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Simulated HAIL DAMAGE EXPERIMENTS IN COTTON

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Summary

Cotton grown on the High Plains and in the Trans-Pecos areas of Texas frequently is damaged by hail. The damage varies from a few punctured or destroyed leaves and fruiting structures to complete destruction of the stem and bark to ground level. A number of experiments have been carried out to simulate hail injuries. Spacing, defoliation, various stalk cutoffs, stem bruises and combinations of injuries have been inflicted by hand. The main features of the results of these treatments follow.

Stands were thinned substantially from the average stand found in the areas without reducing the yield. An optimum stand was found to be two plants per foot of row.

Total defoliation retarded recovery and delayed maturity. The cotton plant, however, was not affected markedly by removal of one-third or two-thirds of its leaves. Furthermore, the cotton plant regenerated new leaves rapidly.

The terminal bud is not necessary for growth and fruiting of the cotton plant. Topping neither decreased nor increased yields significantly.

Early-season stem injuries did not affect growth and fruiting. Treated plants did not lodge after a boll crop was made.

The cotton plant recovered after the stem was severed above the lowest node. The buds at the node forced into growth and a new plant was realized. Early-season injuries did not reduce yield greatly, but considerable loss in yield resulted from treatments later in the season. Results of severing the stem at the middle joint were similar for early treatments, but this injury did not depress yields as much as the low cutoff during the later stages.

A test of the effect of various levels of defoliation in combination with other injuries revealed that no large additional decreases resulted from the combinations except for the 100 percent level of defoliation. The combination of any injury with complete defoliation resulted generally in greater losses in yield than were obtained from either injury separately.

The effect of hail injuries on fiber properties could not be evaluated reasonably.

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HAILSTORMS DO EXTENSIVE DAMAGE IN TEXAS. Crop-hail insurance claims have approached 5 million dollars in some years, although only about 10 percent of the crops in the State are insured. The annual damage from hail is much greater and far exceeds that caused by tornadoes (6).

Hailstorms occur in all areas of the State but are most frequent in West Texas. The annual frequency varies from 10 or more storms in the Panhandle to less than one per season near the coast. Storms strike in every month of the year but are most frequent and cause more damage in the spring and early summer. Many farmers have had the unfortunate experience of seeing their lush crops damaged or destroyed by hail, Figure 1. With increasing costs of production, hail loss becomes of greater economic significance.

Hail injury to cotton consists of leaf destruction, stem bruises and cutoffs, bark and wood injury and destruction of squares, flowers and bolls. The resulting losses are dependent on the severity of the injuries, the stage of growth and seasonal conditions. The amount of loss sustained from hail injury depends also on the structure of the particular crop plant. Damage to cotton, as compared with some crops, has been difficult to evaluate because of the regrowth ability of the plant.

A project was started in 1953 with the objective of estimating the effects of hail damage to cotton by means of simulated hail-like injuries. The purpose of this bulletin is to present the results of the simulated hail tests and a review of the structure and growth habit of cotton in order to provide a more useful guide to the survey of hail damage.

Review of Literature

Simulated hail damage studies have been conducted on many important crop plants such as corn (1, 2, 4, 10), soybeans (1, 9), small grains (5), flax (11), tobacco (15), sugar beets (14), potatoes (18) and onions (7). The results of many of these tests form a sound basis for estimating the effects of hail injuries and have in some instances provided useful information on the management of damaged crops. The main objective of the tests was to develop practical guides for the survey of hail damages, and detailed physiological analyses for the most part are incomplete. The results show consistently that injuries had a more pronounced effect at certain stages of development of the crop plant than at other stages.

Eldredge (4) and Kiesselbach *et al.* (10) after several years work with corn found that leaf damage and destruction were of primary importance. Total defoliation near the tasseling stage resulted in nearly complete failure of the crop. Similar results were noted by Eldredge (5) for small grains and by Klages (11) for flax.

Hawthorne's (7) report on simulated hail damage studies in onions has been particularly useful in determining hail losses to this crop. His report gave results for various levels of defoliation at different stages of bulb formation.

The work of Pointer and Woltz (15) on tobacco illustrated the prime importance of timely and proper cultural treatment of a crop after it has been damaged. It was shown that tobacco fields which were judged as totally destroyed could recover and produce large yields if the damaged fields were "cleaned up" after the storm.

Weber and associates (1, 9) have continued experiments in soybeans and have reported on the effect of defoliation, stand reduction and stem breakage on seed yield, chemical composition of the seed and other agronomic properties. Stage of development of the plants at the time of injury was found to be of primary importance. Defoliation became increasingly important as the plants reached the late flowering stage at which time 100 percent defoliation of the plants resulted in near total loss. Stem breakage alone caused a lowering of yields, but not on the order of that caused by defoliation. Defoliation also had a greater effect on other agronomic properties than did stem breakage.

No simulated hail experiments had been conducted with the cotton plant at the time the present project was initiated. A reasonably good loss adjustment procedure had been devised by tediously cata-

Figure 1. A hailstorm near Crosbyton, Texas, on June 22, 1958, completely destroyed this crop of cotton.

loging damage and returning to the fields in the fall to observe the extent of recovery. Many of the regrowth characteristics of cotton were known, but experimentation was required to substantiate these observations.

Since a knowledge of the structure and growth habit of cotton is of prime importance in assessing hail damage, a review of the two phenomena is presented. In making this review, the works of Eaton (3), Loomis (13) and Hayward (8) were used extensively.

The basic architecture of the cotton plant is simple and rugged. Cotton is a woody plant with an erect, branching central stem and a strong taproot system. The leaves have long stems or petioles, the blades are large with three to five lobes and are arranged spirally on the stem in an alternate fashion. The plant in profile is cone shaped.

The plant is generously supplied with lateral buds. At the cotyledonary node, the buds are single, opposite, vegetative and completely capable of producing another stem of the same gross morphology as the mainstem. There are two buds (or a divided bud) in the leaf axil at all other nodes. The central axillary bud produces a vegetative limb much like the mainstem; the side axillary bud produces a fruiting limb. Fruiting limbs are initiated five to six nodes above the cotyledonary node in Upland varieties whereas vegetative limbs are usually formed below the sixth node. Fruiting limbs, after being differentiated from the terminal bud, begin growth immediately. The growth of central axillary buds, or vegetative buds, does not start until four to six nodes separate them from the apical bud.

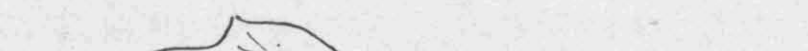


Figure 2. A fruiting limb of cotton. Note two-ranked arrangement of leaves and zigzag manner of growth.

There are several ways to distinguish between the vegetative and fruiting branches produced by a cotton plant, Figures 2 and 3.

1. A fruiting limb is initiated at the side rather than the center of the leaf axil as the vegetative limb.
2. A fruiting limb grows horizontally and in a zigzag manner rather than straightforward and vertically as the vegetative limb.
3. The leaves on a fruiting limb are two-ranked rather than spirally arranged as on a vegetative limb.
4. Most important, the fruiting structures are attached directly to the fruiting limb by the fruit stalk or peduncle. A vegetative limb is sometimes confused for a fruiting limb, but close inspection will reveal that a small second order fruiting limb is present (an example, limb from node 5, Figure 3).

The flower bud is covered by three large bracts and is called a square. The corolla is rolled in the bud, but opens to a showy white to yellow bloom with five petals. The corolla turns reddish after 1 day and usually sheds in 3 days. The fruit of cotton is called a boll. It is a capsule with three to five separate chambers in which the seed and fiber are formed.

The cotton fiber is a single cell which initiates from the outer layer of the seed coat shortly after fertilization takes place. The fiber elongates rapidly and reaches its full length in approximately 21 days. Following elongation the fiber goes through a phase of secondary thickening during which concentric rings of cellulose are laid down on the interior walls of the fiber cell, adding body and strength to the fiber. Both the rate of elongation and the manner of secondary layering are affected by temperature along with other factors. The time required for a boll to mature varies from 45 to 75 days.

Optimum temperature for the germination and growth of the radicle and hypocotyl is approximately 90° F. The interval from time of planting to emergence of the young plant varies from 5 to 15 days, depending on temperature and soil moisture. With optimum conditions, primary roots grow rapidly and a plant will develop a small taproot 6 to 12 inches long within a few days after germination. A lateral root system is developed within the first few inches below the surface of soil. Additional lateral roots are developed at lower intervals as the taproot penetrates the soil.

After emergence, the green cotyledons grow and produce food for the young plant. The first true leaf is visible within 7 to 15 days. Growth of the overall plant under field conditions follows the familiar bell-shaped or sigmoid curve. Rate of growth is slow the first days after emergence, but gradually increases until it is sometimes phenomenal.

Squaring starts about 1 month after emergence. Thereafter, the rate of fruiting is progressive and limited only by growth rate. Under optimum growth conditions the interval between successive fruiting limbs (nodes on the mainstem after squaring has started) averages 3 days. The interval between successive squares on a fruiting limb is 6 days. With optimum stands and growing conditions, enough fruit to produce a bale of cotton per acre can be initiated in a matter of days. Unpublished data on fruiting of cotton grown at Lubbock show that a sufficient number of bolls to produce such yields have been set in a very short period in August.

A cotton plant initiates many more squares and young bolls than are retained in a season. The loss of squares and young bolls is a phenomenon known as shedding. The exact cause, or causes, for shedding are unknown, although the extent of shedding varies with season, variety and other factors. The percentage of young bolls set is generally high during the earlier fruiting stages, but near the end of the season nearly all young bolls are shed.

Temperature plays a controlling part in the development of the cotton plant. Under conditions of above-normal temperatures, a cotton variety fruits faster and stops growing earlier than usual because fruit growth becomes competitive with stalk growth. During seasons of below-normal or mild temperatures, vegetative growth is predominant. Abundant vegetative growth under these conditions is frequently associated with failure in the establishment of young fruit. These temperature relationships are largely responsible for the variable responses noted in growth and maturity from season to season.

As the relative boll load increases with the progress of the season, the overall growth rate starts to decline and finally subsides. This is the critical stage in the growth and development of the bolls and fiber of the crop.

Experimental Methods

The effect of various hail-like injuries both singly and in several combinations was estimated by simulating the injuries by hand. In this manner, the exact nature of the total injury could be defined and related to the results obtained, a task rather difficult to accomplish after real or artificial hail.

The work was done in conventional field experimentation at Lubbock, College Station and Pecos. The customary cultural and management practices of the respective areas were used on the plots.

The treatments of spacing, defoliation, cutoffs and stem bruises were randomly arranged in three-row plots, 35 feet long and replicated three to six times. The combined injury treatments were arranged in four-row plots, 20 feet in length and replicated four times.

SPACING

A number of formal field experiments were carried out in the course of these tests to determine the optimum stands for cotton in Texas. Spacing data were collected for dryland conditions at College Station and for irrigated conditions at Lubbock and Pecos. The check or unthinned plots at Lubbock and College Station contained approximately four plants per foot of row. At Pecos the check stands varied from 6 to 12 plants per foot of row. In the Lubbock and College Station tests, thinning was started when the stand was established, and carried out weekly for 6 weeks. Thinning was done only at one date in the Pecos tests. The stands resulting after thinning were accurate as to number and distribution of plants.

DEFOLIATION

The initial defoliation treatments were removal of 0, one-fourth, one-half, three-fourths and all of the leaves. The fractional amount of leaf area removed was determined by arranging leaves in general size categories, and removing the necessary number of different size leaves. In 100 percent leaf removal, all visible leaves were removed, with particular care taken to insure that buds were not damaged. After the first 2 years of testing, the treatments were changed to 0, one-third, two-thirds and all leaves removed, and the defoliation test became part of the combined injury test.

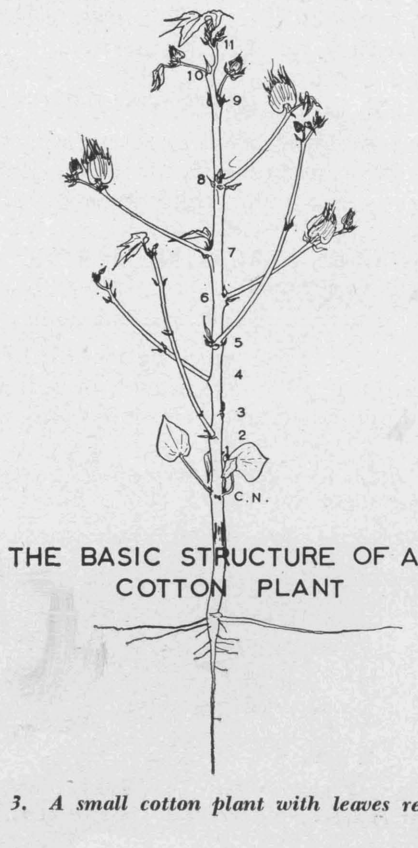


Figure 3. A small cotton plant with leaves removed.

REMOVAL OF TERMINAL BUD

One series of plots was treated by removal of the terminal growing point. Treatments were applied weekly throughout the season.

STALK CUTOFFS

Two degrees of stalk cutoff were applied weekly throughout the season. One consisted of severing the stalk just above the cotyledonary node. The other was a cutoff at midjoint. These treatments will be referred to as the low and middle cutoff, respectively. In making these treatments, the cotyledons, leaves or fruit below the point of the injury were undisturbed.

COMBINATION OF INJURIES

Since the entire scope of hail damage includes an infinite number of combinations of leaf and stem injuries, it was necessary to combine several types of injuries in order to estimate the importance of interactions. This was accomplished by treating plants at four stages of growth with either removal of the terminal bud; a middle cutoff; removal of fruiting limbs or damaging the bark; or an intact check treatment. In addition, treated plants received 0, one-third, two-thirds and total defoliation, Figures 4 and 5.

STEM INJURIES

As a means of estimating the effect of stem bruises on recovery and yield, two degrees of stem and bark damage were inflicted in 1958. One consisted of scraping through the bark with a knife for a distance of 1½ to 3 inches on the stem. The other treatment consisted of inserting a knife through the stem and twisting to separate the wood.

EFFECTS ON FIBER PROPERTIES

Fiber samples were taken several times from experimental plots at Lubbock. However, a report will be made only on samples collected in 1958.

ARTIFICIAL, MACHINE-MADE HAIL DAMAGE

A machine was made to use for blasting plants with cracked ice. This machine was used entirely to inflict damages for instructional or checking purposes, and results with the machine will not be reported. Figure 6 shows the hail machine and the type of damage done with it.

Experimental Results

SPACING

The results of the spacing test are shown in Table I as a percentage yield of the unthinned check plots. These results show that thinning from 6 to 15 inches between plants within a month of stand date did not reduce yield. In fact, the results show that such spacings were better than thicker stands most years. As the time interval between stand date and thinning increased, there was a definite decrease in yield, especially at the wider spacings.

Out of the 11 tests recorded in Table I, the results of 2 tests (1958 at Lubbock and 1957 at Pecos) show a progressive yield decrease from thinning although some of the differences were not statistically significant. The results obtained in 1958 at Lubbock are believed to be a result of the unusually early fruiting of cotton that season. In one test at Pecos, the effect of thinning to 6 inches between plants was almost as great as that of thinning to 5 feet between plants. In this field, thinning was late, relative to development. In addition, the original stand was unusually thick.

In all tests the number of vegetative limbs produced and the number of bolls per fruiting limb were decreased as spacing decreased. The nodal position of the first fruiting limb was higher in the closer spacings.

Within each location the number of bolls produced per foot of row tended to be constant and independent of stand. At Lubbock the number of bolls set per foot of row varied frm 12 to 15. At Pecos the number varied from 20 to 25 bolls.

EFFECT OF DEFOLIATION ON YIELDS

The results of defoliation tests covering 2 years at College Station and Lubbock are shown in Table 2. In general, the results at the two locations were similar and support the following conclusions.

There was no correlation between the percentage of leaves removed from the cotton plant and the final

Figure 4. An example of 100 percent defoliation during the flowering stage.

Figure 5. An example of 100 percent defoliation and removal of fruiting limbs during the flowering stage.

Figure 6. A machine that was made to inflict hail-like injuries by blasting plants with cracked ice (left). An example of heavy damage caused by the hail machine in June at Lubbock (right).

yields. Only 100 percent defoliation consistently resulted in significant decreases. The most critical time for leaf loss was during the flowering and boll development period. Significant reductions from 75 percent defoliation resulted during these stages.

Total leaf removal in the early stages usually resulted in the death of a large percentage of the treated plants and retarded recovery of surviving plants. In contrast, removal of 75 percent of the leaf area, which in the earliest stages would leave only a part of a single leaf, did not cause any noticeable effect on the rate of growth.

Removal of all leaves during the late squaring and the flowering periods induced rapid shedding of almost all of the squares and young bolls existing at that time. The treatment did not induce shedding of the larger bolls.

The cotton plants, with the exceptions noted above, produced new leaves quite rapidly. In these particular experiments, the terminal growing points were intact and plants frequently were fruiting again within a week.

RECOVERY FROM DESTRUCTION OF TERMINAL BUD

A small limb and a tiny square can be found on close examination of the terminal bud after five to six nodes are produced. Many growers have learned to examine the terminal bud closely for the appearance of squares or for insect infestations, and many of them believe that destruction of the bud (commonly called topping) by hail causes rather severe damage to the crop.

The results from several years of testing failed to indicate any large detrimental effects from the destruction of the terminal bud. The mean results from irrigated and dryland tests, Figure 7, showed a small decrease in yield at all stages of growth. The larger decrease in yield incurred during the seedling stage is perhaps due to additional damage to the stem done in the effort to remove the small bud.

Regrowth after the terminal bud was removed in the earlier stages was by the "forcing" and growth of vegetative limbs from the lower nodes. Recovery was more certain and rapid in nominal stands, but retarded in thick stands. Similar regrowth was made following removal of the terminal bud at later stages. Usually, however, at least one lateral branch had been developed by this time. After the plant was topped, this branch became the central axis of the regrowing plant. Quite often topping after the start of fruiting was followed by greater elongation of existing fruiting limbs rather than by growth of lateral branches.

Topping in late season, which has been reported to be beneficial in some areas, reduced yields slightly in these tests. There was no general effect on maturity.

RECOVERY FROM STALK CUTOFFS

The results of severing the stem just above the cotyledonary node are shown in Figure 8 in terms of the mean yields of undamaged plots. These results are from 4 years of experiments in irrigated cotton at Lubbock.

Low cutoffs in early June did not result in losses of any significance and did not result in the production of an immature crop at frost. The reduction in yields from low cutoffs increased during June. After July 1 the injury reduced yields sharply and caused the production of variable amounts of immature and bolly cotton. Variation in yield and maturity following the low cutoff injury in July was extreme from season to season on the High Plains. In 1956, a severe hailstorm near Anton on July 3 defoliated and cut plants off at low levels. However, many of the damaged crops recovered and made three-fourths of a bale to the acre. Similar injuries on July 1, 1957 near Edmunson caused complete failure, although the injured plants finally made promising recovery. Figure 8 shows the accelerated drop in yield as the season progressed, and also the variable results obtained in the experiments during July. In the first week of July yields varied from 85 percent of a crop to total failure.

Figure 9 shows typical recovery from an early June cutoff and also the mode of recovery. Generally both buds at the cotyledon were forced. The rate of recovery was influenced by the presence of the coty-

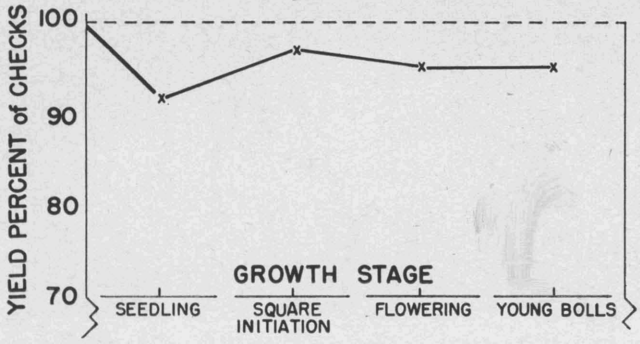


Figure 7. Mean yields in percent of undamaged plots resulting from topping cotton at College Station and Lubbock over a period of years.

ledons and was much slower at later stages after the cotyledons had abscised. Observations have been made following real hail damage to determine the influence of the amount of remaining leaves on the rate of recovery. Recovery was slow and often doubtful when all of the leaves had been destroyed. Generally plants damaged by the low cutoff required from 2 to 4 weeks to return to the square initiation stage.

The injury is likely to kill a large percentage of young plants if they are infected with seedling disease. This occurred in the unfavorable season of 1957. Injured or treated plants also died in other years, but the stand was not noticeably reduced.

The results from severing the stem above mid-joint are shown in Figure 10. As with low cutoffs, the yields were not consistently reduced by the injury during the presquaring stage of growth. Yields were significantly decreased at the squaring, flowering and young boll stages. However, the reductions were not as great or variable, and did not increase with time as did the reductions from the low cutoffs.

In 1958 at Lubbock a typical cotton plant was found to have two-thirds of the boll crop below the middle joint. This observation helps explain the yields obtained after the stalks were cutoff at mid-joint late in the season.

The results of low and middle cutoffs on dry-land at College Station were similar to the results obtained in irrigated cotton in 1953, but yields were 20 percent lower from injuries applied in the pre-squaring and squaring stages during 1954 because of an early drouth that year.

STEM DAMAGE

The results of two degrees of bark and stem damage are shown in Table 3. The injuries had no definite effect on yield or maturity. Although some of the plants lodged shortly after treatment, they did not lodge after a heavy crop of bolls was set. In an effort to determine how strong the injured points on the stem were in the fall, it was found that the majority of stems would break at some place other

TABLE 1. RESULTS OF SPACING COTTON AT STAND DATE AND LATER INTERVALS. RESULTS EXPRESSED AS PERCENTAGE YIELD OF UNTHINNED COTTON

Location	Date	Weeks	Check	Spacing, inches 6	10	15	20	30	40	60
College Station	1953	1[1]	100	100	110	106	84			
		4	100	111	93	83	75			
		6	100	100	106	86	69			
	1954	1	100	94	99	96	106			
		4	100	109	106	100	91			
		6	100	106	94	87	84			
Lubbock	1953	1	100	97	101	108	91			
		4	100	111	97	87	100			
		6	100	89	88	92	82			
	1954	1	100	105	107	103	103			
		4	100	111	105	94	83			
		6	100	100	86	83	83			
	1955	1	100	110	106	100	82			
		4	100	110	100	97	79			
	1956	1	100	108	95	111	108	100	103	77
		4	100	108	97	101	86	80	86	64
		6	100	100	102	91	81	74	77	60
	1957	1	100	116	122	98	118	90	90	76
		4	100	108	90	85	92	65	65	58
		6	100	116	99	111	83	66	71	43
	1958	1	100	92	90	84	87	78	70	57
		4	100	96	90	80	78	75	65	65
		6	100	92	95	86	77	64	60	50
Pecos	1956	[2]	100	95	104	107	111	102	90	76
	1957	[2]	100	74	85	75	64	65	69	60
		[3]	100	99	96	98	88	78	68	63
		[4]	100	111	110	98	96	92	71	49

[1]1 = stand date, 4 = 4 weeks later, and so forth.
[2]About June 15.
[3]Boll counts on Sept. 1.
[4]Actual harvest of boll counts on Sept. 1.

than the injured one. Figure 11 shows the manner of healing from various types of simulated as well as actual hail injuries.

EFFECT OF INJURIES ON FIBER PROPERTIES

A number of fiber samples taken from the combined injuries tests at Lubbock failed to give an insight as to how hail may be expected to lower fiber properties. Several complicating factors seemed to affect the fiber from undamaged as well as damaged plots most of the years. The 1958 samples were exceptional, and the reported data indicate the influence of hail injuries on fiber properties. These data show that 100 percent defoliation during the squaring and flowering stages may delay boll set and cause a reduction in micronaire, Table 4. One hundred percent defoliation during the late boll stage decidedly reduced micronaire. In fact, the bolls on plants treated at this time opened without further development of the fiber. Stalk injuries alone did not seem to affect the fiber properties. Topping combined with defoliation appears to have caused a further decrease in micronaire although the middle cutoff, a more severe injury, did not produce a similar result. Staple length was not affected, and there was no definite effect on strength.

COMBINATION OF INJURIES

The results of five combined injury tests are recorded in Tables 5, 6, 7, 8 and 9. The analysis of variance of the results (less those in Table 7) is given in Table 10. These analyses show that the magnitude of the mean square for defoliation, stages of

TABLE 2. RESULTS OF VARIOUS LEVELS OF DEFOLIATION ON DRYLAND AND IRRIGATED COTTON. RESULTS EXPRESSED AS PERCENTAGE OF MEAN YIELDS OF UNDEFOLIATED PLOTS

Year	Percent leaves removed	Stage of growth			
		Seedling	Squaring	Flowering	Boll
			College Station		
1953					
	0	100	100	100	100
	25	100	94	100	100
	50	97	98	90	100
	75	95	86	100	94
	100	66	68	60	75
1954					
	0	100	100	100	100
	25	100	100	100	100
	50	100	100	90	82
	75	100	100	78	95
	100	86	73	39	73
			Lubbock		
1954					
	0	100	100	100	100
	25	100	100	94	94
	50	100	96	94	86
	75	94	93	80	89
	100	74	78	48	69
1955					
	0	100	100	100	100
	25	94	92	87	90
	50	95	81	86	86
	75	96	81	76	81
	100	75	64	54	51

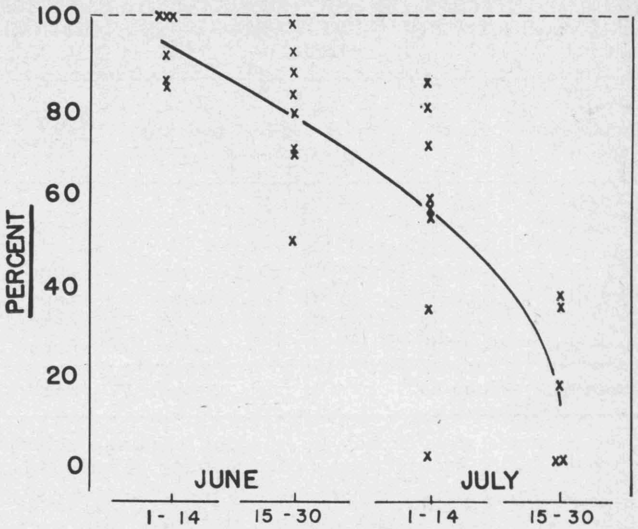


Figure 8. Mean yields in percent of undamaged plots resulting from low cutoffs for four crop years at Lubbock.

growth and added injuries far exceed that of the interactions. Thus, most of the variation is due to these main effects, although certain of the interactions are important.

An examination of Tables 5-9 and Figure 12 shows that the main cause of variation in response to defoliation was the effect of 100 percent defoliation. Removal of two-thirds of the leaves caused some reduction in yield, but only 100 percent defoliation consistently reduced yield. Generally, the losses from 100 percent defoliation more than doubled that of two-thirds defoliation. One hundred percent defoliation tended to kill the plants in the very early seedling stages, and to retard recovery in other stages. It was a serious injury at all stages of growth. The most critical times were the stages of flowering and boll growth. The interaction of years times defoliation was significant largely because of the early season effects in 1953. However, another component of the interaction was the variation in results from 100 percent defoliation in the late stages of growth.

The large mean square for growth stages indicated that injuries were more harmful at certain stages. The data show this was true particularly for the higher percentages of defoliation and for the more serious injuries at the later stages of growth, Tables 5-9.

The effect of the topping injury was similar to that of the single test previously described. However, topping plus 100 percent defoliation was more damaging than either treatment alone, Figure 13. This was true for the very early stages and many of the treated plants died from this combination of injuries.

Cutting the plants off at the middle joint reduced yields from 30 to 50 percent compared to normal controls. The early stage treatments reduced yields more in this test than in the single injury test previously described. One cause for this was that

TABLE 3. EFFECTS OF BARK AND STEM DAMAGE ON YIELD, LODGING, AND FRUITING OF COTTON, LUBBOCK, 1958

Treatment	Date	Yield percent of check	Lodging	Delay in fruiting
Check	June 10	100		
	June 17	100		
	June 24	100		
Bark	June 10	89	none	none
	June 17	102	none	none
	June 24	98	none	none
Stem and wood shattered	June 10	101	none	none
	June 17	101	none	none
	June 24	84	some[1]	none

[1]Several plants were broken by a squall occurring shortly after the injury was inflicted on the morning of June 24.

stands were more dense in the combined injury experiments. The combination of the middle cutoff with one-third and two-thirds defoliation at the later stages of growth produced decreases above that of the stem injury alone, Figure 14. However, the middle cutoff and 100 percent defoliation caused a substantial decrease over that of either damage singly. This was also due to excessive killing by the combination of the injuries.

The year-to-year variation in response to the middle cutoff injury reflects the differences in position of fruit set relative to midjoint of the plants. Approximately two-thirds of the bolls set in 1958 were below the middle node of the plant, whereas in 1954 only half of the crop was below midjoint.

The removal of fruiting limbs at the earlier stages of growth did not reduce yields consistently. In contrast, yields were sharply reduced by removal of the fruiting limbs during the late growth stages. The reductions were greater with total defoliation at this stage, Figure 15. This showed that recovery or production depend on rapid growth of the terminal and new fruiting and that time is short for the recovery from August injuries which strip the plant of fruit. The interaction of growth stage times added injury was consistently significant and reflected largely the effect of removal of fruiting limbs at the late stages of growth.

The interaction of added injury times defoliation was not significant, but certain of the trends towards greater reductions with defoliation in the data have been mentioned for certain injuries.

The results of bark injury showed no added effect over defoliation after the stem became woody, Table 9. During the earliest stage, many of the plants were actually cut off in the effort to scrape through the bark.

A bonafide test of added injury times years' interactions could not be made because of the change in treatments. However, only small mean squares were obtained for these interactions even though the treatment was altered.

The analyses of the combined injury tests show that hail damage can be estimated reasonably by the proper evaluation of the main components: growth stage, degree of defoliation and type of cutoffs. Tables 5-9 provide a practical key for the evaluation of hail damage.

Discussion

Damages and losses resulting from a hailstorm on a cotton crop are difficult to estimate. Only by systematic classification of injuries and by the application of proper loss factors can accuracy be obtained. A number of factors such as stage of growth, type of injuries and seasonal conditions must be considered. An inexperienced person cannot accurately integrate all these factors, and many acres of potentially good cotton have been plowed up because of the incorrect evaluation of hail damage.

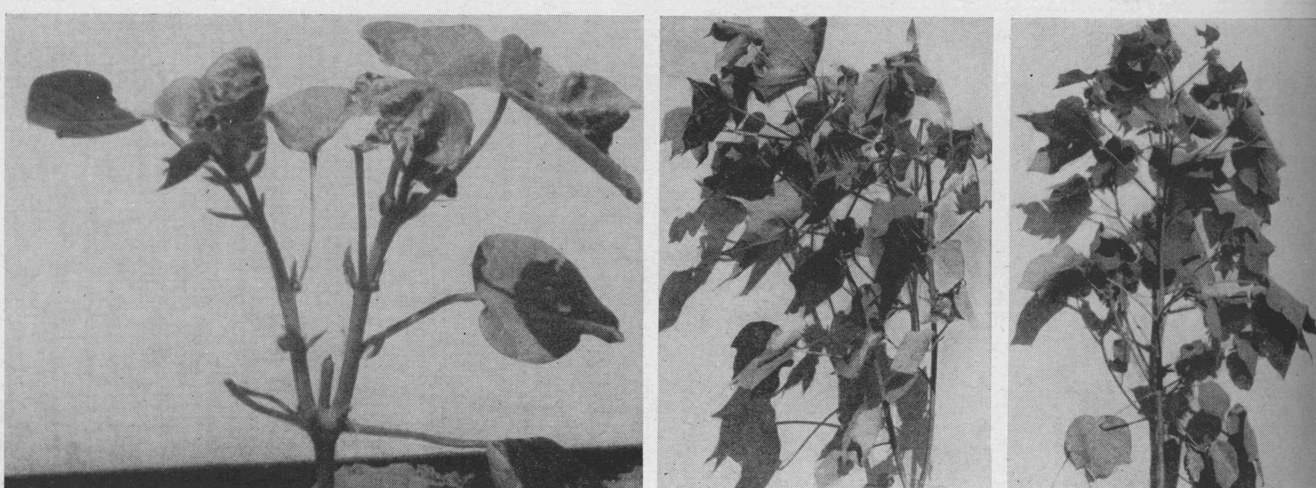


Figure 9. Recovery from a low cutoff made in early June: (A) limbs growing from cotyledonary node, (B) treated plant in August and (C) check plant in August.

TABLE 4. FIBER PROPERTIES OF SAMPLES COLLECTED FROM COMBINED-INJURY TEST, LUBBOCK, 1958

Percent defoliation	Growth stage	Added injury											
		None			Topped			Middle cutoff			Severe bark damage		
		Mic.[3]	UHM[3]	Press.[3]	Mic.	UHM	Press.	Mic.	UHM	Press.	Mic.	UHM	Press.
0	15-day-old	3.9	.92	82	4.1	.95	82	4.1	.93	82	3.9	.88	88
	Squaring	3.9	.96	80	3.8	.91	83	4.1	.98	86	4.1	.94	85
	Flowering	3.6	.88	81	3.9	.94	82	4.2	.96	78	3.4	.94	80
	Late boll	4.1	.96	74	3.9	.97	82	3.8	.95	79	3.6	.94	82
100	15-day-old	3.9	1.00	82	2.8	1.00	78	3.8	1.00	76	3.2	.95	78
	Squaring	3.2	.94	76	3.7	.98	80	3.5	.94	78	3.1	.93	72
	Flowering[1]	3.2	.94	77	2.8	.94	75	3.4	.98	78	3.2	.88	81
	Late boll[2]	2.4	.98	80	2.5	.89	84	2.4	.96	80	2.4	.93	80

[1]Injuries resulted in 50 to 100 percent bolly crop.

[2]All bolls opened prematurely.

[3]Mic. = micronaire, a measure of the weight per unit length of the fiber.

UHM = upper-half-mean, approximately equal to the classer's staple length.

Press. = Pressley strength, a measure of the strength of a bundle of fibers of 1 inch in cross section expressed in thousands of pounds.

Some of the results of these tests should be applicable to the estimation of hail damage. The spacing or stand of a crop is a frequent point of disagreement, but the results of numerous experiments on spacing of cotton have shown that a conservative spacing of about two plants to the foot of row is optimum (12, 16). In contrast, farmers on the High Plains occasionally grow stands of four to twelve plants per foot of row. Such a practice is without experimental support. Actually, yields usually are lowered as a result of these thicker stands and undoubtedly such stands promote some of the immaturity in the High Plains crop by delaying the nodal appearance of the first fruiting limb. One of the reasons given by farmers for extremely heavy planting rates is that it affords some protection against hail loss. The practice actually defeats its purpose, however, because a more spindling plant is grown and fruiting is delayed in nodal position. Storms in July which top or cutout the upper one-third of plants do far more damage in the thickly planted cotton than in reasonably spaced plantings. The contrast between the maturity and position of fruit on an extremely thick stand and on an optimum stand is shown in Figure 16. Another reason given for thick stands is that they facilitate machine harvesting. The consensus of workers who have measured machine efficiency is that a stand of two plants every foot of row (6-inch spacing) can be harvested satisfactorily by strippers or pickers (17).

The results of the spacing tests reported here show that a 6-inch spacing of plants would be a fair and reasonable basis for the adjustment of stand losses by hail.

TABLE 5. YIELDS AS PERCENT OF AVERAGE OF CHECKS RESULTING FROM VARIOUS LEVELS OF DEFOLIATION AND MUTILATION AT DIFFERENT STAGES OF GROWTH, LUBBOCK, 1953

Percent defoliation	Date	Growth stage	Added injury			
			None	Topped	Middle cutoff	Limbs removed
0	6/11	15 day old	100	96	70	102
	7/10	Squaring	100	93	59	96
	7/20	Flowering	100	97	68	96
	8/6	Young bolls	100	112	57	70
33.3	6/11	15 day old	106	83	86	96
	7/10	Squaring	101	100	59	92
	7/20	Flowering	88	84	55	73
	8/6	Young bolls	86	83	46	53
66.6	6/11	15 day old	109	81	82	115
	7/10	Squaring	94	75	65	90
	7/20	Flowering	101	81	55	86
	8/6	Young bolls	106	85	34	68
100	6/11	15 day old	70	29[1]	7[1]	68
	7/10	Squaring	80	59	49	67
	7/20	Flowering	70	56	27	45
	8/6	Young bolls	43	42	2	4

[1]Nearly all plants killed by treatment.

TABLE 6. YIELDS AS PERCENT OF AVERAGE OF CHECKS RESULTING FROM VARIOUS LEVELS OF DEFOLIATION AND MUTILATION AT DIFFERENT STAGES OF GROWTH, LUBBOCK, 1954

Percent defoliation	Date	Growth stage	Added injury			
			None	Topped	Middle cutoff	Limbs removed
0	6/22	15 day old	100	94	65	84
	7/5	Squaring	100	88	74	87
	7/23	Flowering	100	93	63	86
	8/6	Young bolls	100	109	49	70
33.3	6/22	15 day old	100	93	64	100
	7/5	Squaring	90	86	74	84
	7/23	Flowering	91	85	85	64
	8/6	Young bolls	81	78	37	65
66.6	6/22	15 day old	90	88	67	84
	7/5	Squaring	88	85	65	87
	7/23	Flowering	84	79	52	86
	8/6	Young bolls	72	73	28	70
100	6/22	15 day old	76	52	48	82
	7/5	Squaring	67	72	50	39
	7/23	Flowering	63	62	29	7
	8/6	Young bolls	40	40	10	4

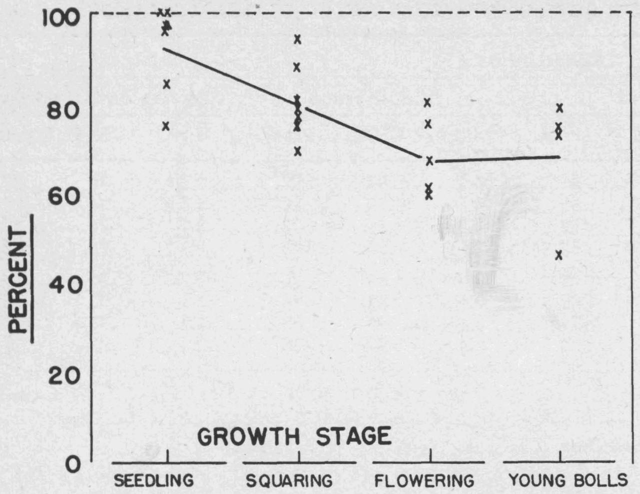


Figure 10. Mean yields in percent of undamaged plots resulting from medium cutoffs for four crop years at Lubbock.

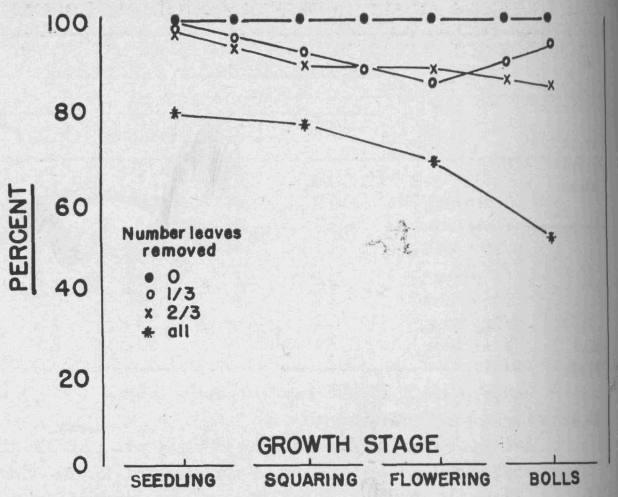
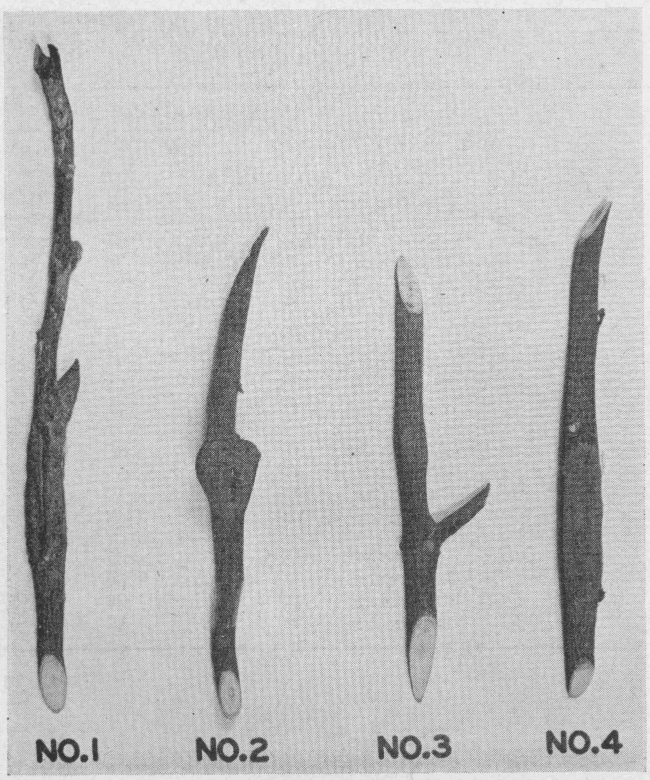


Figure 12. The effect of various levels of defoliation at different stages of growth on yields of cotton.

Another feature of these results applicable to hail damage estimation is the differences observed between early and late-season injuries. An injury early in the season does not cause as much loss as a similar injury incurred later in the season. Crops have regrown and produced normal yields after extremely heavy damage in June. Similar damage in July or August caused considerably larger losses in yield. The cotton plant has a remarkable capacity for growth after serious injury; if most of the growing season occurs after the storm, the plant can recover to the point that the effects of the early hail damage are difficult to distinguish. Farmers are prone to worry about the "setback" to their crop by hail injury. The delay in fruiting and development caused by hail damage often appears to be more than it really is because injury to small plants destroys less dry matter than appearances indicate. The small loss in dry matter and the slowing down of growth as plants reach maturity reduce the significance of the "setback" to the crop that seems so obvious on the day after the storm.

Figure 11. An example of healing by an injured cotton stem. Number 1 is an example of healing after real hail injury. Numbers 2, 3 and 4 show healing after simulated injury.



Careful attention should be given to the extent of leaf and stem damage. A crop that is totally defoliated and has the bark stripped on the stem early in the season does not recover rapidly, and many plants may fail to recover. On the other hand, if a small amount of leaf tissue remains undamaged, the buds will live and recovery is more certain. Perhaps the most severe injury overall to the cotton plant is total defoliation; but if a few leaves remain, new leaves will be regenerated in a short time. An intact terminal growing point is important in cases of heavy defoliation as fruiting will occur much sooner.

The terminal bud, with the exception stated above, is not necessary for the regeneration of the cotton plant. When the terminal is intact, it is important as it plays a predominant role in the development of the plant. After a plant is topped, axillary buds become active and control growth.

The low cutoff as described and reported is a common hail injury. It is a particularly troublesome injury near the end of June as it leaves the crop looking totally destroyed. But the results of several years' testing, and long experience with hailstorm injury, show that the potential yield after low cutoffs in June is high, which warrants working the crop in many cases rather than replanting either to sorghum or cotton. Early June losses as a result of the injury are not great but it would be even more difficult to show a decrease in yield from cutoffs in May on the Texas High Plains because so little growth is made during that month. However, because of a degree of uncertainty with damaged crops, and because a

TABLE 7. YIELDS AS PERCENT OF AVERAGE OF CHECKS RESULTING FROM VARIOUS LEVELS OF DEFOLIATION AND MUTILATION AT DIFFERENT STAGES OF GROWTH, RALLS, 1954

Percent defoli-ation	Date	Growth stage	Added injury			
			None	Topped	Middle cutoff	Limbs re-moved
0	6/22	Presquare	100	89	81	88
	7/14	Squaring	100	92	67	89
	8/11	Young bolls	100	98	40	33
33.3	6/22	Presquare	94	92	79	88
	7/14	Squaring	94	77	65	77
	8/11	Young bolls	94	81	33	44
66.6	6/22	Presquare	98	96	79	104
	7/14	Squaring	98	92	63	79
	8/11	Young bolls	83	83	38	35
100	6/22	Presquare	75	50	33	81
	7/14	Squaring	83	71	44	27
	8/11	Young bolls	60	52	17	0

certain amount of replanting seems necessary from a number of causes, farmers in the area invariably replant crops damaged in May. The practice is not questionable because the latter part of May is the normal time of planting much of the cotton in the area. It has been observed, however, that crops surviving early hail damage are often more mature at frost than replanted ones.

The low and middle cutoff injuries produced similar results when applied early in the season and there is no reason to distinguish between the types. The presence of leaves, undamaged bark and a healthy root system are more important factors than the type of stem cutoffs in affecting recovery in early stages of growth. Later in the season the middle cutoff did not reduce yield as much as the low cutoff. It is probable that the results from the middle cutoff at late season cannot be applied directly to hail damage as any storm severe enough to cause this injury would also likely destroy all the fruit below midjoint. There is a tendency for plants severed at the higher nodes to produce several side branches. Such plants may be late in fruiting if excessive vegetative growth is made. Furthermore, this type of regrowth hinders machine harvesting.

TABLE 8. YIELDS AS PERCENT OF AVERAGE OF CHECKS RESULTING FROM VARIOUS LEVELS OF DEFOLIATION AND MUTILATION AT DIFFERENT STAGES OF GROWTH, LUBBOCK, 1956

Percent defoli-ation	Date	Growth stage	Added injury			
			None	Topped	Middle cutoff	Limbs re-moved
0	6/4	15 day old	100	91	70	100
	6/19	Squaring	100	89	65	99
	7/10	Flowering	100	95	61	99
	8/7	Young bolls	100	99	63	8
33.3	6/4	15 day old	105	106	75	102
	6/19	Squaring	85	93	87	94
	7/10	Flowering	80	86	75	81
	8/7	Young bolls	110	106	60	10
66.6	6/4	15 day old	96	90	61	93
	6/19	Squaring	83	83	56	92
	7/10	Flowering	81	68	60	85
	8/7	Young bolls	82	80	53	9
100	6/4	15 day old	75	62	40	90
	6/19	Squaring	87	82	50	70
	7/10	Flowering	79	71	38	71
	8/7	Young bolls	60	56	33	0

Early stem bruises caused by hail rarely result in the subsequent lodging of plants after a boll crop is set. Tissues continue growing and adding new wood during the healing of the cotton stem. A healed stem is often strongest at the point of injury. The practice of breaking stems by hand at the point of injury after a hailstorm is a poor indication that lodging will occur later. Plants that have grown several side branches from the lower nodes frequently split at the fork. This is not related to hail bruises. Although the results of the tests on the effect of stem injuries showed little reduction in yield, plants injured by hail in this manner are sometimes slow in recovery. Also, unexpected amounts of dying after hail injury have been associated with the severity of the stem injuries. The bark must remain intact and secure up to the position of living buds which regenerate the damaged plant. The initial foods required for the growth of buds must be translocated from the root or stem and the movement of foods occurs through the bark tissues.

Figure 17 is an example of the healing of a stem that was injured at an early stage by inserting a knife through the stem to separate the wood. The treated plants developed and fruited normally, Figure 17A. Figure 17, B and C, shows opposite sides of the injured point. Note the extra thickness of wood made in the healing process.

TABLE 9. YIELDS AS PERCENT OF AVERAGE OF CHECKS RESULTING FROM VARIOUS LEVELS OF DEFOLIATION AND MUTILATION AT DIFFERENT STAGES OF GROWTH, LUBBOCK, 1958

Percent defoli-ation	Date	Growth stage	Added injury			
			None	Topped	Middle cutoff	Severe bark dam-age
0	6/11	15 day old	100	103	70	89
	6/25	Squaring	100	97	90	85
	7/23	Flowering	100	89	78	105
	8/21	Late bolls	100	101	76	100
33.3	6/11	15 day old	104	92	90	100
	6/25	Squaring	98	99	86	84
	7/23	Flowering	84	92	80	88
	8/21	Late bolls	101	92	70	80
66.6	6/11	15 day old	98	98	83	81
	6/25	Squaring	89	96	78	91
	7/23	Flowering	91	79	52	103
	8/21	Late bolls	80	74	62	83
100	6/11	15 day old	99	67	43	63
	6/25	Squaring	71	83	81	79
	7/23	Flowering	60	41	43	50
	8/21	Late bolls	54	58	72	64

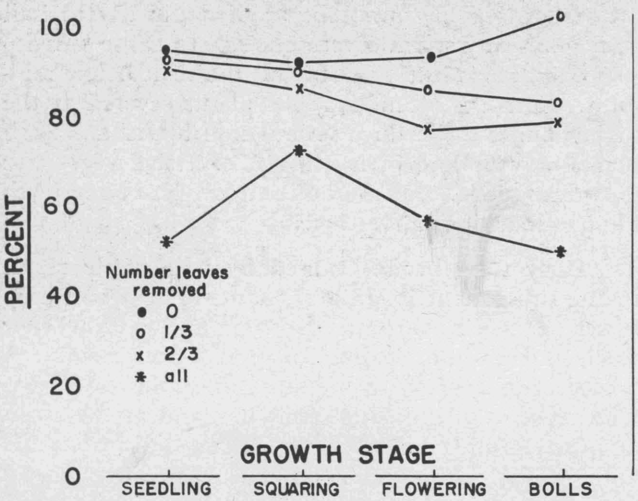


Figure 13. The effect of various levels of defoliation combined with topping at different stages of growth on yields of cotton.

It is sometimes difficult to separate shedding resulting from hail injuries from natural shedding. In general, hail-induced shedding of a few squares and flowers during the beginning periods of fruiting is not harmful. Hail-induced shedding of the flowers and small bolls after a normal set of bolls is realized cannot be considered to affect yields since these structures shed naturally. The results of the spacing experiments showed that the number of bolls set reached a maximum number. This number of bolls seemed to be a function of the whole soil and climatic complex. As the maximum number of bolls set was reached, the subsequent flowers were shed. This same phenomenon occurs for other plants (9). The principles involved in the growth and fruiting activities of plants provide a basis for judging the significance of shedding caused by hail. Eaton (3) and Loomis (13) have described these principles.

The farmer's problem after his crops are damaged by hail is a difficult one. He must examine the damaged crop and decide what to do in order to produce the best crop. One of the common mistakes that is made after a hailstorm is the failure to examine the damaged plants closely. Farmers have been observed replanting cotton that was damaged superficially by hail. Near the end of the cotton-planting season, this type of mistake could be very costly.

The following procedure of examining and caring for crops damaged in June has been used successfully on the High Plains. One should delay an examination to ascertain the extent of hail injury until at least an accurate estimate of the number of plants that will die can be made. In the meantime, it is necessary to give the damaged crop protection against blowing sand or crusting. Figure 18 shows a "sand-fighter" being used the morning following a late-evening storm. This storm occurred near Lubbock in 1958. Blowing sand burned the buds on the "stubs" left in many fields and destroyed any possibility of recovery. In some areas where crusting oc-

TABLE 10. ANALYSIS OF VARIANCE OF COMBINED INJURY TESTS

Source of variation	df	Mean square				Combined	
		1953	1954	1956	1958	df	Mean Square
Total	255					1,023	
Years						3	243.77
Reps	3	0.40	16.80	0.26	2.58	3	5.04
Defoliation	3	8.69	42.99	8.13	18.89	3	68.51
YXD						9	3.50
Error A	9	0.18	1.38	0.32	0.26	45	1.43
Growth stage	3	1.98	17.02	10.62	3.09	3	26.07
G X Y						9	2.24
G X D	9	0.35	1.87	0.29	1.12	9	1.19
G X Y X D						27	0.62
Error B	36	0.09	0.57	0.22	0.23	144	0.27
Added injury	3	6.33	32.57	12.50	6.62	3	40.22
A X D	9	0.15	0.79	0.30	0.27	9	0.16
A X G	9	0.51	2.24	6.12	0.88	9	0.34
A X D X G	27	0.10	0.61	0.13	0.54	27	0.46
Error C	144	0.06	0.21	0.16	0.25	576	0.17

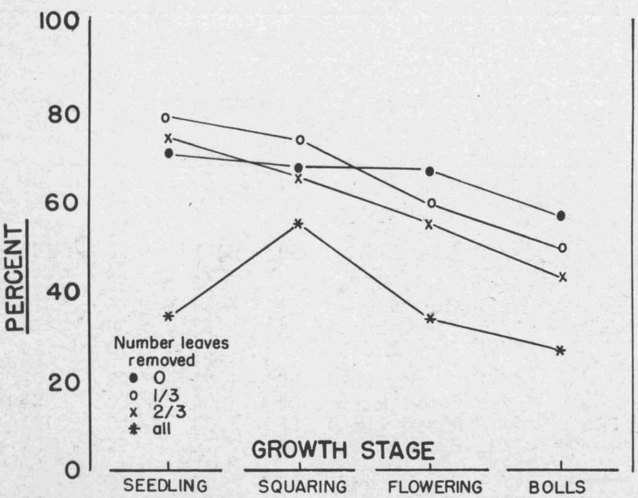


Figure 14. The effect of various levels of defoliation combined with middle cutoffs at different stages of growth on yields of cotton.

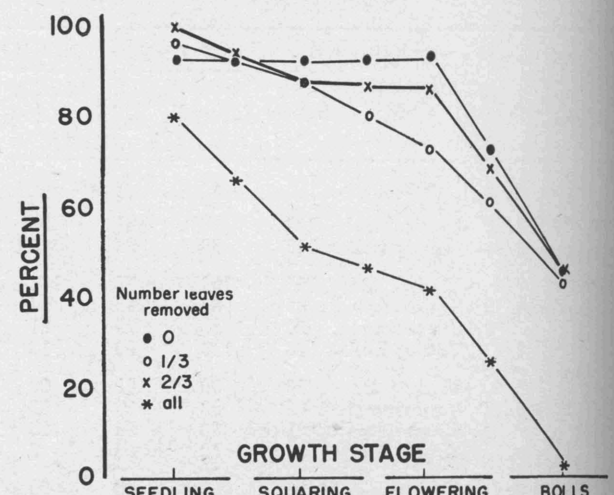


Figure 15. The effect of various levels of defoliation combined with removal of fruiting limbs at different stages of growth on the yield of cotton.


Figure 16. The contrast in maturity between an extremely thick stand and an optimum stand of cotton. The stands were photographed on the same day at Lubbock in 1958.

curs following rain or hail, it is important and necessary to cultivate the damaged crop as soon thereafter as possible.

In examining a hail-damaged crop, all parts of the field should be checked to determine if the damage is uniform. Hail is often "spotty" in intensity and some areas within a given field will be damaged more than others. Whether a field should be replanted is often determined by the size of the area receiving the most damaging injuries. It seems unwise to plow up several good acres because a few are damaged seriously. Also, it is not feasible to grow a few acres of another crop such as sorghum, for example, in the middle of a large acreage of cotton. As mentioned previously, injured plants may continue to die for several days. However, an accurate estimate of the stand that will survive usually can be made within a week's time. Stands can be thinned considerably by hail without causing much loss, but the remaining stand should be reasonably distributed.

The important step in the examination of hail damage is that of determining whether leaves or traces of leaves are still attached to the plants. The fact that only traces of leaves enable an injured plant to recover with more certainty than when all leaves are destroyed bears re-emphasis. Figure 19 shows a situation where an abundance of leaves were left after a hailstorm. Although the stems of these plants were badly bruised by a driving hail, the amount of leaves remaining indicated the crop could regrow. The damaged crop was cultivated and it recovered and made three-fourths of a bale of average grade lint per acre.

If all of the leaves are destroyed by hail, a closer examination of the condition of the stem and buds should be made before a final decision about the crop is reached. Many cotton crops have recovered when all of the leaves were destroyed. Recovery is usually slower under these conditions and is dependent on whether the bark is intact and free from large breaks up to the point of living buds. If the bark and stem are free of bruises and breaks, the buds will swell and show signs of starting growth in a short time after the storm. Inspection of plants sustaining a heavy beating by hail often revealed that the stem was shattered and the bark was loosened and broken to a point below the cotyledonary node. In such cases farmers were advised that recovery was very doubtful.

After a hail-damaged crop starts to regrow, it is extremely important to protect the young shoots from the feeding of cotton insects. The aphid, thrip and fleahopper are most troublesome. These insects interfere with the initiation and establishment of squares, flowers and bolls. The failure to retain the earliest fruit is often the cause of plants making excessive vegetative growth.

No definite rules on how to manage the irrigation of a damaged crop can be made. It can be stated that the proper use of irrigation is necessary to the success of growing a damaged crop. In general, growth should not be forced by abundant watering

Figure 17. Recovery from a stem injury made by inserting a knife blade through the stem when it was small: (A) the entire plant, (B and C) opposite sides of the injured area of the stem.

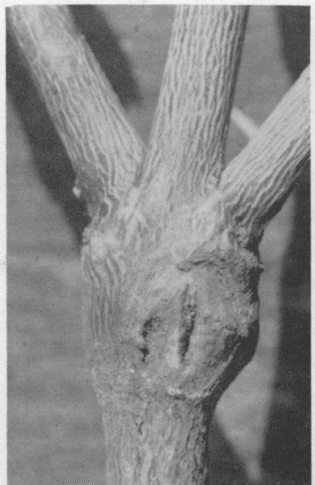
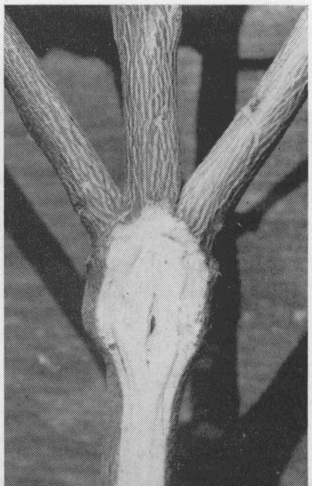




Figure 18. A "sand-fighter" being used to reduce sand blowing after a hailstorm.

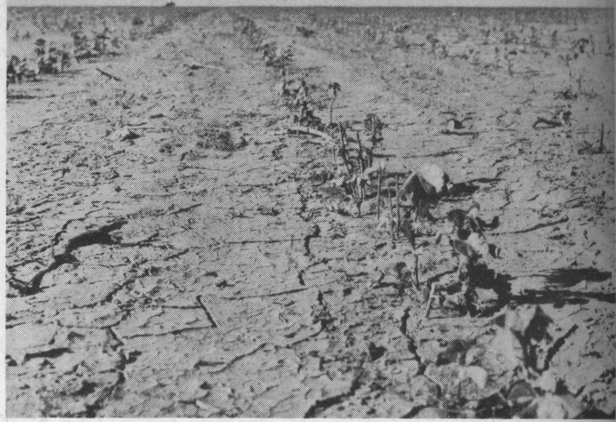


Figure 19. A crop injured severely by hail but with enough leaves left to assure recovery.

as this will tend to interfere with or prevent the establishment of the earliest fruit. Farmers in the High Plains area usually grow late-planted cotton with one summer irrigation. This practice would probably be better most of the time with the more seriously damaged crops. Crops that are damaged in July or August in this area are often more successfully grown without additional irrigation.

The results of the simulated hail damage experiments have demonstrated the regrowth potential of the cotton plant. At the same time, considerable variation was noted for some of the treatments. It is the variation in responses from season to season which has made learning by observation difficult. In fact, it is necessary to understand the growth responses of the cotton plant to explain these variations. In regard to future work, it would be most advantageous to investigate more thoroughly the responses of cotton to controlled variables of temperature and other conditions in order to provide a better basis for the explanation of the variation in the plant's behavior.

Another problem that may become more important with time is the effect of hail injury on cotton quality. The purely empirical methods used in these studies failed to give a clear insight to the relation of hail injury to fiber quality. By no means is hail the cause of all the underdevelopment in the High Plains crop, and further basic work is required before general principles can be established. Perhaps closer examination of the relation of the age of plants at the time of injury to the maturity realized would provide a partial answer to how hail damage affects the fiber.

Cotton can be planted successfully for a period of about 30 days in most areas of Texas. In the long run, hail insurance to the farmer will be cheaper if a fair and equitable basis for replanting crops damaged in these intervals could be devised. Additional results on the effect of planting date on yield are needed for some areas.

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