. Include Band width if relevant; pics in crop.

Product name	Rate (L/ha)	Area treated (ha)	Number of applications	Application method*
Pre-season glyphosate (450 or 690)				
In season glyphosate (450 or 690)				

**Application method*: Groundrig (G), Aerial (A)

Insecticides

Q18 In relation to insecticides, please detail the type, rate and application method for your Bt cotton fields during the 2019-20 season. Include Band width if relevant.

Product name	Amount used	Application method*

**Application method*: Groundrig (G), Aerial (A)

Q19 Application of beneficials to cotton.

Beneficial	Number /ha	Application method	Area treated (ha)

Q20 Did you plant a **trap crop** or **Nursery**?

YES	NO

If yes, could you please provide the following details:

Crop type	Area (ha)	No. of cultivations	Herbicide /fungicide applied	Insecticide applied.

Staff costs

Q 21 How may full time equivalents (FTEs) did you have assisting you with the Bt cotton during this cotton season (not including harvest)?

Length of cotton season (months)	Number of FTE staff

Potential Water stress

Q22 Water stress could strongly affect potential yield. To gauge stress, could you please provide estimates of the number of times the crop experienced the following stress:

Crop	None	1-4 days	5-9 days	> 10 days
Wilt after flowering				
Reach permanent wilt after flowering				

Close:

Thank you for assisting with this important survey. Your responses will be aggregated with other growers to maintain your anonymity.