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CSD Liverpool Plains Fruit Removal Experiments

2018-2021

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Executive summary

Crops in cool or short-season areas such as the Liverpool Plains are subject to the same risk of fruit loss from insects and abiotic stress as plants in other cotton-growing areas. However, cotton plants in this region generally do not have sufficient time in the season to compensate for fruit loss which may consequently reduce yield potential. This series of experiments involving artificial fruit loss aimed to answer three questions that could help to better manage cotton in the Liverpool Plains:

1. **Does tipping cause yield loss and maturity delay?** Early season tip damage at nodes 5-7 is often caused by thrips and therefore has implications for early season pest management.
   - Tipping damage did not significantly affect yield in the 2017/18 study, however there was a significant reduction in yield (1.49 bales/ha) during the 2018/19 season. This was an extreme drought year with very hot periods throughout January that may have affected the ability of plants to compensate for fruit loss.
   - Tipping damage did not significantly delay maturity but maturity was 3.8 days late during the drought year.
   - The risk of some amount of yield loss and maturity delay was estimated as occurring 1 out of every 3 years.
2. **How much fruit loss can plants sustain before yield loss occurs?** This question has relevance on two levels, for damage to part of the crop which morelikely simulates insect damage, and for damage to the whole crop which simulates abiotic stress.
   - During the drought year, removal of fruit from the lower 6 Fruiting branches on 100% of plants significantly reduced yield by 2.04 bales/ha. Slightly higher losses (2.36 bales/ha) were seen for the same treatment in the subsequent season.
   - In a cooler year with more rainfall and moderation of the distribution of damage, there were no significant yield losses for the same treatment on 50 and 100% of plants (0.7 and 1.0 bales/ha, respectively). Yield increased by 0.6 bales/ha when only 33% of plants were damaged.
   - Maturity was delayed by 4.22 days when fruit were removed from higher Fruiting branches (FB 7-12) but not when combined with removal of fruit from FB 1-6. Removal of fruit from FB 1-6 did not delay maturity by more than 1.32 days.
   - The risk of yield losswas estimated as occurring 2 out of 3 years and for maturity delay 1 out of 2 years but the latter only for fruit removed at FB 7-12.
   - Our results suggest that earlier fruit loss to one third of the crop may result in an over-compensatory response rather than incur losses. Compensation is also influenced by seasonal conditions and crop management, hence the answer to this question is complex. It further depends on the degree of loss a grower is prepared to tolerate and the economics of pest control versus the financial gain of crop protection.
3. **Do plants compensate for fruit loss?** This question would indicate how much damage growers might tolerate before using chemical pest control which has implications for Integrated Pest Management (IPM).
   - Compensation occurs on two levels: the plant level and the crop level. At the plant level, Position 1 and 2 bolls of the lower 12 Fruiting branches were the main contributors to yield in undamaged plants. In damaged plants (FB 1-6), these

contributions varied depending on the degree of damage. The more plants per metre that were damaged, the lower the contribution from these locations.

- The contribution of bolls from Vegetative branches increased in response to the decrease in the mainstem contribution, hence within pant compensation occurred.
- Bolls from Positions 1, 2 and 3 of Fruiting branches 13+ only contributed between 8 and 12 % to total yield.
- At the crop level, compensation only occurred in the FB 1-6 treatment when applied to one third (33%) of plants with an increase in yield of 11.12%.
- Ginout percentages were more variable for bolls higher up in the canopy and for Position 3 bolls. Boll weight was more consistent through FB 7-12 for Position 1 and Position 2 bolls.

Our experiments show that tipping damage and a small degree of fruit loss can be tolerated without significant yield loss in the Liverpool Plains as plants can compensate for damage during early and mid-flowering. However, plant responses are strongly influenced by variable seasonal conditions which make crop and pest management decisions even more difficult. Growers have to determine an acceptable level of potential yield loss against the costs – financial and ecological – of pest control. Insurance policy pest control, either as seed treatment or prophylactic, are risky in terms of resistance management and may contribute to unnecessary pest control. Tolerance of early-season pests such as thrips or low levels of pests such as mirids during early-mid flowering may be of benefit by stimulating the crop into overcompensation. This reduces resistance risk and pesticide costs and preserves early beneficial populations to aid in controlling other pests such as Silverleaf whitefly. The cotton industry still uses large amounts of pesticides and the focus is shifting to finding better ways of reducing pesticide reliance. Improving our understanding of plant responses to insect damage to better advise growers in cool-season areas with decision making, is a step in that direction. More detailed experiments over a longer period would greatly improve the strength of our data.

1. Introduction

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.

The metric of retention is a concept that was first used when *Helicoverpa* spp. were the primary pests of conventional and Ingard® cotton and resistance to insecticides was on the increase. The management focus was on early retention, especially in Ingard® crops where the protection of a single Bt *(Bacillus thuringiensis*) gene (Cry1Ac, Bayer) would decrease as the season wore on, and fruit and growing tips of plants could be damaged repeatedly. Therefore early retention was important as bolls set in the lower canopy would contribute significantly to yield which was typically 8-10 bales/ha. 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). Bollgard® II cotton with two Bt genes (Cry1Ac and Cry2Ab, Bayer) changed this concept because *Helicoverpa* spp. were no longer the primary pests and growers could focus on other important management aspects such as irrigation and nutrition which would contribute to the increase in yield that was seen. Another factor that has contributed to yield increase is the smaller seed size of Bollgard® 3 cotton, stacked with 3 Bt genes (Cry1Ac, Cry2Ab and Vip3A, Bayer) that afford season-long protection from *Helicoverpa* spp. and delay the onset of resistance. Without the threat of *Helicoverpa* damage later in the season, Bollgard® 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.

Fruit loss in the 2016-17 cotton season was generally high and while much of it could be attributed to heat and water stress, cold shocks and other factors, some of it may have been due to mirids. Since *Helicoverpa* spp. are not the primary pests of transgenic cotton anymore, some of the secondary pests that were previously controlled coincidentally with broad spectrum sprays aimed at *Helicoverpa*, have become more problematic. Management of sucking pests such as Green mirids (*Creontiades dilutus*) and Silverleaf whitefly (SLW, *Bemisia tabaci*) are now a regular concern in Bollgard® 3 crops. Mirids can damage the same cotton structures as *Helicoverpa* spp.- terminals, squares and young bolls and, if present, can contribute to low early retention. While crop management for abiotic stresses is difficult, managers can do something about insects. From an IPM perspective, the danger in years of variable weather conditions and high insect pressure is the increase in chemical applications which can accelerate insect resistance. As retention dropped during the 2016-17 season, mirid sprays increased. Coupled with additional sprays to control thrips, mites, aphids and shield bugs, beneficial insects were severely impacted leading to a build-up of Silverleaf whitefly populations as bolls began to open. Lint contamination with Silverleaf whitefly honeydew was an issue of concern at the end of the 2016-17 cotton season.

The cotton production area has expanded both south, east and north. The eastern areas, e.g. near Willow Tree, are characterised by similar day-length to nearby central regions, e.g. the Namoi Valley, but cooler, shorter seasons. However, with Bollgard II/III and RRFlex varieties, cotton is an attractive proposition in terms of gross margins and consequently growers in these areas have been growing irrigated and dryland cotton crops over the past 3-5 seasons. A key concern for these growers is that early season damage from pests such as thrips and mirid nymphs will delay the onset of fruiting. This could carry through to delayed crop maturity with risks to yield and fibre quality if crops are maturing under the cool condition in Feb-April. Previous experiments in short season regions such as the Upper Namoi, Macquarie and Eastern Darling Downs suggest that the risk of suffering yield loss from thrips damage to seedlings is about 1 year in 2 (50%). 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.

2. Materials and Methods

2.1 Study Area

All experiments were carried out at Spring Ridge, NSW, (31.3963° S, 150.2441° E), either at Gowrie or Dimby Plains. Plots were set up in a planted field of cotton with overhead irrigation.

2.2 Materials and Methods

Experimental Design

All experiments were set up and executed in the same design, however, treatments varied between years (Figs 1&2). Experiments were set up 50-100 m into the crop so that plots were not affected by the travelling irrigator. The parameters for each experiments were:

- 4 randomized complete blocks (5 treatments x 4 reps = 20 plots)
- Plot size 8 rows x 6 m + 1 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 by the grower

Figure 1: Field Plan 2018/19 & 2019/20

		Centre of Pivot			
	17 Tipping @ N5/6	18 Fruit removal @ FB 1-6 & 7-12	19 Control	20 Fruit removal @ FB 1-6	
	13 Fruit removal @ FB 1-6	14 Fruit removal @ FB 7-12	15 Tipping @ N5/6	16 Fruit removal @ FB 1-6 & 7-12	
	9 Fruit removal @ FB 1-6 & 7-12	10 Control	11 Fruit removal @ FB 7-12	12 Tipping @ N5/6	
	5 Fruit removal @ FB 7-12	6 Fruit removal @ FB 1-6	7 Fruit removal @ FB 1-6 & 7-12	8 Control	
	1 Control	2 Tipping @ N5/6	3 Fruit removal @ FB 1-6	4 Fruit removal @ FB 7-12	
	Rep 1	Rep 2	Rep 3	Rep 4	
	6 Rows	6 Rows	6 Rows	8 6 Rows	

Figure 2: Field Plan 2020/21

		Centre of Pivot			
	17 Tipping @ N3/4	18 Fruit removal @ FB 1-6 33%	19 Control	20 Fruit removal @ FB 1-6 100%	
	13 Fruit removal @ FB 1-6 100%	14 Fruit removal @ FB 1-6 50%	15 Tipping @ N3/4	16 Fruit removal @ FB 1-6 33%	
	9 Fruit removal @ FB 1-6 33%	10 Control	11 Fruit removal @ FB 1-6 50%	12 Tipping @ N3/4	
	5 Fruit removal @ FB 1-6 50%	6 Fruit removal @ FB 1-6 100%	7 Fruit removal @ FB 1-6 33%	8 Control	
6 m + 1 m buffer	1 Control	2 Tipping @ N3/4	3 Fruit removal @ FB 1-6 100%	4 Fruit removal @ FB 1-6 50%	
	Rep 1	Rep 2	Rep 3	Rep 4	
	6 Rows	6 Rows	6 Rows	6 Rows	

Damage implemented

The number of fruit removed from each experiment and the dates at which they were removed are summarised in Table 1.

Tipping Damage (4 plots + Controls)

- 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.

Figures 3-6 show bolls remaining on damaged and undamaged plants. Leaves have been removed for visibility.

Table 1: Summary of fruit removal treatments Spring Ridge, NSW, 2017/18 - 2020/21

Treatment	Planting Date 11/10/2018	Planting Date 11/10/2019	Planting Date 06/10/2020
Variety	Sicot746B3F	Sicot746B3F	Sicot746B3F
Tipping	Node 5/6 06/12/2018 557 DD	No Tipping	Node 7/8
Damage to Fruiting Branches 1-6 Peak Flower (1300-1400 DD)	29/01/2019 1436 DD	30/01/2020 1479 DD	26/01/2020 1162 DD
Damage to Fruiting Branches 7-12 Green Boll (1572 DD)	11/02/2019 1642 DD	Not accomplished due to 128 mm RF during February	Not planned
Combined Damage to Fruiting Branches 1-12	29/01/2019 & 11/02/2019 1436 & 1642 DD	Not accomplished due to 128 mm RF during February	Not Planned
First Maturity Pick 60% Open Boll (2050 DD)	13/03/2019 2050 DD	Not done due to Covid 19 restrictions Machine Picks Data only	12/04/2021 – 2% 1889 DD (26/04/2021 – 20-40% - 1963 DD) (03/05/2021 – 50% - 2006 DD) (19/05/2021 – 80-90% - 2070 DD)
Last Maturity Pick End of Season	22/04/2019 2422 DD	Not done due to Covid 19 restrictions	25/05/2021 – 100% 2098 DD
Strata Pick	Not Done	18/06/2020 2476 DD	25/05/2021 2098 DD

Table 2: Fruits removed from plants at Spring Ridge, NSW, in each year (mean/m)

	Squares	Candlewicks	Yellow Flower	Pink & Purple Flower	Green Bolls	Open Bolls	Total Fruit removed/m
2018/19							
Fruiting Branches 1-6 – 100%	46.75	3.96	1.29	4.42	24.63	0	81.04
Fruiting Branches 7-12 – 100%	30.75	6.21	3.25	9.46	59.50	0	109.17
Fruiting Branches 1-6 & 7-12 – 100%	87.42	16.33	6.13	12.08	72.96	0	195.21
2019/20							
Fruiting Branches 1-6 – 100%	69.29	1.88	4.46	6.54	27.92	0	110.09
2020/21							
Fruiting Branches 1-6 – 33%	15.92	1.00	0.67	0.83	2.25	0	20.67
Fruiting Branches 1-6 – 50%	23.50	1.08	0.92	1.75	3.25	0	30.50
Fruiting Branches 1-6 – 100%	47.88	1.71	2.25	3.67	8.67	0	64.18

Data collection

Data collected is summarised in Table 3

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)

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.

2.3 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.

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

Table 3: Data collected for each experiment at Spring Ridge, NSW, 2017/18 – 2020/21

Year	Tip damage inflicted	Fruit Damage at Nodes	No. of plants per metre damaged	Yield measured	Maturity Delay measured	Plant Partitioning	Stratum Pick
2018-19 Gowrie Sicot 746B3F	Nodes 5-6 Actual Node 6	1-6 7-12	100%	✓	✓		
2019-20 Gowrie Sicot 746B3F	No Tipping	1-6 7-12	100% Not accomplished Due to 128 mm RF during February	✓	Not done due to Covid 19 restrictions	Mean Ht & Nodes Control @ FB 1-6 Damage 20/12/19 30/01/20	✓
2020-21 Dimby Plains Sicot 746B3F	Nodes 3-4 Actual Node 7	1-6 7-12	33% 50% 100%	✓	✓	Control after damage 18/01/2021	✓

Figure 3: FB 1-6 – Control. All plants undamaged. Spring Ridge 2020/21

Figure 4: FB 1-6 – 33%. Removal of fruit from every 3rd plant, left plant is damaged. Spring Ridge 2020/21

Figure 5: FB 1-6 – 50%. Removal of fruit from every 2nd plant, left plant and second plant from right are damaged. Spring Ridge 2020/21

Figure 6: FB 1-6 – 100%. Removal of fruit from every plant. Spring Ridge 2020/21

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 2017/18 Pilot Study (0.06 bales/ha, Figure 7, Data summarised in Appendix 1), however there was a significant reduction in yield (1.49 bales/ha) during the 2018/19 season, This was an extreme drought year with very hot periods throughout January that may have affected fruit retention. In 2020/21, tipping reduced yield by 0.82 bales/ha, which was again not significant. The combined analysis for the three seasons (Figure 8) showed a mean reduction in yield of 0.76 bales/ha which was statistically not significant. Differences in yield were driven by individual boll weight rather than the number of bolls per metre (Table 4).

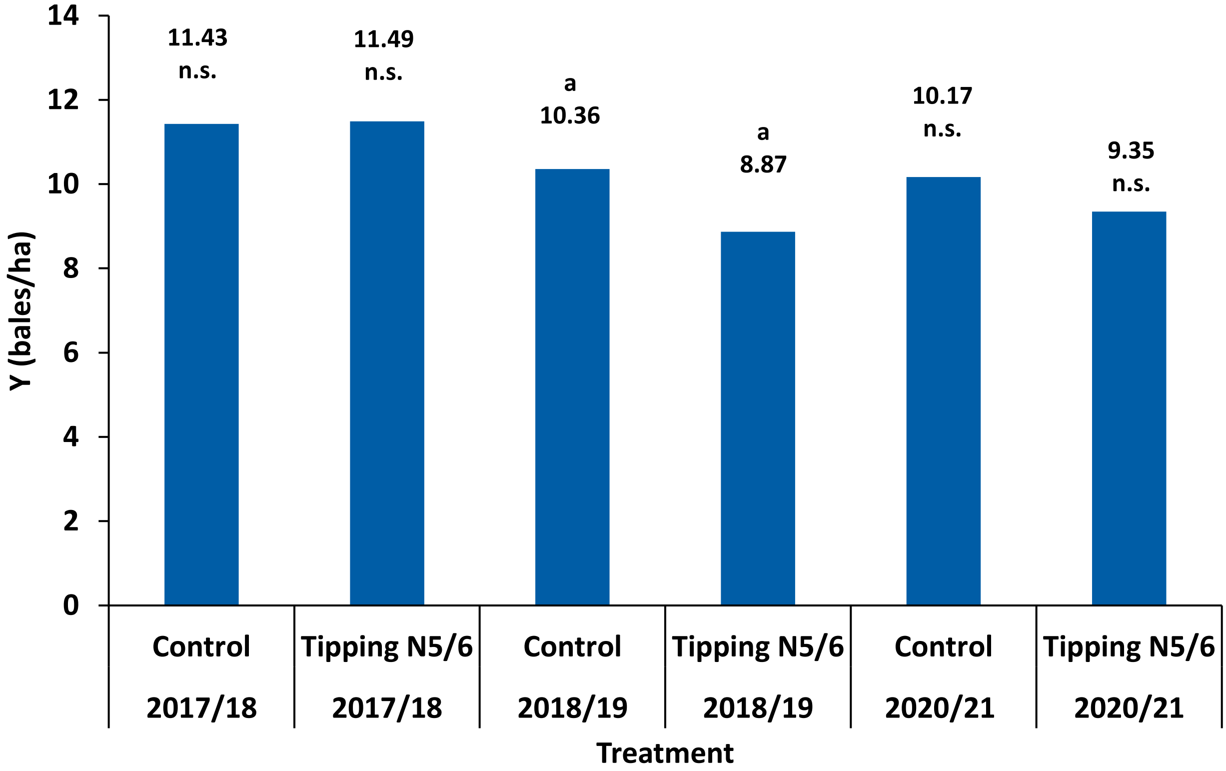


Figure 7: Effects of tipping out below Node 8 on yield at Spring Ridge for each year, 2017/18 to 2020/2. Note that comparisons for significance are between Control and Tipping for each year. Actual Nodes tipped were 2017/18 – Nodes 5/6, 2018/19 – Node 6, 2020/21 – Node 7. Statistical analyses for 2017/18 – P <0.00, LSD = 1.34, 20018/19 – P = 0.048, LSD = 1.91, 2020/21 – P = 0.462, LSD = n.s.

Table 4 : Three-year summary of harvest parameters for tipped plants, Spring Ridge, NSW, 2017/18, 2018/19 & 2020/21

Parameter	Control	Tipping Nodes 5-7	Analysis
Bolls per m	125.08	130.08	P = 0.469 n.s.
Boll Weight (g/boll)	4.35	3.94*	P = 0.012 LSD = 0.309
Ginout %	41.60	41.56	P = 0.972 n.s.
Yield (bales/ha)	10.66	9.90	P = 0.154 n.s.
Maturity @ 60 % Open Boll (days)	190.99	191.34	P = 0.730 n.s.

Combined Analysis

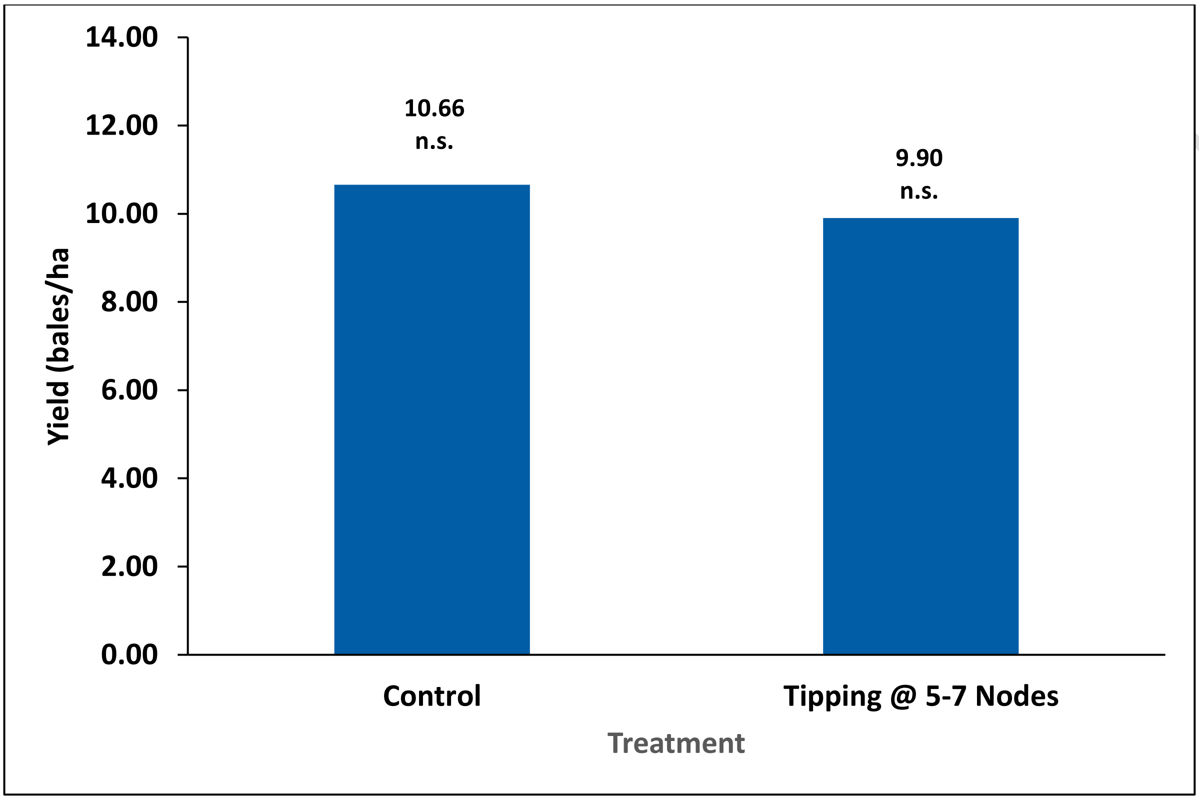


Figure 8: Combined analysis for 3 years of tipping data (2017/18 – 2020/21). P = 0.154, LSD = n.s.

3.2 Does Tipping out delay Maturity?

Tipping damage did not significantly affect maturity at 60 percent open boll in the 2017/18 Pilot Study (2.4 days delay Figure 9), however there was a significant increase in maturity (3.8 days) during the 2018/19 season. In 2020/21, tipping reduced maturity by 3.65 days, which was not significant. The combined analysis (Figure 10) for the three years showed a mean delay in maturity by 0.35 days. which is statistically and practically not significant.

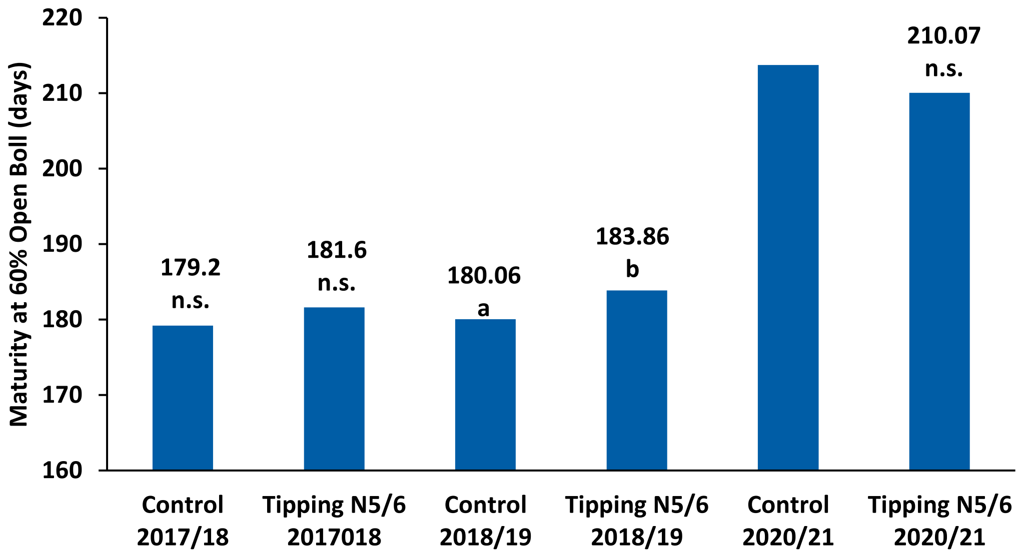


Figure 9: Effects of tipping out below Node 8 on maturity at Spring Ridge for each year, 2017/18 to 2020/2. Note that comparisons for significance are between Control and Tipping for each year. Actual Nodes tipped were 2017/18 – Nodes 5/6, 2018/19 – Node 6, 2020/21 – Node 7. Statistical analyses for 2017/18 – P <0.001, LSD = 3.9, 20018/19 – P = 0.032, LSD = 2.75, 2020/21 – P = 0.039, LSD = 3.67

Combined Analysis

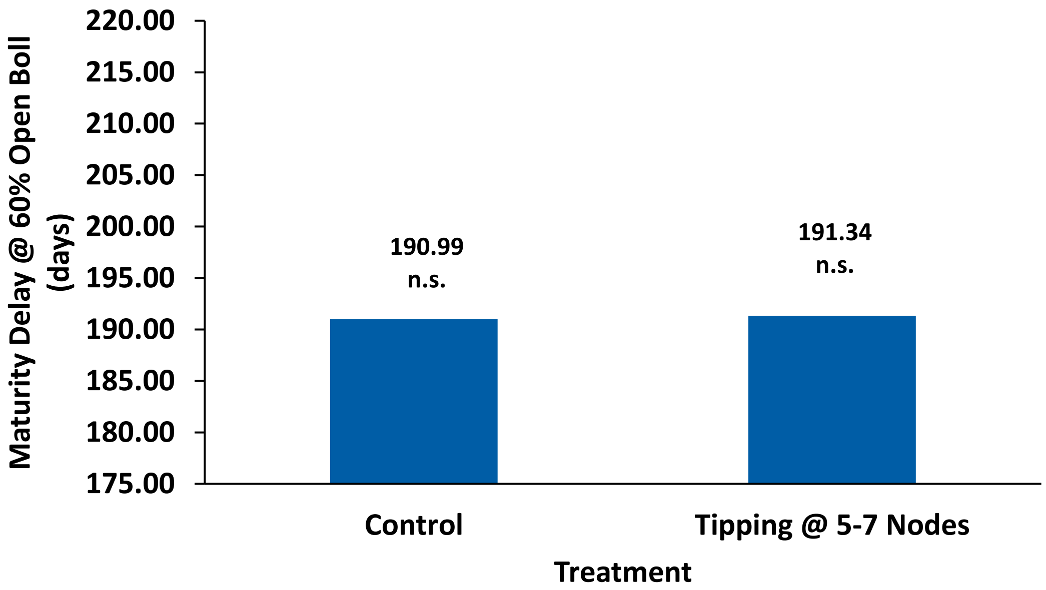


Figure 10: Combined yield analysis for 3 years of maturity data (2017/18 – 2020/21). P = 0.730, LSD = n.s.

Tipping Damage Discussion

A one-off tipping event between nodes 5 and 7 had overall little to no effect on yield with losses of less than 1 bale/ha. During drought years, however, losses can be magnified by conditions that affect crop growth and compensation or fruit retention, such as water shortage and high temperatures. Tipping also had little effect on crop maturity with seasonal conditions likely to override the effect.

In the Liverpool Plains, annual reports of thrips damage usually relate to crops planted close to maturing wheat, where thrips move into the adjacent rows of cotton seedlings. Such early-season damage can be tolerated, especially if it remains an edge effect, or maybe managed by band spraying rather than whole field coverage. This decision will depend on the extent, duration, and severity of the damage. Yield losses are realistic and growers need to weigh the cost of spraying against the loss of a marginally small amount of yield. Maturity delays of 1-3 days are generally not critical unless there is impending rain which would extend crop exposure by several weeks. While overall effects of tipping are not significant, there is high seasonal variability with extreme situations in drought years and years of higher rainfall which make predictions less reliable.

The experiments carried out under the current project only considered tipping but did not simulate the crippling effects on leaves caused by thrips. 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. 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. All of the studies were carried out in the Namoi or Gwydir, which are warm-season areas. Mo *et al.* (2018) repeated Wilson's leaf damage experiments in the Riverina, which is also a shorter growing season area, and found that defoliation initially shortened plants but that by 100 DAS height differences evened out in 2 out of 4 seasons. Total boll numbers per plant were not affected by defoliation but there were significant delays in maturity (up to 18 days) where plants were completely defoliated. Due to many unopened bolls at defoliation, yield in damaged plots was reduced.

Experiments carried out in warmer regions of northern and southern NSW may not be wholly applicable to the cool northern growing regions. Compared to the Liverpool Plains, the southern cotton growing areas have longer day length during the cotton season and can accumulate more radiation, and therefore have better conditions for crop compensation. To assess the effect of thrips more thoroughly on cotton in the Liverpool Plains, it would be prudent to carry out tipping experiments that include different levels of simulated thrips leaf damage. This is important as the risk of economic thrips damage carries other implications.

Management of thrips with seed treatments is an insurance policy that may not be needed in every growing situation especially since the effects of seed treatments are generally not noticeable unless thrips numbers are high. Another consideration is neonicotinoid resistance in *Frankliniella occidentalis* which has known resistance to neonicotinoids and may displace *Thrips tabaci* in farming systems. The cotton industry is considering its use of insecticides and the sustainability of chemical insect pest control, with a large proportion of total seasonal insecticide load contributed by seed treatments.

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

Yield

In 2018/19, 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 from on both dates.

Fruit removal from the lower six fruiting branches resulted in a significant yield loss of 2.04 bales/ha to 8.32 bales/ha (Fig. 11) compared to the average of 10.36 bales/ha for Controls. Removing fruit from mid-canopy fruiting branches (FB 7-12) resulted in a loss of 1.69 bales/ha to 8.67 bales/ha, which was statistically not significant, and removal of fruit from the lower half of the plant (FB 1-12) gave a loss of 3.12 bales/ha to 7.24 bales/ha.

In 2019/20, we only managed to carry out the removal of fruit from the lower six fruiting branches due to extended wet weather throughout February. Yields were lower for that season with Control plots yielding only 8.69 bales/ha. Removing fruit from FB 1-6 caused yield to drop by 2.36 bales/ha to 6.33 bales/ha (Fig 12).

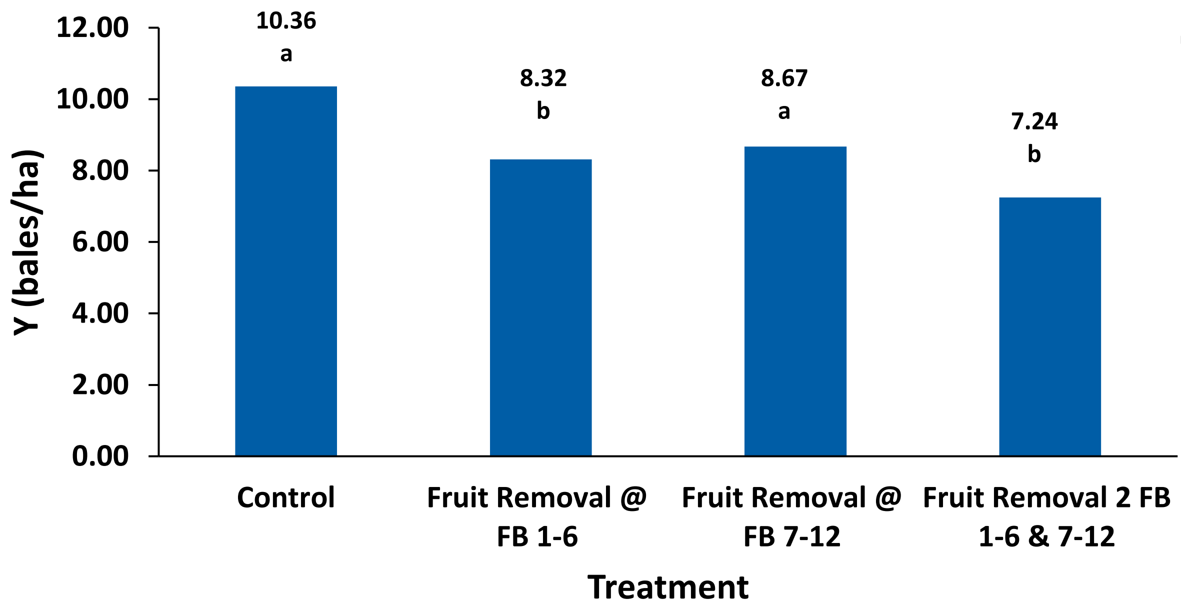


Figure 11: Yield at Spring Ridge 2018/19, P <0.001, df (4, 19), LSD = 1.91

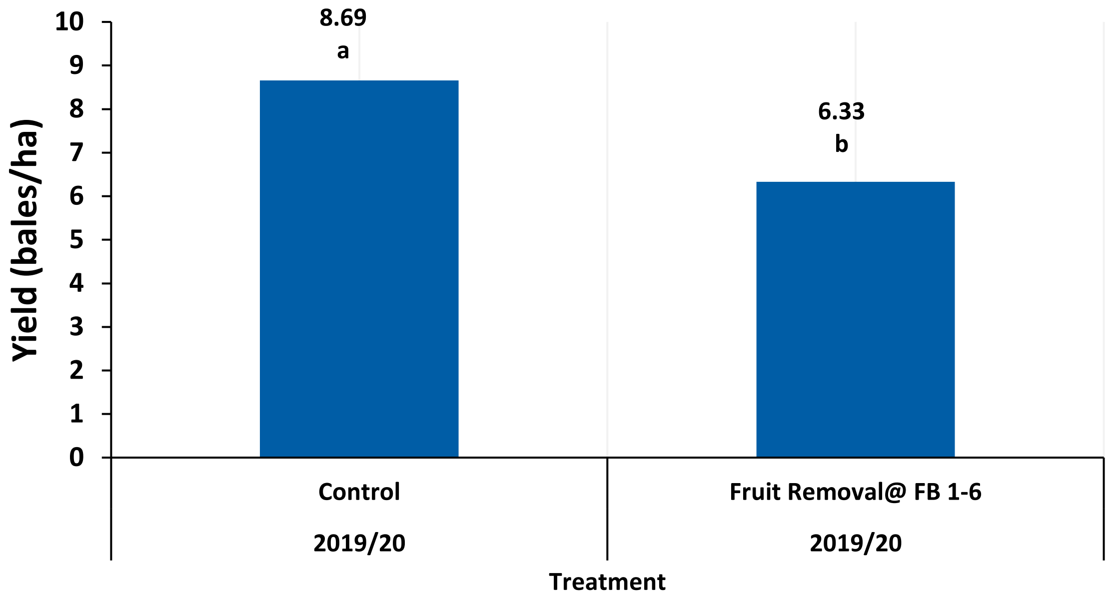


Figure 12: Yield at Spring Ridge 2019/20, P = 0.009, df (1, 7), LSD = 1.20

In 2020/21, we modified the experiment to reflect variable damage to fruiting branches in the lower canopy (FB 1-6). We again simulated damage at 100% which could represent environmental stresses experienced by all plants in the field. By damaging either 33% (every third plant) or 50% (every second plant) of plants in the plot, we aimed to simulate two different levels of pest damage which tends to occur irregularly in a field situation. Control yield was high for the season at 10.17 bales/ha and yield losses due to fruit removal were not significant (Fig. 13). Fruit removal from the lower canopy of all plants (FB 1-6 – 100%) resulted in the loss of 1 bale/ha. When only half the plants were damaged (FB 1-6 – 50%) , losses reduced to 0.7 bales/ha. Fruit removal from every third plant (FB 1-6 – 33%) resulted in a slight increase in yield (0.6 bales/ha). The combined analysis of the FB 1-6 – 100% treatment over the three years showed a mean loss of 1.79 bales/ha, which was highly significant (Fig. 14). However, separate analyses for each year show high variability between seasons.

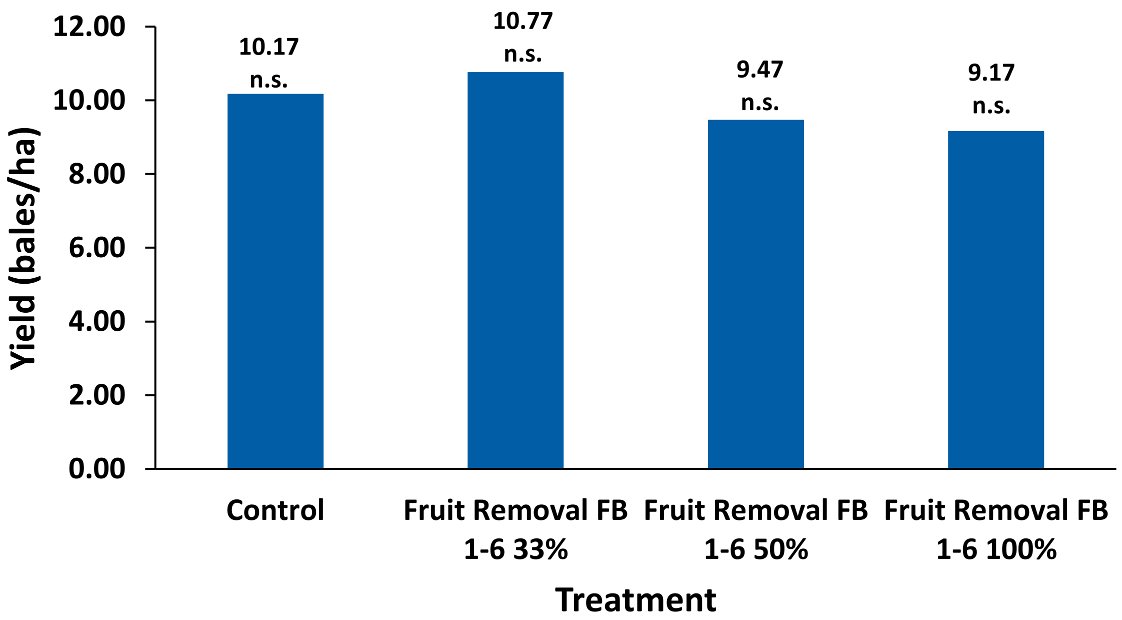


Figure 13: Yield at Spring Ridge 2020/21, P = 0.46, df (4, 19), LSD = n.s.

Combined Analysis

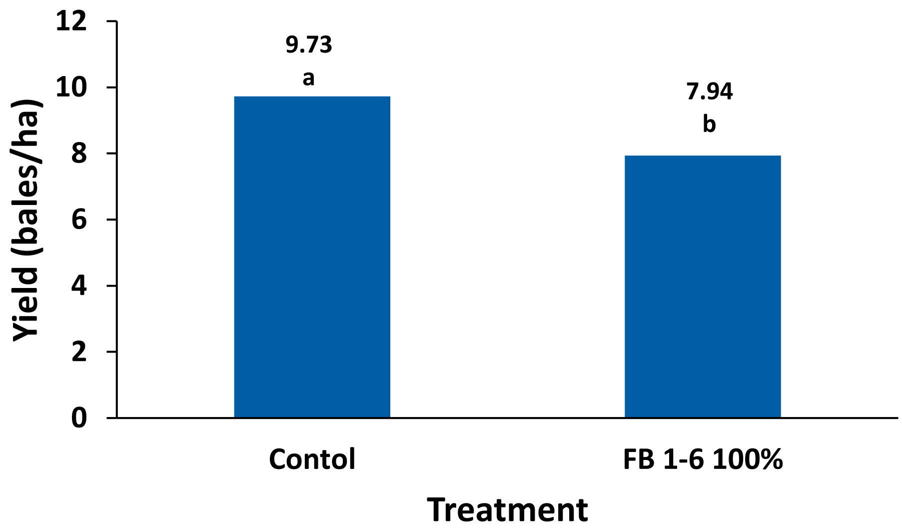


Figure 14: Combined yield analysis for 3 years of yield data (2018/19, 2019/20 & 2020/21). P = 0.001, LSD = 0.975

Boll Numbers

Boll numbers were recorded for maturity pick data in 2018/19 and 2020/21. Statistically, treatments did not produce significant differences in the number of bolls per m (Figs 15 & 16), however the patterns reflect the yield differences during those years.

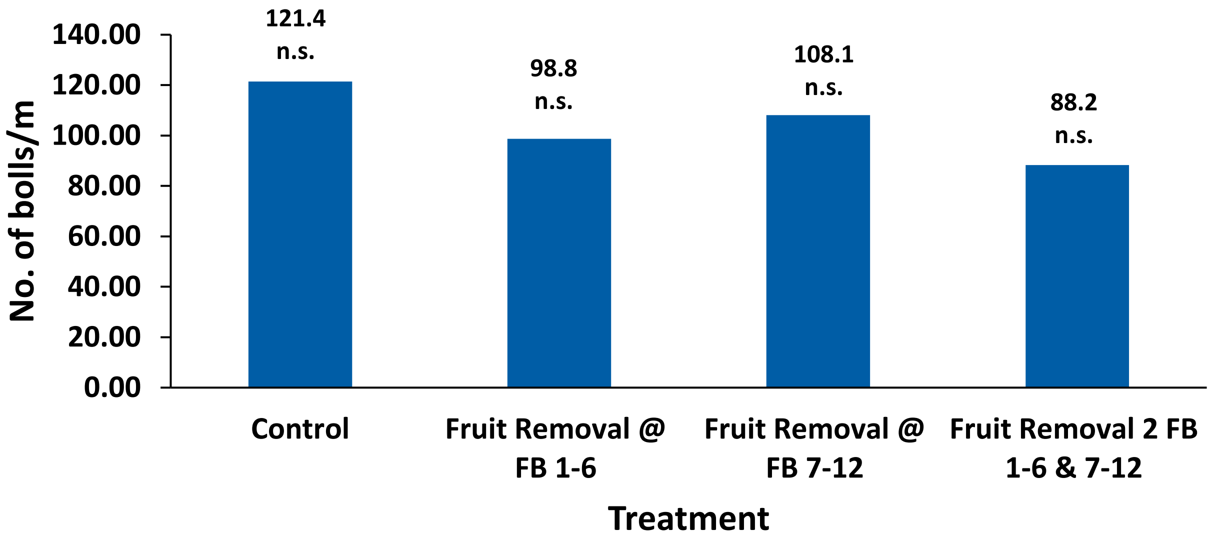


Figure 15: Boll Numbers at Spring Ridge 2018/19, P = 0.050 df (4, 19), LSD = n.s.

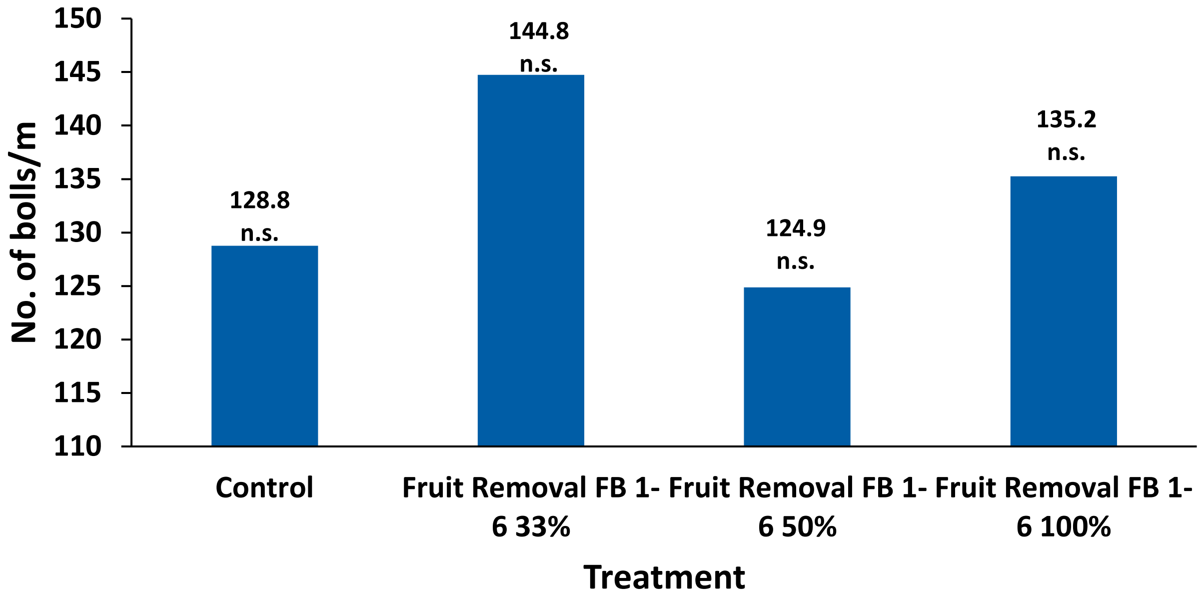


Figure 16: Boll Numbers at Spring Ridge 2020/21, P = 0.362 df (4, 19), LSD = n.s.

Boll Weight

Boll weight was also recorded for maturity pick data in 2018/19 and 2020/21. Again, treatments did not produce statistically significant differences in weight per boll (Figs 17 & 18), though the patterns also reflect the yield differences during those years.

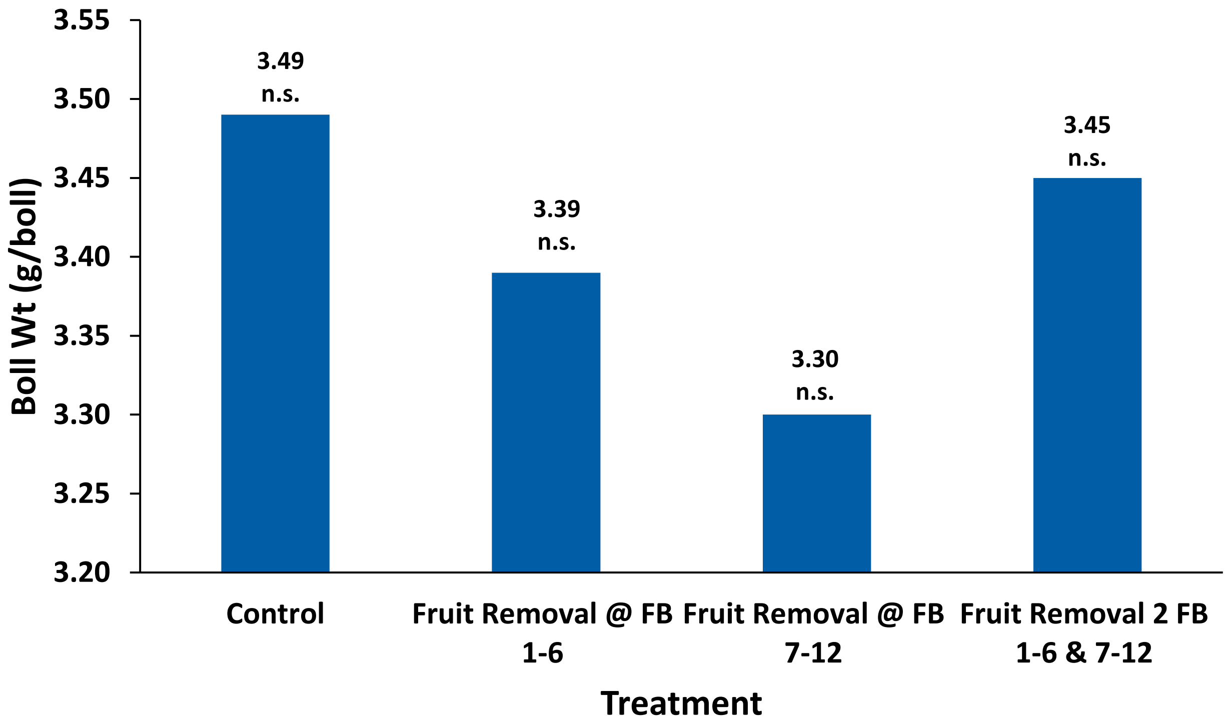


Figure 17: Boll Weight at Spring Ridge 2018/19, P = 0.148, df (4, 19), LSD = n.s.

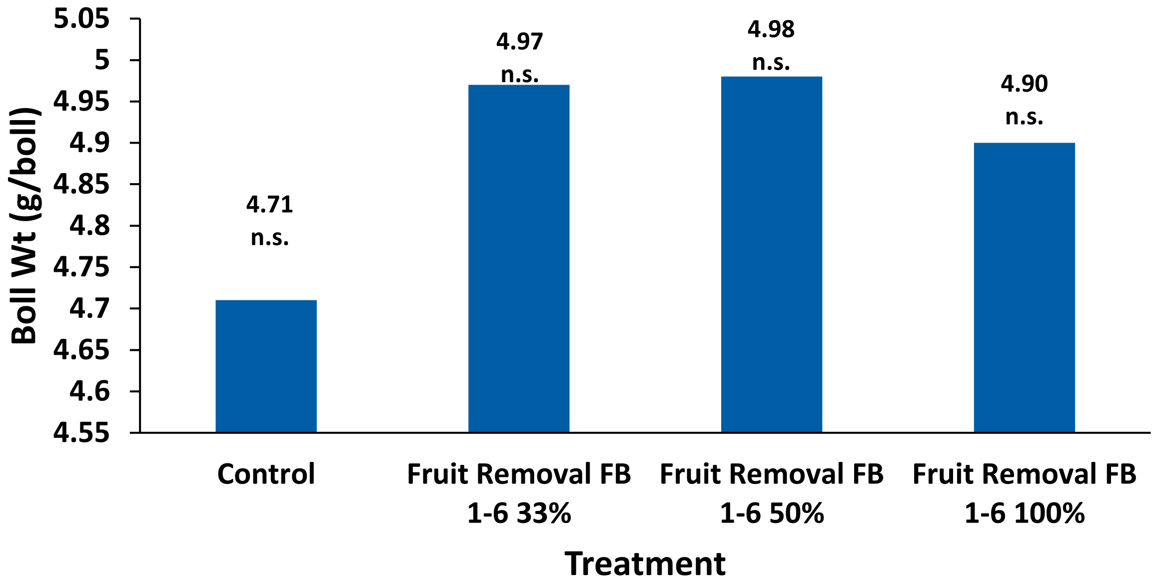


Figure 18: Boll Weight at Spring Ridge 2020/21, P = 0.269, df (4, 19), LSD = n.s.

Maturity

In 2018/19, the maturity delay for fruit removal from fruiting branches 1-6 (1.32 days) was not significantly different from the control (180.06 days) while the later treatment (FB 7-12) was (4.22 days, Fig. 19). Peculiarly, the treatment with the highest fruit loss (FB 1-12) was not significantly late (2.29 days). Differences in maturity during the 2020/21 season were no more than 1 day (Fig 20).

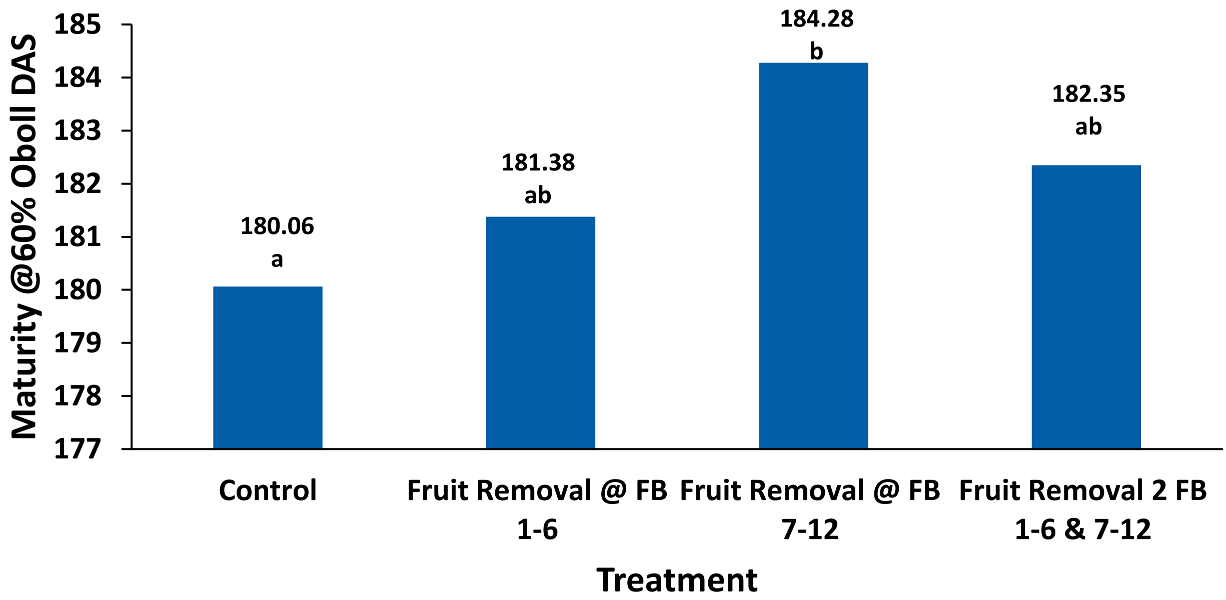


Figure 19: Maturity at Spring Ridge 2018/19, P = 0.032, df (4, 19), LSD = 2.75

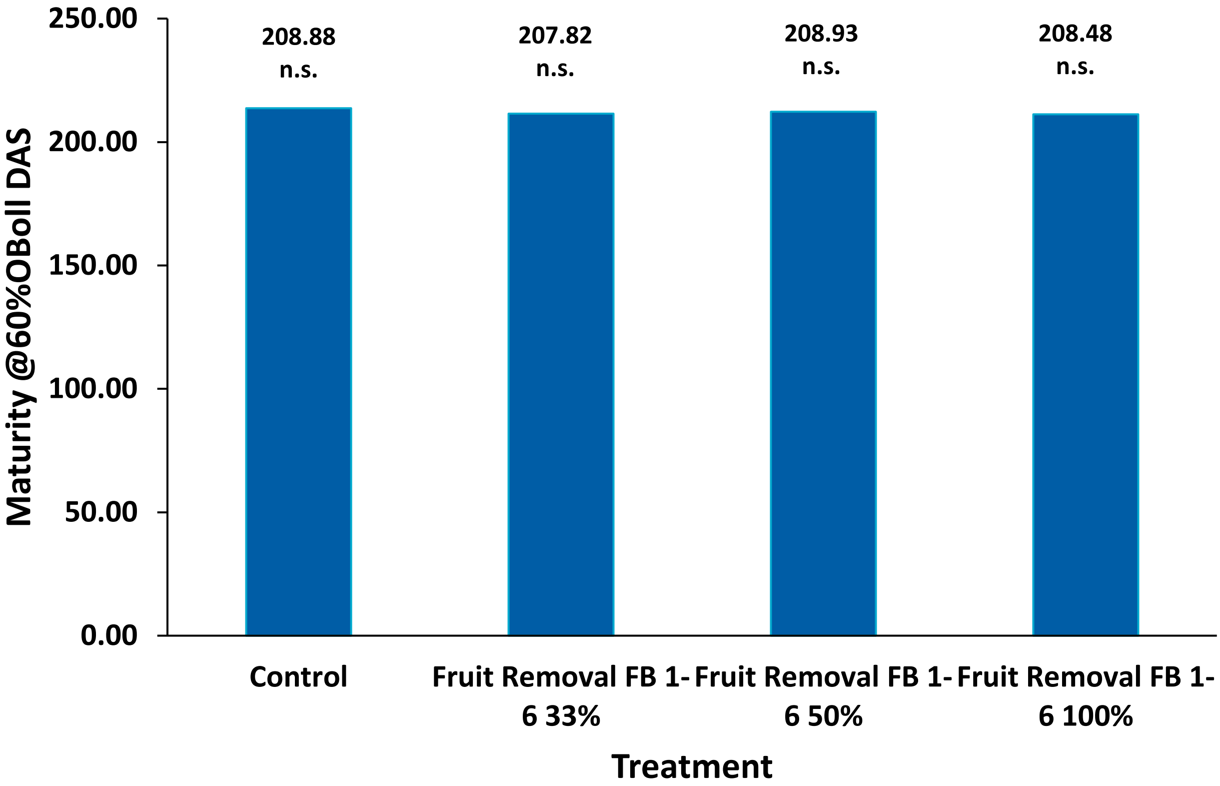


Figure 20: Maturity at Spring Ridge 2020/21, P = 0.879, df (4, 19), LSD = n.s.

Fruit Removal Discussion

The Pilot Study in 2017/18 gave us a good indication of extreme fruit loss below Node 12, which was implemented past peak flower and included the loss of green bolls, leading to a yield loss of 3.85 bales/ha (Appendix 1). Subsequent damage in this project was less severe with damage to fruiting branches 1-6 implemented before or during peak flower, and damage to fruiting branches 7-12 during late flowering and early boll formation (Table 2). Control yields in 2018/19 and 2020/21 were similar at 10 bales/ha indicating an average season. Yield was markedly lower for Controls in 2019/20 at 8.69 bales/ha. This season was marked by high temperatures during early squaring and flowering as well as several days of overcast, wet weather between the 7th and 19th of February. These environmental conditions would have contributed to fruit loss of the crop resulting in much lower yield.

Results for the 2018/19 season indicated that removing fruit from either the lower 6 or the middle 6 fruiting branches in the canopy incurred similar losses (2.0 vs 1.7 bales/ha) though statistically the results differed. Hence, the combined treatment (FB 1-12) resulted in significantly more yield loss but did not quite equal the combined losses for both treatments. In 2019/20 we were unable to carry out the second damage due to the rainfall in February and we only have data for the lesser damage at FB 1-6 which still caused a significant yield reduction (2.36 bales/ha). The treatment that we consistently implemented across the three seasons was the removal of fruit from fruiting branches 1-6 on 100% of plants in the plot (FB 1-6 – 100%). In 2020/21 this was our most severe treatment but it did not result in a significant yield loss (1 bale/ha). It can be argued that the statistical significance of loss will have no bearing on a grower's perception of loss. In realistic terms a loss of 1-1.5 bales/ha will not be acceptable to a grower. Lesser damage (FB 1-6 to 33% and 50% of the plot) also did not result in significant yield reductions.

Fruit loss from the lower six fruiting branches on 100% of plants had a significant impact on yield in two out of three seasons. The combined data set for the FB 1-6 – 100% treatment showed a significant yield loss over the three experiments indicating a trend with high variability between seasons. In seasons where climatic conditions are good, i.e. adequate water and warm temperatures, cotton crops in the Liverpool Plains have the capability to compensate for early fruit loss. The uncertainty lies in predicting which seasons are ideal and which are adverse, a risk that growers are unwilling to speculate on.

In both 2018/19 and 2020/21, boll weight and boll numbers did not differ significantly between treatments. However, their combination constitutes yield and it is plausible that boll numbers per metre drive yield more strongly. Correlation analyses have shown that bolls/m^2 is the major yield determinant (Worley *et al.*, 1974). For example, in 2018/19, fruit removal from FB 1-12 resulted in 33.2 fewer bolls than the Control treatment. Calculating at 3.45 g/boll and 41.5 % ginout, this would amount to 475 kg/ha of extra lint or 2.09 bales/ha in yield. It is therefore understandable why growers place high value on fruit retention.

Fruit loss can cause maturity delays between 1 and 5 days though that is strongly dependent on the season and the finishing conditions as demonstrated by the 2020/21 season, which had a very late finish (3 weeks later than the 2018/19 season) though the crop finished evenly, irrespective of damage.

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.21). The plot does not include all control treatments but we used a control yield of 11.43 bales/ha which we considered an average yield from 4 years of experiments. The graph shows that fruit loss accounts for 60% of yield reduction (R^2 = 0.6) and this figure can be improved to 76 % by removing the very low yield from 2019/20. However, it is important to note that there is not a steep decline in yield as fruit are removed, and the rate of yield loss may be much greater with the addition of abiotic factors that affect fruit retention.

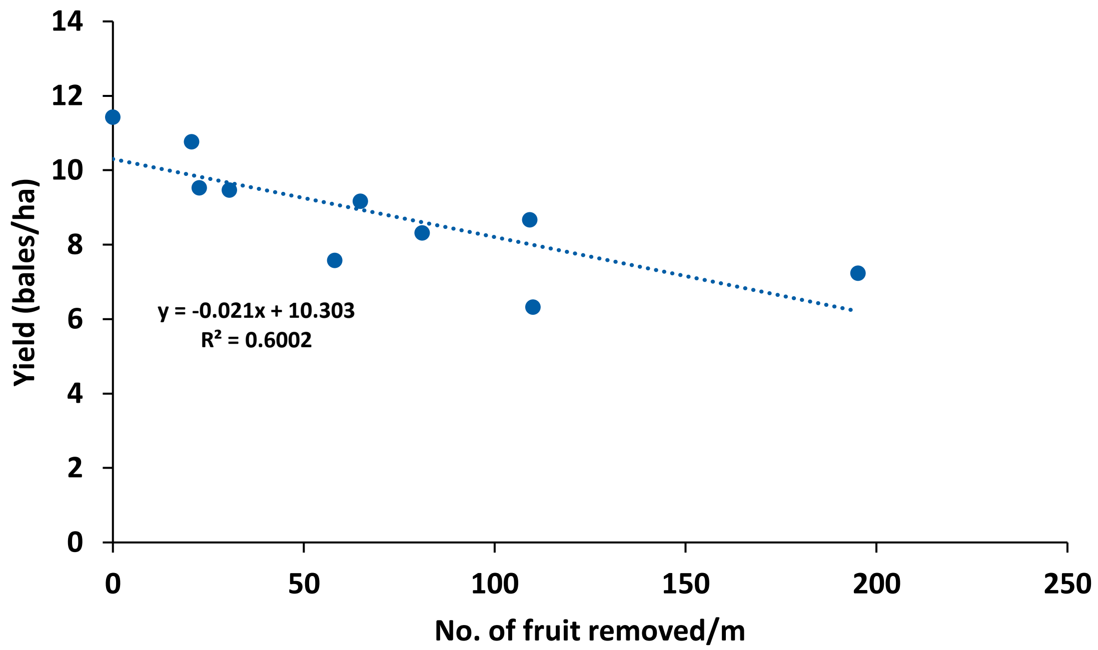


Figure 21: Relationship between fruit loss per metre and yield (bales/ha) at Spring Ridge, Liverpool Plains, NSW (2017/18-2020/21)

3.4 Does cotton compensate for fruit loss?

Segmented Pick Data 2019/20

A segmented pick of 2 m per plot was carried out on the 18/06/2020 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. Yield from segmented picks (Table 5) were very close to yields calculated from maturity picks, 8.97 vs 8.69 bales/ha for Controls and 6.18 vs 6.33 bales/ha for the FB1-6 (100%) treatment. There were no significant differences between treatments for several parameters measured including the number of vegetative branches per metre, number of bolls on vegetative branches, the number of bolls per vegetative branch, and the individual boll weight of bolls from vegetative branches. This indicates that any compensation that may have occurred, was not due to higher boll production on vegetative branches as has often been put forward for situations where plants were tipped out by insects. Lei (2000) suggested that tipped plants respond by forming several mainstems which means more lateral branches that can intercept light more efficiently and provide more potential fruiting sites and higher square production. There were also no significant differences in bolls weights of fruit from fruiting positions 1, 2, and 3, suggesting that yield differences were due to boll numbers.

Table 5: Segmented Pick parameters (treatment mean/m), Spring Ridge 2019/20

Treatment	No. Vegetative Branches	VB No. of Bolls	No Bolls/VB	VB Boll Wt (g/boll)	Position 1 Boll Wt (g/boll)	Position 2 Boll Wt (g/boll)	Position 3 Boll Wt (g/boll)	Total Yield (bales/ha)
Control	31.0	29.5	0.93	3.34	2.87	2.14	1.39	8.97
FB 1-6 (100%)	26.0	29.13	1.16	3.27	2.96	2.72	0.74	6.18*
P(0.0)	0.149	0.840	0.058	0.456	0.699	0.466	0.20	0.001
df					(1, 7)			
LSD	n.s.	n.s.	n.s.	n.s.	n.s	n.s.	n.s.	0.76

Data from the segmented picks are presented in diagrams of stylised cotton plants to enable a visual comparison (Figs 22 & 23). Figures in the plant maps summarise the number of bolls harvested from each stratum and fruiting position. Boll numbers were converted to yield in bales/ha and represent their contribution to total yield.

In Control plants, fruiting branches 1-12 were the major contributor to yield with a combined proportion of 73.35%. In these two strata, Position 1 and 2 bolls provided most of the lint (49.81 and 28.85%, respectively, Fig. 22). Therefore, in undamaged cotton plants, 71.98 % of yield is derived from the core of the plant in addition to 19.95% from bolls on vegetative branches. Only about 8 percent of yield came from Fruiting branches 13-17 or position 3 fruits. The difference in yield between the Control and fruit removal treatments was due to significant fruit loss from Positions 1 and 2 on fruiting branches 1-6 (-15.66% and -12.17%, Fig. 23). Overall the loss for fruiting branches 1-6 amounted to 27.59% of total yield. Within plant compensation occurred most strongly on fruiting

Figure 22: Segmented pick, 2019/20 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+ **Yield 0 bales/ha**			
Fruiting Branch Nodes 13-16 9.37 Bolls **Yield 0.60 bales/ha** **6.68%**	9.25 Bolls Yield 0.59 bales/ha 6.51%	0.12 Bolls Yield 0.01 bales/ha 0.11%	
Fruiting Branch Nodes 7-12 48.96 Bolls **Yield 3.51 bales/ha** **39.13%**	31.38 Bolls Yield 2.34 bales/ha 26.08%	17.20 Bolls Yield 1.13 bales/ha 12.69%	0.38 Bolls Yield 0.05 bales/ha 0.56%
Fruiting Branch Nodes 1-6 41.38 Bolls **Yield 3.07 bales/ha** **34.22%**	20.50 Bolls Yield 1.54 bales/ha 17.16%	19.50 Bolls Yield 1.44 bales/ha 16.05%	1.38 Bolls Yield 0.09 bales/ha 1.00%
Vegetative Branches and poorly developed fruiting branches without fruit 31 VB, 29.50 Bolls **VB Yield = 1.79 bales/ha** **19.95%**			Total Mainstem Bolls = 99.71 Yield 7.18 bales/ha 80.04% **Total Bolls = 129.13** **Total Yield 8.97 bales/ha**
Mainstem Nodes **Cotyledonary Nodes**	**Position 1** 61.13 Bolls **Yield 4.46 bales/ha** **49.81%**	**Position 2** 36.82 Bolls **Yield 2.58 bales/ha** **28.85%**	**Position 3** 1.76 Bolls **Yield 0.14 bales/ha** **1.56%**

Figure 23: Segmented pick, 2019/20 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+ 1 Boll **Yield 0.02 bales/ha** **0.32%** **+0.32%**	1 Boll Yield 0.02 bales/ha 0.32% +0.32%		
Fruiting Branch Nodes 13-16 14.38 Bolls **Yield 0.66 bales/ha** **10.67%** **+3.99%**	12.12 Bolls Yield 0.63 bales/ha 10.19% +3.68%	2.25 Bolls Yield 0.03 bales/ha 0.48% +0.37%	
Fruiting Branch Nodes 7-12 49.88 Bolls **Yield 3.43 bales/ha** **55.55%** **+16.42%**	28.75 Bolls Yield 2.22 bales/ha 35.59% +9.51%	20.00 Bolls Yield .17 Bales/ha 18.93% +6.24%	1.12 Bolls Yield 0.04 bales/ha 0.65% +0.09%
Fruiting Branch Nodes 1-6 7.00 Bolls* **Yield 0.41 bales/ha** **6.63%** **-27.59%**	2.00 Bolls* Yield 0.12 bales/ha 1.94% -15.66%	3.62 Bolls* Yield 0.24 bales/ha 3.88% -12.17%	1.38 Bolls Yield 0.05 bales/ha 0.81% - 0.19%
Vegetative Branches and poorly developed fruiting branches without fruit 26 VB, 29.13 Bolls **VB Yield = 1.66 bales/ha** **26.86%** **+7.36%**			Total Mainstem Bolls = 72.3* Yield 4.53 bales/ha 73.30% **Total Bolls = 101.4*** **Total Yield 6.18 bales/ha** **-31.10%**
Mainstem Nodes **Cotyledonary Nodes**	**Position 1** 43.87 Bolls* **Yield 2.99 bales/ha** **48.04%** **-1.77%**	**Position 2** 25.87 Bolls* **Yield 1.44 bales/ha** **23.29%** **-5.`56%**	**Position 3** 2.50 Bolls **Yield 0.09 bales/ha** **1.43%** **-0.13%**

branches 7-12 in Position 1 bolls (+9.51%) and position 2 bolls (+6.24%). Fruiting branches 13-17 only contributed 4.31 % but bolls on vegetative branches contributed another 7.36%. While the small, segmented yield contributions were not significant, combined they made up for the loss on fruiting branches 1-6. However, while the plant compensated for early losses, the overall compensation was not adequate to reach the yield of undamaged plants during the 2019/20 cotton season.

Segmented Pick Data 2020/21

At the end of the 2020/21 season, the segmented pick of 2 m per plot was carried out 2 months earlier, on the 25/04/2021. There were no significant differences in yield between the treatments (P=0.723, Table 6) and a maximum difference between the highest and lowest yielding treatments of 1.65 bales/ha (FB 1-6 – 33% > Control (-1.02b/ha) > Tipping @N7/8 (-1.12 b/ha) > FB 1-6 – 100% (-1.56 b/ha) > FB 1-6 – 50% (1.65 b/ha)). Control plots gained most of their yield from bolls set on vegetative branches (36.64%) followed by bolls on FB 7-12 and FB 1-6 ((31.40% + 26.39% = 57.79%, Fig. 24). Through the vertical axis, Position 1 and 2 bolls contributed 57.80 % to total yield, most through the middle stratum (FB 1-12), as seen in the same pattern during the 2019/20 season but with lower proportions for individual positions. Position 3 bolls and those from FB 13-17+ only contributed 10.26% to yield compared to 8.24% in 2019/20. The difference between 2019/20 and 2020/21 yields was small, only 0.2 bales/ha (8.97 vs 9.17 bales/ha) so we can compare the crop structure in relation to yield. During the 2020/21 season, bolls from vegetative branches contributed 18.85% more to yield than in 2019/20 despite there being fewer vegetative branches though with double the number of bolls per branch.

Table 6: Segmented Pick parameters for vegetative branches (treatment mean/m)

Treatment	No. Vegetative Branches	VB No. of Bolls	No Bolls/VB	VB Boll Wt (g/boll)	VB Yield (bales/ha)	Total TRT Yield (bales/ha)	VB Ginout %
Control	20.50 ^{b}	42.00 (9.1)	2.16 ^{b}	4.33 ^{a}	3.36 ^{b}	9.17	42.15
Tipping @N7/8	23.10 ^{ab}	76.40 (1.5)	3.50 ^{a}	3.79 ^{b}	5.41 ^{b}	9.07	42.99
FB 1-6 (33%)	20.90 ^{bc}	50.50 (3.9)	2.41^{b}	4.17 ^{b}	3.99 ^{b}	10.19	42.64
FB 1-6 (50%)	16.90 ^{c}	45.60 (12.1)	2.76 ^{b}	4.82 ^{a}	3.99 ^{b}	8.54	43.07
FB 1-6 (100%)	25.40 ^{a}	67.80 (4.8)	2.60 ^{b}	3.83 ^{b}	4.88 ^{a}	8.63	43.31
P(0.0)	0.004	0.126 (0.170)	0.013	0.011	0.178	0.723	0.809
df			(4, 19)				(4, 79)
LSD	3.715	n.s.	0.696	0.563	n.s.	n.s.	n.s.

Note: No. of green bolls (GB) in brackets

The Tipping treatment yielded 0.1 bale/ha (-1.1%) less than the Control. Mainstem fruit contributed 40% to yield and yield contribution changed mainly through the FB 1-6 (-6.22%) and the FB 7-12 (-12.11%) strata and a significantly reduced contribution of the FB 13-16 stratum (-4.53%, Fig. 25). Bolls in Position 1, 2 and 3 were also affected (-10.27, -8.84 & -3.59%, respectively). However, tipped plants compensated by producing more bolls on vegetative branches which contributed about 60% to total yield. This supports Lei's (2000) suggestion that tip damage by insects does not necessarily result in significant yield loss as plants produced more stems and fruiting positions. Last season, we could not demonstrate this as plants in both treatments produced the same number of bolls on vegetative branches with the same boll weight (Table 5). Bolls on vegetative branches weighed significantly less than control bolls (Table 7) but plants produced enough mature bolls to match yields. While none of the plots had significant numbers of green bolls, the Control plot had more at picking than the Tipping treatment (9.1 vs 1.5).

The plant structure of the FB 1-6 – 33% treatment resembled most closely that of Control plants with the mainstem contributing about 60% and vegetative branches about 39% to total yield (Fig. 26). Small losses occurred through the FB 1-6 stratum (-3.82%) and Position 1 Bolls (-7.65%) but there was a small but significant gain through the FB 13-16 stratum in Position 1 fruit (+1.37%). The main reason that the yield was 1.02 bale/ha (+11.12%, n.s.) higher than the Control yield was that bolls in the FB 1-6 – 33% were heavier than Control bolls in almost every stratum and position (Table 7).

Damaging FB 1-6 on 50% of plants in the plot resulted in a yield of 8.54 bales/ha, a non-significant yield reduction of 0.63 bales/ha from the Control treatment. Mainstem fruit contributed about 53% while Vegetative branches contributed 47% to yield. The main losses occurred through the FB 1-6 stratum of Position 1 (significant) and 2 bolls (n.s., Fig 26)). Small gains were made through the FB 7-1 stratum in P2 and P3 bolls (+2.23 and +0.82%) but within the plant, the main compensation came from vegetative branch bolls (+11%). While boll weights were as high as for the 33% treatment (Table 7), there were about 25 bolls/m less. Overall, the crop did not compensate for the yield loss with a reduction of nearly 7% compared to the Control.

In the FB 1-6 – 100% treatment, yield was reduced by 0.55 bales/ha to 8.63 bales/ha (-6%). Mainstem bolls contributed 41% and Vegetative branch bolls 57% (Fig.27). Significant losses occurred through the FB 1-6 Position 1 bolls with further losses through strata FB 7-16, and Position 2 bolls. Very small within plant gains occurred at in the upper strata at Positions 1, 2 and 3 (+1.05% total). Position 1 boll numbers on FB 1-6 were much lighter than P2 and 3 bolls in that stratum (Table 7). When comparing to the 2019/20 data, plants in 2020/21 did not compensate within the plant through the higher strata or Positions 2 and 3. Most of their within plant compensation occurred on Vegetative Branches (+19.90 cf +7.36%).

Ginout percentages were not significant but were more variable for bolls higher up in the canopy and for Position 3 bolls (Table 8). Boll weight was also not significant but was more consistent through FB 7-12 for Position 1 and Position 2 bolls.

Table 7: Boll weights for Spring Ridge Experiment 2020/21

TRT	Position 1				Position 2				Position 3			
	FB 1-6	FB 7-12	FB 13-16	FB 17+	FB 1-6	FB 7-12	FB 13-16	FB 17+	FB 1-6	FB 7-12	FB 13-16	FB 17+
Control	5.64	4.43	2.78	0	4.89	3.04	1.92	0	3.47	3.01	0	0
Tipping @ N 7/8	5.11	3.84	1.63	0	3.55	2.57	1.19	0	7.73	1.06	0	0
FB 1-6 – 33%	6.39	4.56	2.82	0.86	4.79	2.99	4.02	0	4.71	3.45	0.79	0
FB 1-6 – 50%	6.53	4.64	3.00	0	7.49	3.11	1.56	0	4.99	3.21	0	0
FB 1-6 – 100%	3.67	4.61	2.76	0.55	6.62	3.24	2.53	0	4.89	5.60	0	0
P (0.05)	0.505				0.312				0.46			
Df	(12, 79)											
LSD	n.s.				n.s.				n.s.			

Table 8: Ginout percentages for Spring Ridge Experiment 2020/21

TRT	Position 1				Position 2				Position 3			
	FB 1-6	**FB 7-12**	**FB 13-16**	**FB 17+**	**FB 1-6**	**FB 7-12**	**FB 13-16**	**FB 17+**	**FB 1-6**	**FB 7-12**	**FB 13-16**	**FB 17+**
Control	42.59	43.3	40.1	0	43.20	39.46	18.46	0	41.60	42.10	0	0
	(0.13)	(0.50)	(0.13)		(0.25)				(0.13)			
Tipping @ N 7/8	42.90	43.00	27.30	0	44.24	41.75	14.15	0	28.30	20.00	11.4	0
		(0.12)				(0.50)			(0.25)			
FB 1-6 – 33%	39.00	44.00	39.00	17.70	42.08	40.72	35.02	0	37.90	36.90	10.	0
		(0.50)					(0.38)		(0.13)			
FB 1-6 – 50%	43.20	43.9	40.20	0	44.64	40.72	36.99	0	37.00	40.10	7.9	0
	(0.13)		(1.25)		(0.13)		(0.25)					
FB 1-6 – 100%	30.90	42.40	38.20	11.20	33.55	39.21	23.56	0	35.70	35.60	5.5	0
P (0.05)	0.443				0.056				0.477			
Df	(12, 79)											
LSD	n.s.				n.s.				n.s.			

Figure 23: 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+ 0 Bolls **Yield 0 bales/ha**	0 Bolls Yield bales/h		
Fruiting Branch Nodes 13-16 9.63 Bolls **Yield 0.47 bales/ha** **5.13%**	8.50 Bolls Yield 0.42 bales/ha 4.58%	0.88 Bolls Yield 0.05 bales/ha 0.55%	0.25 Bolls Yield 0.01 bales/ha 0.11%
Fruiting Branch Nodes 7-12 40.22 Bolls **Yield 2.88 bales/ha** **31.40%**	23.80 Bolls Yield 2.00 bales/ha 21.81%	13.8 Bolls Yield .73 bales/ ha 7.96%	2.62 Bolls Yield 0.15 bales/ha 1.64%
Fruiting Branch Nodes 1-6 26.25 Bolls **Yield 2.42 bales/ha** **26.39%**	11.12 Bolls Yield 1.14 bales/ha 12.43%	10.38 Bolls Yield 0.96 bales/ ha 10.46%	4.75 Bolls Yield 0.32 bales/ha 3.49%
Vegetative Branches and poorly developed fruiting branches without fruit 20.50 VB, 42.00 Bolls **VB Yield = 3.36 bales/ha** **36.64%**			Total Mainstem Bolls = 76.35 Yield 5.77 bales/ha 62.92% **Total Bolls = 118.35** **Total Yield 9.17 bales/ha**
Mainstem Nodes **Cotyledonary Nodes**	**Position 1** 43.67 Bolls **Yield 3.56 bales/ha** **38.82%**	**Position 2** 25.06 Bolls **Yield 1.74 bales/ha** **18.98%**	**Position 3** 7.62 Bolls **Yield 0.47 bales/ha** **5.13%**

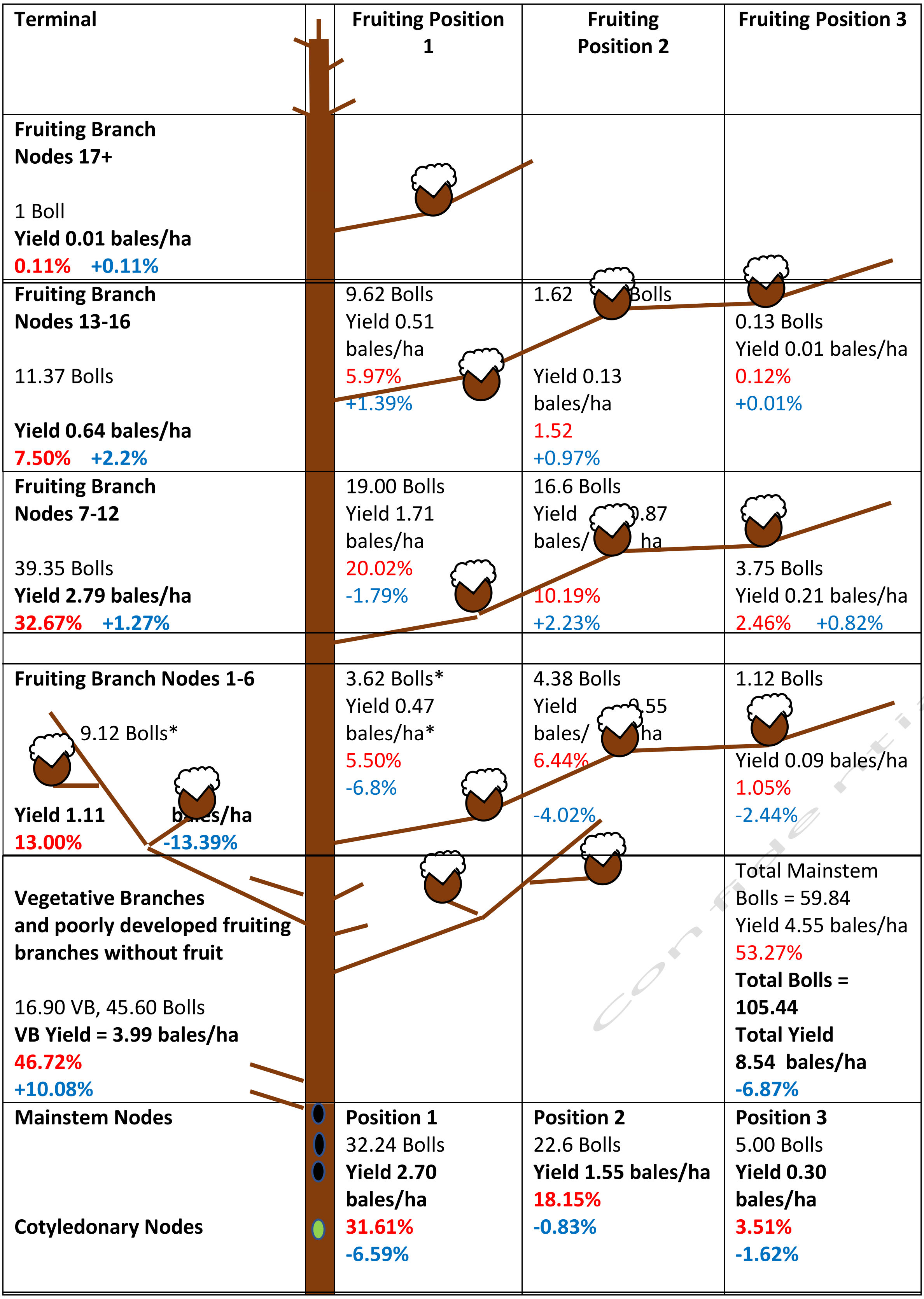
Figure 25: Segmented pick, 2020/21Tipping @ Node 7 (data are mean per metre of row). The yield for each stratum and each boll position is summarised in bold black figures. The percentage contributions of each segment (bales/ha) to total yield are signified in red, while the difference for each segment (bales/ha) from the figures in the Control treatment are shown in blue (Fig 24). 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+ **+0.11%**		Bolls Yield 0.01 bales/ha 0.11%		
Fruiting Branch Nodes 13-16 2.12 Bolls **Yield 0.07 bales/ha*** **0.77%** **-4.53%**		1.88 Bolls* Yield 0.06 bales/ha* 0.66% -3.92%	0.25 Bolls Yield 0.001 bales/ha 0.11% -0.44%	
Fruiting Branch Nodes 7-12 25.63 Bolls **Yield 1.75 bales/ha** **19.29%** **-12.11%**		18.00 Bolls Yield 1.35 bales/ha 14.88% -6.93%	6.88 Bolls Yield 0.37 bales/ha 4.08% 3.88%	0.75 Bolls Yield 0.03 bales/ha 0.33% -1.31%
Fruiting Branch Nodes 1-6 19.96 Bolls **Yield 1.83 bales/ha** **20.17%** **-6.22%**		11.88 Bolls Yield 1.19 bales/ha 13.12% +0.77%	7.20 Bolls Yield 0.54 bales/ha 5.95% -4.65%	0.88 Bolls* Yield 0.10 bales/ha 1.1% -2.39%
Vegetative Branches and poorly developed fruiting branches without fruit 23.13 VB, 76.40 Bolls **VB Yield = 5.41 bales/ha** **59.64%** **+23.00%**				Total Mainstem Bolls = 47.72 Yield 3.65 bales/ha 40.24% **Total Bolls = 124.12** **Total Yield 9.07 bales/ha** **-1.09%**
Mainstem Nodes **Cotyledonary Nodes**		**Position 1** 31.76 Bolls **Yield 2.59 bales/ha** **28.55%** **-10.27%**	**Position 2** 14.33 Bolls **Yield 0.92 bales/ha** **10.14%** **-8.84%**	**Position 3** 1.63 Bolls **Yield 0.14 bales/ha** **1.54%** **-3.59%**

Figure 26: 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 24). 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+ 0.25 Boll **Yield 0.01 bales/ha** **0.01% +0.01%**	0.25 Bolls Yield 0.01 bales/ha 0.01%		
Fruiting Branch Nodes 13-16 13.13 Bolls **Yield 0.68 bales/ha** **6.67% +1.37%**	10.25 Bolls Yield 0.50 bales/ha* 4.90% +0.32%	2.75 Bolls Yield 0.17 bales/ha 1.67% +1.12%	0.13 Bolls Yield 0.01 bales/ha 0.01% -0.1%
Fruiting Branch Nodes 7-12 43.78 Bolls **Yield 3.22 bales/ha** **31.60% +0.2%**	24.20 Bolls Yield 2.16 bales/ha 21.20% -0.61%	15.2 Bolls Yield [illegible].81 bales/ha 7.95% -0.01%	4.38 Bolls Yield 0.25 bales/ha 2.45% +0.81%
Fruiting Branch Nodes 1-6 24.22 Bolls* **Yield 2.30 bales/ha** **22.57% -3.82%**	12.12 Bolls Yield 1.23 bales/ha 12.75% +0.32%	9.12 Bolls Yield 0.86 bales/ha 8.44% -2.02%	2.88 Bolls Yield 0.21 bales/ha 2.06% -1.43%
Vegetative Branches and poorly developed fruiting branches without fruit 20.90 VB, 50.50 Bolls **VB Yield = 3.99 bales/ha** **39.15% +2.51%**			Total Mainstem Bolls = 72.3 Yield 6.19 bales/ha 60.74% **Total Bolls = 126.97** **Total Yield 10.19 bales/ha** **+11.12%**
Mainstem Nodes **Cotyledonary Nodes**	**Position 1** 46.82 Bolls **Yield 3.89 bales/ha** **31.17%** **-7.65%**	**Position 2** 27.15 Bolls **Yield 1.84 bales/ha** **18.06%** **-0.92%**	**Position 3** 2.50 Bolls **Yield 0.46 bales/ha** **4.51%** **-0.62%**

Figure 27: 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 24). 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+ 1 Boll **Yield 0.01 bales/ha** **0.11% +0.11%**			
Fruiting Branch Nodes 13-16 11.37 Bolls **Yield 0.64 bales/ha** **7.50% +2.2%**	9.62 Bolls Yield 0.51 bales/ha 5.97% +1.39%	1.62 Bolls Yield 0.13 bales/ha 1.52 +0.97%	0.13 Bolls Yield 0.01 bales/ha 0.12% +0.01%
Fruiting Branch Nodes 7-12 39.35 Bolls **Yield 2.79 bales/ha** **32.67% +1.27%**	19.00 Bolls Yield 1.71 bales/ha 20.02% -1.79%	16.6 Bolls Yield 0.87 bales/ha 10.19% +2.23%	3.75 Bolls Yield 0.21 bales/ha 2.46% +0.82%
Fruiting Branch Nodes 1-6 9.12 Bolls* **Yield 1.11 bales/ha** **13.00% -13.39%**	3.62 Bolls* Yield 0.47 bales/ha* 5.50% -6.8%	4.38 Bolls Yield 0.55 bales/ha 6.44% -4.02%	1.12 Bolls Yield 0.09 bales/ha 1.05% -2.44%
Vegetative Branches and poorly developed fruiting branches without fruit 16.90 VB, 45.60 Bolls **VB Yield = 3.99 bales/ha** **46.72%** **+10.08%**			Total Mainstem Bolls = 59.84 Yield 4.55 bales/ha 53.27% **Total Bolls = 105.44** **Total Yield 8.54 bales/ha** **-6.87%**
Mainstem Nodes **Cotyledonary Nodes**	**Position 1** 32.24 Bolls **Yield 2.70 bales/ha** **31.61%** **-6.59%**	**Position 2** 22.6 Bolls **Yield 1.55 bales/ha** **18.15%** **-0.83%**	**Position 3** 5.00 Bolls **Yield 0.30 bales/ha** **3.51%** **-1.62%**

Figure 28: 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+ 0.38 Bolls **Yield 0.01 bales/ha** **0.11% +0.11%**	0.38 Bolls Yield 0.01 bales/ha 0.11%		
Fruiting Branch Nodes 13-16 7.25 Bolls **Yield 0.36 bales/ha** **4.17% -0.96%**	6.00 Bolls Yield 0.29 bales/ha 3.36% -1.14%	1.12 Bolls Yield 0.05 bales/ha 0.58% +0.03%	0.13 Bolls Yield 0.01 bales/ha 0.11% -0%
Fruiting Branch Nodes 7-12 33.78 Bolls **Yield 2.49 bales/ha** **28.85% -2.55%**	17.10 Bolls Yield 1.54 bales/ha 17.84% -3.97%	12.8 Bolls Yield .73 bales/ha 8.46% -0.50%	3.88 Bolls Yield 0.22 bales/ha 2.55% +0.91%
Fruiting Branch Nodes 1-6 10.88 Bolls* **Yield 0.89 bales/ha** **10.31% -16.08%**	3.50 Bolls * Yield 0.32 bales/ha* 3.71% -8.72%	4.50 Bolls Yield 0.38 Bales/ha 4.40% -6.06%	2.88 Bolls Yield 0.20 bales/ha 2.32% -1.17%
Vegetative Branches and poorly developed fruiting branches without fruit 25.40 VB, 67.80 Bolls **VB Yield = 4.88 bales/ha** **56.54%** **+19.90%**			Total Mainstem Bolls = 52.29 Yield 3.75 bales/ha 40.55% **Total Bolls = 120.09** **Total Yield 8.63 bales/ha** **-5.89%**
Mainstem Nodes **Cotyledonary Nodes**	**Position 1** 26.98 Bolls **Yield 2.16 bales/ha** **25.03%** **-13.79%**	**Position 2** 18.42 Bolls **Yield 1.16 bales/ha** **13.98%** **-5.00%**	**Position 3** 6.89 Bolls **Yield 0.43 bales/ha** **4.98%** **-0.32%**

Compensation Discussion

We analyzed two years of segmented picking data to gain more information about where on the plant compensation – if any – would occur. We had two very different seasons, 2019/20, a drought year with high day and night temperatures during January, and 2020/21, a wetter year with cooler temperatures during flowering. Yield data from the segmented picks were presented visually in stylised plant diagrams (Figs 22-28) and treatments were compared to their respective Controls. The comparison was expressed as a percentage of contribution to total yield. These percentages were then regarded as either losses or gains at their designated location on the plant.

As expected, in undamaged plants Position 1 and 2 bolls of the lower 12 Fruiting branches were the main contributors to yield (Table 9). The next largest contribution was from bolls on vegetative branches and the remainder of yield was contributed by position3 bolls and bolls from Fruiting Branch 13 upwards. However, season plays an important part as evidenced by the 17-18 percent shift in the proportions of FB 1-2 and Vegetative branches between the 2 years of data. The difference in the remaining positions was only small (3%).

Table 9: Summary of yield contribution by different areas of cotton plants, Spring Ridge 2019/20-2020/21.

Treatment	Mainstem FB 1-12 P1&2	Vegetative Branches	Mainstem FB 13+, P1,2 &3
Control 2019/20	72%	20%	8%
Control 2020/21	54%	37%	11%
Tipping 2020/21	38%	60%	2%
FB1-6 – 33% 2020/21	51%	40%	9%
FB 1-6 – 50% 2020/21	42%	47%	11%
FB 1-6 – 100% 2019/20	60%	27%	12%
FB 1-6 – 100% 2020/21	35%	57%	8%

This is mirrored in the two years of data for the FB 1-6 – 100% treatment. While fruit loss from the lower Fruiting branches altered the strata and position contributions to yield, there were 30-35% discrepancies between the figures for the two years but only a small difference (4%) between the remaining positions.

Tipping and fruit loss from the lower 6 Fruiting branches markedly altered the locations of where fruit set through the plant. Tipping increased the contribution from Vegetative branches at the expense of mainstem positions. This is more supportive of the ideas from Lei (2000) regarding vegetative branch compensation after tipping by insects, though it appears that insect damage is not the sole factor in this shift. Sadras (1996) demonstrated that damage to the terminal in cotton plants allowed yield increases in their neighbours which led to complete or overcompensation at the crop level.

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. The FB 1-6 – 33 % treatment illustrated this well as within the plants subtle changes in boll number and weights resulted in marginally higher yield. Similar changes in boll distribution could be seen in the FB 1-6 – 50% treatment but with more fruit loss, and no compensation. Overall though, boll weights were not lower than the Control boll weights.

At the individual plant level, compensation will occur whenever a plant is damaged. How well a plant compensates depends on what its neighbours are doing. Therefore, the 100% damage treatment represents abiotic rather than insect damage as heat waves or water limitations would affect a crop more uniformly. Our results for this treatment show large seasonal variability. During 2019/20 the larger contribution to yield came via mainstem branches 1-12 and Position 1 and 2 bolls with less than one-third of yield being contributed by bolls from Vegetative branches. Yield in this year was greatly reduced. While boll weight was not affected, the total number of bolls was reduced. In the 2020/21 season those mainstem bolls made up only 35% of yield with 57% from Vegetative branch bolls but little reduction in yield as neither boll weights nor numbers were affected. This suggests that, given adequate resources and spared abiotic stress, yield loss after extensive crop damage may be influenced by good management.

Our experiments have shown that a small degree of fruit loss can be tolerated without yield loss in the Liverpool Plains as plants can compensate for 33% damage during early and mid-flowering. The question is one of risk as to how favourable the season may be to support plant compensation or bring additional environmental stresses that cause fruit loss and hamper compensation. Understanding compensatory responses and plant damage thresholds helps us to develop better economic pest thresholds, which for mirids in the Liverpool Plains, may differ from those used in other growing areas.

4. Conclusion

Fruit loss in cotton may be due to insect damage or abiotic stresses. Artificial damage can simulate both scenarios, though the interpretation of extreme damage may be biased due to crop compensation. We carried out tip and fruit damage under different seasonal scenarios which affected how crops responded to damage and highlighted the importance of seasonal conditions for compensation in a cool-season area. Tipping combined with severe abiotic stress (heat and limited water) could significantly reduce crop yield and delay maturity which happened in 1 out of 3 seasons. Fruit removal from FB 1-6 in 100% of plants resulted in significant yield loss in 2 out of 3 seasons and fruit loss from FB 7-12 may cause equally unacceptable yield loss. Under good seasonal conditions, however, plants may be able to compensate, and reduced damage to only one-third of the crop may stimulate overcompensation. Maturity was affected in 1 out of 2 years but only for damage to the FB 7-12 stratum in the drought year. The implications of being able to tolerate damage to lower fruiting branches during flowering are important for Integrated Pest Management, as even one delayed spray would enable beneficial insects to build their populations. This would work towards the Cotton industry’s goal of reducing pesticide use and reducing costs for growers while supporting their natural pest control. More detailed experiments over a longer period would greatly improve the strength of the data.

5. References

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Appendix 1: Results from 2017/18 Pilot Study

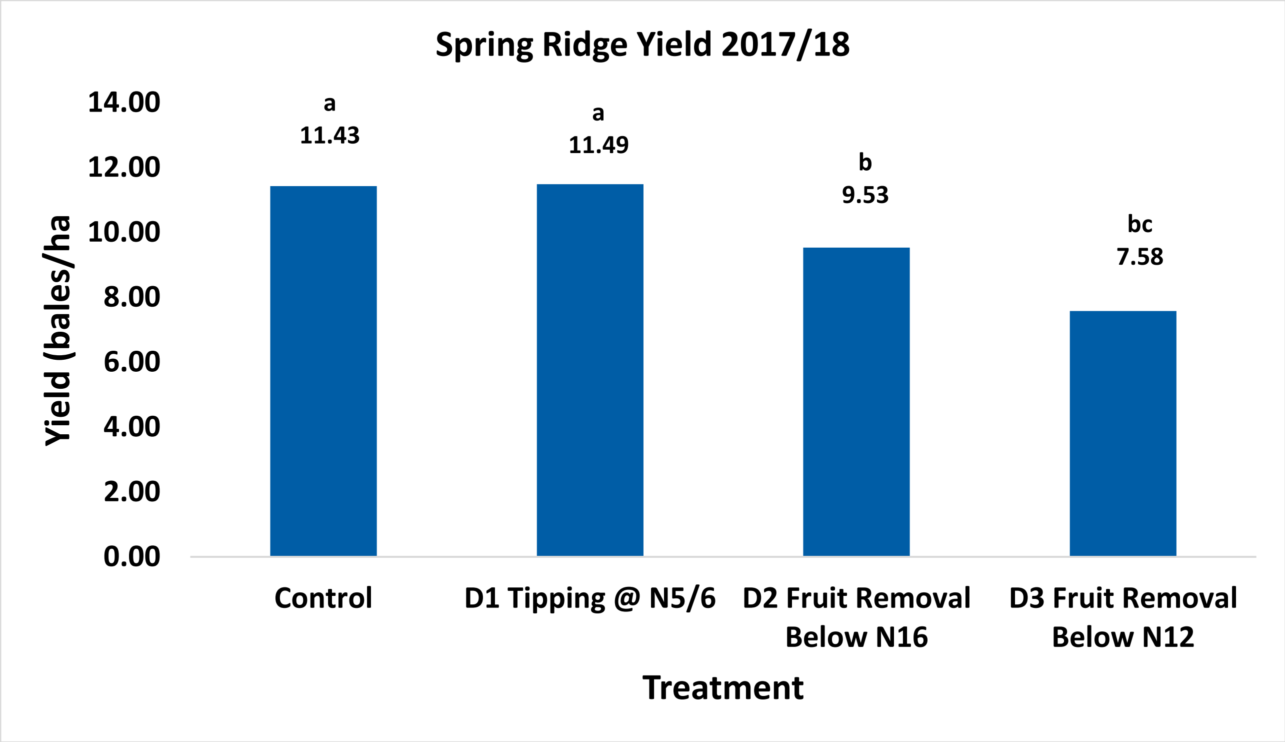

Figure 1: Yield at Spring Ridge 2017/18, P <0.001, LSD = 1.34. Note that D3 Fruit Removal below N12 occurred past peak flower and included the removal of fully formed green bolls.

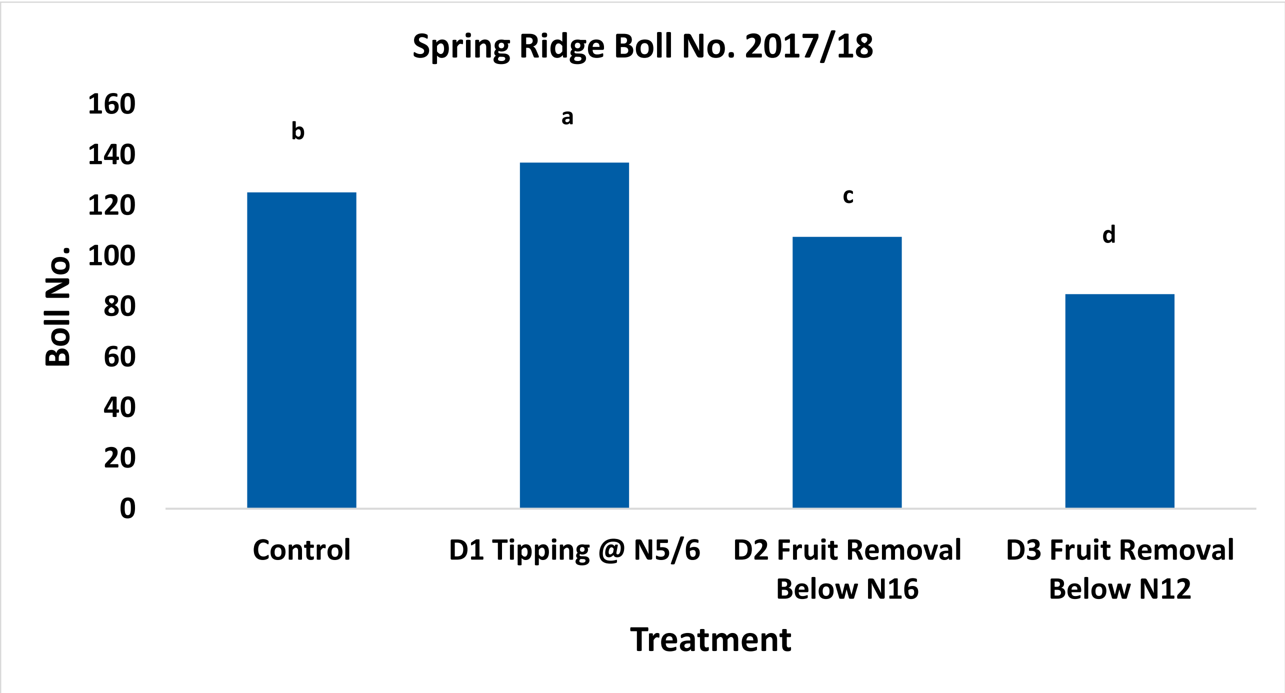

Figure 2: Boll Numbers at Spring Ridge 2017/18, P < 0.001, LSD = 16.18

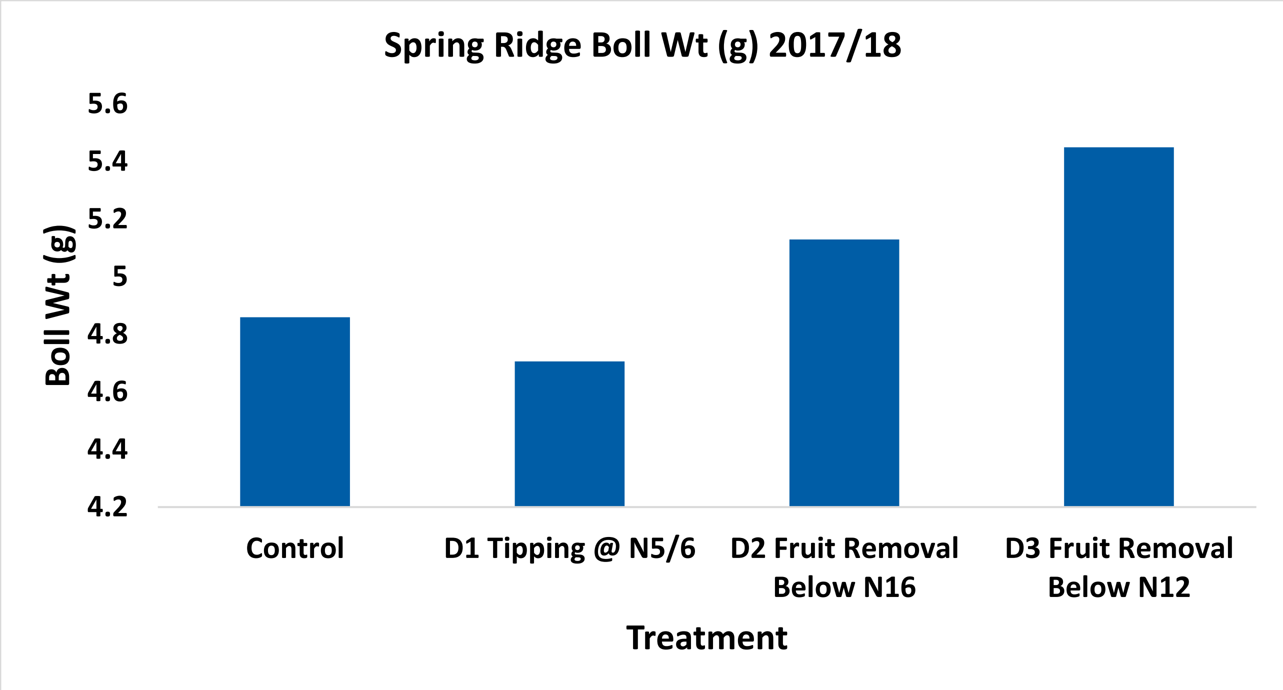

Figure 3: Boll Weights at Spring Ridge 2017/18, P = 0.185, LSD = n.s.

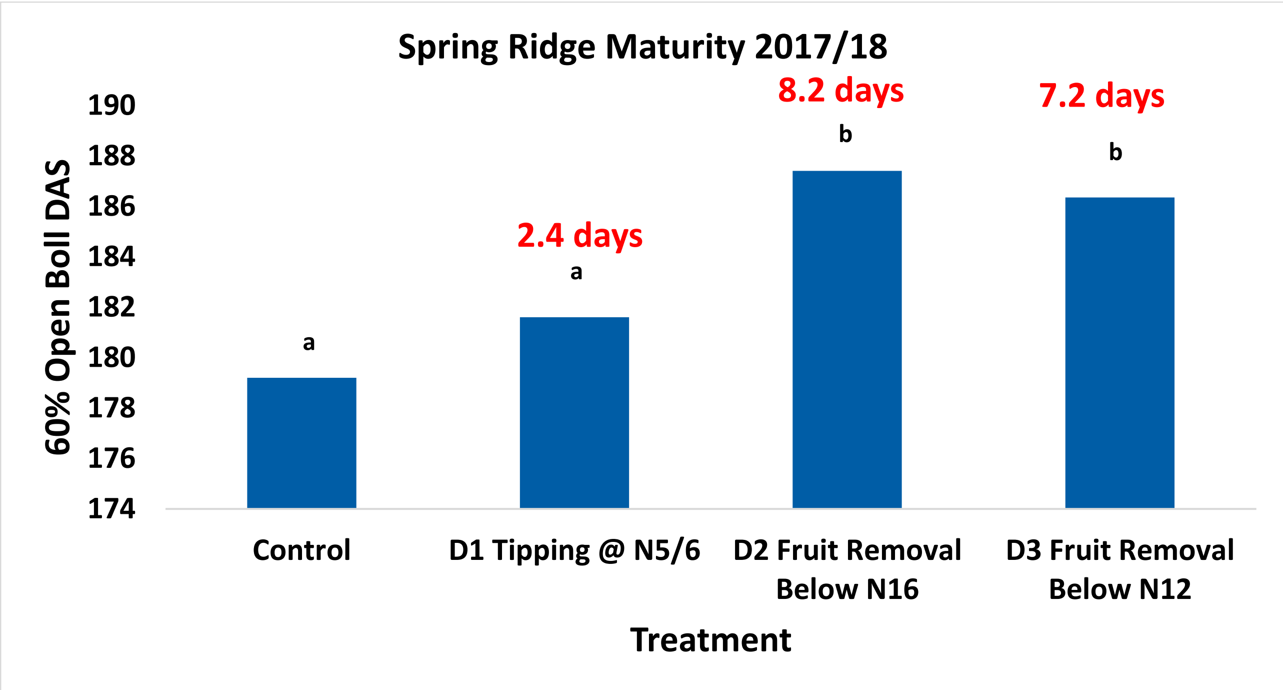

Figure 4: Maturity at Spring Ridge 2017/18, P <0.001, LSD = 3.9

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