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AGRONOMY AND SOILS

Cotton Response to Simulated Hail Damage and Stand Loss in Central Texas

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ABSTRACT

Hail damage poses a significant threat to many cotton-producing regions in the U.S. Stand reductions, or loss of leaves, stem, and fruit can occur from these events, and growers must make critical management decisions on whether to keep or replant a damaged crop. To address these questions, field trials were conducted near College Station, TX in 2012 to 2014 to investigate the impact of stand loss and node removal on yield under both dryland and irrigated conditions. To simulate stand losses, stands of three different varieties seeded at 111,197 seed ha^{-1} were thinned by up to 84%. The critical plant population where yield reductions occurred was inconsistent under irrigated conditions, depending upon the year. Consistent yield losses were experienced only when 84% stand reduction occurred under dryland conditions. To investigate the impact of node removal, field trials were conducted where the upper portions of cotton plants were clipped at 2-, 4-, 8-, 12-, 16-, and 20-node growth stages. Significant yield losses were experienced only when clipping occurred early in the season, between the 2- and 8-node growth stages.

Crop damage from severe weather such as hailstorms poses a significant threat to cotton (*Gossypium hirsutum* L.) production in many regions. In an analysis of U.S., hail fall data derived from NEXRAD from 2007 to 2010, Cintineo et al. (2012) revealed that the majority of the southeastern U.S. experiences an increased frequency of hail during April as compared to western and northern states. Hail frequency is greatest during the month of June, primarily in the Central U.S., including major cotton-producing regions of Texas. Furthermore, Changnon and Changnon (1999) observed that hail events were trending upward across the High Plains of the U.S., including most of Oklahoma and the large cotton-producing regions of northwest Texas. From 2010 to 2014 in the U.S., an average of more than 111,000 hectares of cotton was damaged by hail annually, resulting in average annual indemnity payments of more than $8 million (USDA-RMA, 2017). Hail events can cause varying degrees of damage, possibly resulting in stand loss (plant mortality) and/or injury (loss of or damage to plant tissue). The decision of whether to replant a field following hail damage can be difficult due to the effort and costs involved.

Cotton grown with reduced population densities has shown the ability to compensate by producing a greater number of fruiting sites, retaining a greater proportion of fruit, and producing larger bolls (Bednarz et al., 2000). Irrigated cotton grown in North Carolina at a population of 20,000 plants ha^{-1} resulted in similar cumulative yield as that produced by populations of 120,000 plants ha^{-1} (Jones and Wells, 1998). Bolls from plants grown at 20,000 plants ha^{-1} were generally larger, and a greater portion of harvestable yield came from flowers produced later in the season as compared to plants grown at 120,000 plants ha^{-1} (Jones and Wells, 1998). Smith et al. (1979) found that irrigated cotton grown in Arkansas at a population of 33,976 plants ha^{-1} produced lower yields than cotton grown at populations of 101,595 plants ha^{-1} but did not differ from the yield of populations of 169,880 plants ha^{-1}. Additionally, no differences in fiber length, strength, elongation, or micronaire were observed among these three plant populations (Smith et al., 1979). In studies conducted in Virginia and North Carolina, O’Berry et al. (2008) found that cotton yields were reduced at plant populations below 53,000 plants ha^{-1}. Furthermore, in a four-year irrigated study in the Mississippi Delta, Wrather et al. (2008) found that lint yield was lower from populations of 23,782 plants ha^{-1} compared to populations of 33,976 to 135,904 plants ha^{-1} in two years but provided yields comparable to higher populations in the other two years of the study.

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Following a hail event over cotton variety trials in Georgia, Peacock and Hawkins (1974) found the yield of severely injured plants (those with loss of the terminal and extensive stem and leaf injury) was decreased by more than 79% as compared to those with only slight damage. In addition, severely injured plants exhibited a lower percentage of lint than those with lesser degrees of injury. Longer and Oosterhuis (1999) found that the loss of the first true leaf along with one cotyledon nine days after emergence reduced lint yields by 5 to 71%, depending upon environmental conditions following defoliation. Under favorable conditions, such as those in a growth chamber, cotton showed great potential for recovery and regrowth. Temperature and moisture stress limited regrowth in field studies, but substantial recovery was seen when more favorable growing conditions returned (Longer and Oosterhuis, 1999).

When subjected to defoliation, earlier maturing cotton varieties have been observed to recover more quickly than later maturing genotypes (Smith and Varvil, 1984). In Pima cotton (*Gossypium barbadense* L.), Kittock et al. (1976) observed differences among genotypes in their regrowth ability following hail damage. In this study, a negative correlation was found between the yield potential of the genotype and the ability of that genotype to produce new leaf tissue after hail damage. To assist growers in assessing hail damage to cotton in Arizona, Wang (2011) outlined a method where yield losses are estimated based on the number of destroyed or damaged plants using USDA cotton loss standards (USDA-FCIC, 2017). By this method, hail damage during vegetative stages of growth is recorded as the number of plants destroyed in a 3-m row-length sample; damage in the surviving plants is evaluated and USDA-FCIC (2017) standards are used to estimate yield based on the stage of growth and position on the main stem where damage occurred (Wang 2011). When hail damage occurs during reproductive stages of growth, Wang described a similar method where the growth stage and position of damage, number of fruiting branches destroyed, and the number and size of bolls destroyed were used to estimate yield loss based on USDA-FCIC (2017) standards.

To better understand cotton's ability to recover from hail damage in Central Texas, research was conducted to investigate the impacts of stand loss and node removal at different stages of growth on cotton lint yield across genotypes.

MATERIALS AND METHODS

Experiment 1. Stand Reduction. Trials were conducted at the Texas A&M AgriLife Research Farm at Snook, TX from 2012 to 2014 to evaluate various levels of cotton stand loss when grown under dryland and irrigated conditions. Treatments were arranged in a factorial arrangement within a randomized complete block design with three replications. Factor A consisted of three cotton varieties and Factor B consisted of six levels of stand reduction. In 2012, cotton was grown on a Ships clay, whereas cotton in 2013 and 2014 was grown on a Weswood silty clay loam. Plots consisted of four 1-m rows by 15 m in length and were planted on 05 April 2012, 08 April 2013, and 09 April 2014 at a seeding rate of 111,197 seed ha^{-1} (Warrick et al., 2002).

To simulate cotton stand losses, six targeted stand reduction treatments of 0, 20, 40, 60, 80, and 90% were implemented by mixing UA 48 (conventional) cotton seed into glyphosate-tolerant seed in the appropriate ratios to achieve the desired stand reduction following application of glyphosate. Three cotton varieties were evaluated: FiberMax 1740 B2F (early-to-medium maturity), Phytogen 499 WRF (medium maturity), and DeltaPine 1044 B2RF (medium-to-full maturity). Glyphosate (Roundup PowerMAX, isopropyl amine salt of glyphosate, Monsanto Company, St. Louis, MO) was applied at a rate of 1.26 kg a.e. ha^{-1} per application in two applications from 2 to 4 wks after emergence, eliminating the nonglyphosate-tolerant seedlings to achieve the desired stand reductions. Cotton was managed throughout the season according to Texas A&M AgriLife Extension Service recommendations for fertility, plant growth regulators, pest management, and harvest-aids. Nitrogen fertilizer was applied at rates of 38, 125, and 25 kg ha^{-1} according to soil test recommendations provided by the Texas A&M AgriLife Extension Service Soil, Water, and Forage Testing Laboratory in College Station, TX, where residual soil nitrate-N was quantified to a depth of 61 cm and credited toward a lint yield goal of 1400 kg ha^{-1}. Plant stands were measured at the four- to six-leaf stage and were found to slightly differ from the targeted stand reductions, shown in Table 1. The center two rows of each plot were harvested on 24 September 2012, 05 September 2013 (dryland), 24 September 2013 (irrigated), 26 September 2014 (dryland), and 02 October 2014 (irrigated) with a modified John Deere 9910 cotton picker and cotton was ginned on a 10-saw gin (Continental Eagle, Prattville, AL) to obtain seed and lint weight to calculate turnout.

Lint yield and lint turnout were subjected to analysis of variance (ANOVA) using JMP Pro 12 (Table 2) (SAS Institute, 2015). For the dryland trial, no interactions were observed between stand reduction and year or variety, thus stand reduction data were pooled across years and varieties. For the irrigated trial, a significant year * stand reduction interaction was observed, thus data were pooled across variety and analyzed separately by year. Means were separated using Fisher's Protected LSD at the p = 0.05 level of significance.

Experiment 2. Node removal. To investigate the impact of loss of leaf and stem tissue from hail damage, experiments were conducted in 2012 to 2014 at Snook, TX at the Texas A&M AgriLife Research Farm under both dryland and irrigated conditions. Cotton was grown on a Weswood silty clay loam in all 3 yrs. Plots consisted of four 1-m rows that were 15 m in length and were planted on 05 April 2012, 08 April 2013, and 09 April 2014 at a seeding rate of 111,197 seed ha^{-1}. The experimental design was a factorial arrangement of treatments within a randomized complete block with three replications. Factor A comprised two varieties and included FM 1740 B2F and DP 1044 B2RF. Factor B consisted of 16 clipping treatments. Clipping treatments were implemented by removing the upper portion of the plant by hand clipping the main stem immediately below nodes at six stages of growth. The clipping treatments were: N2C2 (cotton at the 2-node stage of growth, clipped immediately below the second node), N4C2, N4C4, N8C4, N8C6, N8C8, N12C8, N12C10, N12C12, N16C12, N16C14, N16C16, N20C16, N20C18, and N20C20. Nitrogen fertilizer was applied at rates of 42, 125, and 25 kg ha^{-1} according to soil test recommendations provided by the Texas A&M AgriLife Extension Service Soil, Water, and Forage Testing Laboratory where residual soil nitrate-N was quantified to a depth of 61 cm and credited toward a lint yield goal of 1400 kg ha^{-1}. Cotton was managed throughout the season according to Texas A&M AgriLife Extension Service recommendations. Plant growth regulators were applied uniformly across the experiments each year, with the timing and rate determined by the state of nontreated check plots. The center two rows were harvested on 28 September 2012, 05 September 2013 (dryland), 24 September 2013 (irrigated), 26 September 2014 (dryland), and 01 October 2014 (irrigated) with a modified John Deere 9910 cotton picker and cotton was ginned on a 10-saw gin.

Table 1. Final plant stands achieved for each target stand reduction treatment at Snook, TX, 2012-2014

Target stand reduction %	Dryland		Irrigated	
	plants ha^{-1}	actual % reduction	plants ha^{-1}	actual % reduction
0	77975	0	73125	0
20	63973	18	61731	16
40	51480	34	50199	31
60	34366	56	34961	52
80	19631	75	18304	75
90	12172	84	14003	81

Table 2. Analysis of variance for main effects and interactions on lint yield for stand reduction trials at Snook, TX, 2012-2014

Source	Dryland		Irrigated	
	% Lint	Yield	% Lint	Yield
Year	0.0007	0.0006	<0.0001	<0.0001
Variety	<0.0001	0.1199	<0.0001	0.0002
Year * Variety	<0.0001	0.8317	0.0340	0.4873
Stand Reduction	0.5071	0.0491	0.6604	0.0001
Year * Stand Reduction	0.1088	0.9611	0.0041	0.0048
Variety * Stand Reduction	0.8126	0.9988	0.0585	0.9526
Year * Variety * Stand Reduction	0.0165	0.9995	0.3331	0.9747

Lint yield and lint turnout data were subjected to analysis of variance (ANOVA) using JMP Pro 12 (SAS Institute, 2015). The results are shown in Table 3. For both dryland and irrigated trials, no interaction between clipping treatment and year or variety on either lint percentage or lint yield were observed, thus these data were pooled across years and varieties for analysis. Means were separated using Fisher's Protected LSD at the $p = 0.05$ level of significance.

RESULTS AND DISCUSSION

Experiment 1. Stand reduction. Actual stand reductions differed slightly from the targeted reductions, due to less than 100% emergence of planted seed. A range of final plants stands from 12,172 to 77,975 plants ha^{-1} was present in the dryland trial and from 14,003 to 73,125 plants ha^{-1} in the irrigated trial. Under dryland conditions, a yield reduction of 28% was observed when 84% of the stand was lost (resulting in a final plant stand of 12,172 plants ha^{-1}) (Table 4). For the irrigated trial, no yield reduction was observed following any level of stand loss in the 2012 season. In 2013, yield reductions of 25 and 28% occurred when 75 and 81% of the stand was lost (final stands of 18,304 and 14,003 plants ha^{-1}), respectively. Yields were reduced by 36% in 2014 following an 81% reduction in stand (final stand of 14,003 plants ha^{-1}). Final plant stands as low as 34,961 plants ha^{-1} in 2013 and 18,304 plants ha^{-1} in 2014 did not differ from the 0% stand reduction treatment (final stand of 77,125 plants ha^{-1}). These results agree with both Siebert et al. (2006) and Wrather et al. (2008) where populations as low as 33,975 plants ha^{-1} resulted in yields comparable to populations well over 100,000 plants ha^{-1}.

Experiment 2. Node Removal. The two cotton varieties in these trials (FM 1740 B2F and DP 1044 B2RF) did not differ in their response to clipping treatments under either dryland or irrigated conditions. A summary of the impact of clipping treatments on lint percentage and yield is shown in Table 5. Under dryland conditions, only the N8C4 clipping treatment resulted in a significant yield loss (21.6%) compared to the nontreated check. Two of the clipping treatments conducted at the eight-node stage of growth, N8C6 and N8C4, resulted in a lower lint percentage than N16C14, N12C12, and N16C12 (40.3 and 40.2% vs 41.8, 41.8, and 41.6%, respectively), but did not differ from the nontreated check (40.9%). For the irrigated trial, the N8C4, N4C2, and N2C2 clipping treatments resulted in an 8.4, 9.7, and 12.1% yield decrease in yield compared to the nontreated check, respectively. These yield losses do not fully correlate to the yield losses predicted by Wang (2011), where yield losses of 35, 25, and 15%, respectively, would be expected with similar node removals at similar stages of growth if using the USDA-FCIC (2017) standards. None of the other clipping treatments resulted in significant yield loss. The N4C2 treatment resulted in lower percentage lint than the N16C14 treatment (40.0% vs 42.1%) but did not differ from the nontreated check (41.7%). This is similar to what was observed by Smith and Varvil (1981) where clipping treatments applied from the 4- to 10-node stages of growth did not impact percent lint compared to the nontreated control. Smith and Varvil (1981) reported yield losses of 16 to 31% following clipping treatments applied at 10-, 12-, and 14-node stages of growth, whereas no significant yield losses relative to the nontreated check were observed in this trial beyond the eight-node stage of growth. These differences could be attributed to environmental differences or differences in the total nodes removed by Smith and Varvil (1981), where some treatments removed as many as eight nodes from the upper portion of the plant, whereas clipping treatments in this study removed only the upper one to four nodes at any stage of growth.

Table 3. Analysis of variance for main effects and interactions on lint percentage and lint yield for both dryland and irrigated simulated hail injury trials at Snook, TX, 2012-2014

Source	Dryland		Irrigated	
	% Lint	Yield	% Lint	Yield
Year	<0.0001	<0.0001	<0.0001	0.5808
Variety	0.0003	0.8706	0.0347	0.7607
Year * Variety	0.0001	0.0171	0.0362	0.2431
Clipping Treatment	0.0007	<0.0001	0.0184	0.0001
Year * Clipping Treatment	0.8922	0.7646	0.8196	0.5097
Variety * Clipping Treatment	0.9990	0.8224	0.2954	0.6258
Year * Variety * Clipping Treatment	0.9530	0.5222	0.1602	0.4685

Table 4. Lint yield as affected by stand reduction at Snook, TX, 2012-2014

Stand reduction %	Final plant stand plants ha^{-1}	Dryland kg ha^{-1}		
0	77975	1929 az		
18	63973	1850 a		
34	51480	1776 a		
56	34366	1831 a		
75	19631	1621 ab		
84	12172	1379 b		
LSD p = 0.05		359		
			Irrigated	
Stand reduction %	Final plant stand plants ha^{-1}	2012	2013 kg ha^{-1}	2014
0	73125	2549	2445 a	2342 a
16	61731	2633	2338 a	2275 a
31	50199	2851	2355 a	2211 a
52	34961	3003	2256 a	2152 a
75	18304	2854	1842 b	2021 a
81	14003	2734	1772 b	1493 b
LSD p = 0.05		NS	224	326

[z] Within a column, means followed by different letters are significantly (p < 0.05) different.

Table 5. Lint percentage and lint yield as affected by node removal at Snook, TX, 2012-2014

Treatment	Dryland		Irrigated	
	lint %	yield kg ha^{-1}	lint %	yield kg ha^{-1}
nontreated	40.9 ab[z]	1372 a	41.7 ab	1706 abc
N2C2	40.9 ab	1221 ab	40.7 ab	1501 e
N4C2	40.7 ab	1190 ab	40.0 b	1541 de
N4C4	40.6 ab	1245 ab	41.5 ab	1714 abc
N8C4	40.2 b	1076 b	40.9 ab	1563 de
N8C6	40.3 b	1248 ab	41.3 ab	1665 bcd
N8C8	40.9 ab	1357 ab	41.5 ab	1815 a
N12C8	40.7 ab	1256 ab	41.0 ab	1605 cde
N12C10	41.2 ab	1343 ab	41.5 ab	1769 ab
N12C12	41.7 a	1417 a	41.6 ab	1767 ab
N16C12	41.6 a	1433 a	41.5 ab	1717 abc
N16C14	41.8 a	1374 a	42.1 a	1715 abc
N16C16	41.4 ab	1429 a	41.7 ab	1743 ab
N20C16	41.1 ab	1400 a	41.6 ab	1659 bcd
N20C18	41.0 ab	1339 ab	41.4 ab	1731 abc
N20C20	41.2 ab	1443 a	41.6 ab	1732 abc
LSD p = 0.05	1.3	282	1.8	138

[z] Within a column, means followed by different letters are significantly (p < 0.05) different.

CONCLUSIONS

When hail damage occurs, growers must make the decision to either replant or keep the remaining stand. These studies demonstrate that under both dryland and irrigated conditions in Central Texas, cotton stands can be reduced to 12,172 to 18,304 plants ha^{-1} before significant yield losses can be expected. Furthermore, the three cotton varieties included in these trials did not differ in their response to stand reduction under either dryland or irrigated conditions, despite differing maturities and different growth habits. It is important to note that the findings from the stand loss trials might not be directly applicable to stand losses from hail, because the remaining plants in the field were unharmed but does provide insight into the ability of cotton to compensate following stand losses due to hail.

Yield loss due to node removal in this trial was observed only when clipping was conducted early in the season and was not observed when clipping took place on later growth stages. This same trend was observed by Smith and Varvil (1981), where early season defoliation treatments (4-10–nodes stages of growth) resulted in greater yield loss than mid-season defoliation (10-14–node stages of growth). These results do not necessarily follow the standards outlined by Wang (2011), and likely serve to demonstrate the complexity of cotton response to hail events. As noted above, the results of this trial might not be directly applicable to all instances of cotton damage after a hail event as these events are difficult to fully simulate. However, these results do offer further insight into the ability of cotton plants to withstand and recover from defoliation and loss of apical dominance, such as what occurs following hail damage.

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