THE EFFECTS OF SIMULATED HAIL DAMAGE ON QUALITY OF HEAD LETTUCE

by

John E. Warneke

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This thesis has been approved on the date shown below:

Leland A Burkhart 7-7-58

DR. LELAND BURKHART — Date
Head of Department of Horticulture

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

The major lettuce growing areas in the United States are in Arizona, California, and Texas (9). A large portion of the lettuce grown in these areas is shipped to Chicago, New York, and Philadelphia.

Trends in acreage, yield, production, and shipment show an increasing demand for lettuce. This demand plus increasing disease problems in older growing areas has led to the development of new areas for growing lettuce. One of the newest areas is located near Willcox in Cochise County in Southeastern Arizona known as the Kansas Settlement.

Most lettuce plantings in the lower elevations of Arizona are made from September 1 to February 15. Harvesting begins around November 15 and continues until about May 1. The elevation of Willcox is 4,200 feet and is comparatively higher than other lettuce producing areas of Arizona, which vary from 150 to 1,500 feet. Mean temperatures at Willcox average at least 10 degrees cooler so that lettuce can be harvested in June and summer plantings can begin in July. Willcox lettuce can be marketed during periods when most other Arizona areas are out of production. The geographical location of Willcox allows this area to

ship lettuce to eastern markets at reduced shipping costs and is somewhat closer than most other western areas.

The opening of this new area has brought about interest in the extent of damage brought about by infrequent hail storms. Quality and yields of vegetable crops grown under adverse conditions can be greatly affected.

STATEMENT OF PROBLEM

Thunderstorms occur frequently in Arizona during July and August and are often accompanied by hail (21). Fifteen hailstorms have been reported in the Willcox, San Simon area during the last 19 years. Lettuce planted in July in the Willcox area is subject to hail damage during the early stages of growth. The first planting of lettuce in the Willcox area, consisting of several hundred acres, was made in 1957. A hailstorm occurred on August 30, 1957, but extent of damage to the crop was not known. Hail from previous storms was reported to range in size from one-fourth to three-fourths inch in diameter and, in a few instances, up to one inch. Hail damage was usually reported whenever the hail was one-eighth inch or larger.

Hail insurance is now available for many crops including lettuce. In an effort to better help the grower and insurance adjuster to estimate the damage and possible losses, an experiment to simulate hail damage on lettuce was begun. Hail either removes leaf area or makes it non-functional, but the exact damage to lettuce and resulting effect on production is not known.

The most common method used to simulate crop hail damage is by the removal of leaves or growing points of plants. Damage to the lettuce in the experimental plots was caused by cutting off definite percentages of the leaf area to simulate various degrees of hail damage. Prolonged hailstorms often cause injury to the growing tip. Simulated hail damage to the tip was made by dropping a steel ball on the center of the plant. Hail may occur any time during the early stages of growth; therefore, damage to the plants in the experimental plots was simulated at four different stages of growth. The plots were observed to determine the effect of simulated hail damage on yield and quality of the heads.

LITERATURE REVIEW

Experiments on simulated hail damage were first begun by Dungan (2) in 1927 at the Illinois Experiment Station. Corn was damaged moderately, to simulate hail damage, with a whip consisting of twenty strands of wire and heavy damage was inflicted by jerking off the leaf blades. The bruising and tearing effect of the whip resembled hail damage. Jerking the leaf blades in the early silk stage of corn resulted in the highest reduction of yields of any treatments, but damage to young plants had little effect.

Dungan (3) removed a definite percentage of the leaf area of corn by clipping. He found that yields were reduced in proportion to the amount of leaf surface removed. There was a slight tendency for the portion not removed to be more efficient after clipping. Small differences were noted when one-half or two-thirds the leaf area was removed, but when all the leaves were removed yield reduction was high. At the stage of growth between tasseling and fresh silk stage, yield was reduced 100 percent by complete removal.

Both Klages (12) and Eldredge (5) obtained similar results from simulated damage on small grains. Damage consisted of cutting plants off even with the ground and

whipping or beating them. Plants recovered best from cutting because the growing tip was not damaged. Klages concluded that the degree of recovery from injury is dependent to a large measure upon climatic conditions following infliction of injury.

Soybeans were subjected to simulated damage by Kalton et al. (10) by beating and clipping. A comparison of the two methods showed a difference in yield of only one-tenth bushel. Weber (22) simulated damage on soybeans by pinching off leaf surface at various stages of growth and obtained decreased yields with increased damage.

Simulated injury to corn and soybeans was also conducted by Eldredge (4), Kiesselbach and Lyness (11), and Camery and Weber (1).

In studies with onions, Hawthorn (8) removed one-half and all foliage with a grass shears. Reduction in yield was produced by both the removal of one-half the foliage and all the foliage with the percentage loss in yield due to complete removal significantly greater than that due to the loss of one-half the foliage.

Sparks et al. (20) removed foliage of potatoes by clipping and beating. Loss in yield and loss of grade U.S. No. 1 potatoes resulted regardless of the stage of growth at the time of foliage removal. The percentage loss of yield of U. S. No. 1 potatoes increased with greater amounts of foliage removed.

Morris (14) reduced sugar beet leaf area 25, 75, and 100 percent by whipping the plant. In early stages of growth there was practically no difference between the control and 25 and 50 percent removal. Later in the season, the 50 percent removal reduced yields, but not as great as complete removal. Nitrogen applied after simulated injury had a beneficial effect on sugar beets grown on unfertilized land.

Pointer (16) simulated damage to tobacco by punching holes in the leaf and clipping off foliage. Holes three-fourths inch in diameter were punched in the leaf with a hand punch to simulate damage up to 50 percent. The yield was not influenced appreciably, but the selling price was depressed because of poor quality of the leaf. Reduction of leaf surface by cutting reduced yields more as the plant became more mature. Comparison of results with crops actually damaged were generally in agreement with the simulated damage.

Simulating injury on cotton, Fisher (7) found that removal of leaves resulted in only a slight yield reduction. However, removal of leaves and young stem tips reduced yield as much as 40 percent.

A most recent method of simulating hail injury on plants makes use of a special machine by which wind, water, and ice can be applied in varying degrees. Preliminary reports by Snyder (19) on beans, potatoes, and tomatoes indicate only slight reductions in yield from injury during

the early vegetative period of growth. He states that there appears to be a definite relationship between degree of damage and stage of maturity of the plant. Also, weather conditions following damage have an important bearing on yield and quality.

Lane (13) constructed an ice blowing machine to simulate hail damage on cotton. He found that survival depends on severity of damage, condition of the plant, and the time of growing season.

There were no reports found of any simulated damage to lettuce or related leafy vegetable crops. Literature reports on simulated hail damage to corn and other crops appears to have no direct bearing on lettuce, but it is interesting to note that essentially all the methods employed consisted of the removal of parts of the plant or making them non-functional. As a result, yields were usually reduced in proportion to the amount of plant leaf surface removed.

METHODS AND MATERIALS

Description of Experimental Plots: The experimental plots were located at the University of Arizona Campbell Avenue Farm (elevation 2,350), Tucson, Arizona, (figure 1). Both the temperature and the soil were in a suitable range for lettuce production (6). An excellent opportunity was afforded to observe the extreme climatic effects on the treatments as the fall planting was subjected to below freezing temperatures and the spring planting was subjected to very high temperatures.

The fall planting was made on September 26, 1957. It consisted of four beds, each 208 feet long, 40 inches in width, with two rows 14 inches apart on the bed. The area was divided into four replicated blocks. Within each block, the 16 combinations of leaf removal and stage of growth were randomly assigned. Each plot for a given treatment was 13 feet long, 2 rows wide, and consisted of approximately 20 plants. Variety of lettuce used was Great Lakes 659.

The stage of growth is designated as the number of leaves on the plant at the time of leaf removal. The four stages of growth used in both the fall and spring plantings were: 1st stage--4 leaves; 2nd stage--6 leaves; 3rd stage--8 leaves; 4th stage--10 leaves. The plants reached the

Figure 1. View of experimental plots
University of Arizona
Campbell Avenue Farm

4-leaf stage at thinning and the 10-leaf stage was shortly before the plant began to head. The 6- and 8-leaf stages were used to give intermediate ranges of growth. No damage was inflicted after the plant began to head. Any damage occurring after this period would result in an unmarketable head.

The treatments included the removal of various percentages of leaf surface, with percentage of leaf surface removed as follows:

Fall Planting	Spring Planting
100%	100%
50%[a]	75%[a]
50%[b]	50%[b]
0	0

[a]Removal of alternate leaves.
[b]Removal of one-half or three-fourths of each leaf.

The spring planting was made on February 17, 1958. Due to cool, damp weather that followed the planting, a poor stand was obtained on the south end of the area. On March 11, the area of poor stand was replanted. The spring planting consisted of five beds, each 208 feet long, the fifth bed being used for an experimental treatment on tip injury. Three randomized blocks were used with the 16 combinations of leaf removal and stage of growth randomly assigned within each block.

Seeding: The lettuce was planted with a Planet Jr. seeder with the plate adjusted to drop seed at the rate of

two and one-half pounds per acre. The seed was planted at a depth of one-eighth inch.

Irrigation: The plantings were irrigated immediately after seeding with well water from the farm. Water was allowed to fill the furrows to within approximately two inches from the top of the bed. Water then subbed up to the top of the bed. Irrigations were made when the top half inch of soil became dry, which varied from one week to 10 days. Many irrigations were supplemented by rain.

Dates of Irrigations or Rain

Fall Planting	Sept.	26, 30.
	Oct.	9, 12*, 14*, 15*, 19, 22*, 28*, 31*.
	Nov.	9, 16*, 25.
	Dec.	5*, 6*, 15*, 20, 28.
	Jan.	8, 18.
Spring Planting	Feb.	17, 28.
	Mar.	4*, 7*, 12*, 17*, 28*.
	Apr.	4*, 8*, 21, 28.
	May	5, 12, 19, 23.

*Dates of greater than .15 inches of rain.

Thinning: In both plantings the lettuce seedlings were thinned 12-14 inches apart when the plants had approximately four leaves. The fall planting was thinned on September 26, 1957, and the spring planting on March 25, 1958.

Fertilization: Ammonium nitrate (33.5% N.) was side dressed at a rate of two pounds per 100 feet of bed immediately after thinning. The experimental plot area

had been treated prior to planting with a mulch of barn yard manure.

Cultivation: Each planting was weeded by hand hoeing at the time of thinning and later in the growing season to destroy weeds.

Insect Control: The fall planting was infested by cabbage looper worms in October. Malathion was used for insect control consisting of a 50 percent Malathion concentrate diluted by adding one tablespoon of Malathion per gallon of water.

Method of Inflicting Damage: Removal of leaf surface on the lettuce plants was accomplished by using scissors. The amount of leaf removal was estimated and then clipped off.

The removal of leaf surface in all treatments was done carefully to avoid damaging the growing tip. A steel ball bearing, three-fourths inch in diamter, was dropped directly on the tip from a height of approximately 18 inches. The injury inflicted from the ball is an approximation of damage expected from a hail stone of comparable size dropping directly on the tip after protecting leaves have been removed. The three-fourths-inch steel ball was used because it produced some visible damage each time it was dropped and it could be dropped with accuracy.

Measurements: The fall planting did not produce measurable heads until early in January. Measurements were

Figure 2. Removal of leaf area at the first stage of growth

Figure 3. Removal of leaf area at the second stage of growth

Figure 4. Removal of leaf area at the third stage of growth

Figure 5. Removal of leaf area at the fourth stage of growth

begun on the plant on December 14 and the heads on January 11 to insure against the killing of the plant by freezing temperatures. Plant measurements were made with a 12-inch ruler measuring both the leaf area, diameter, and height of the plant. Head measurements during growth were made with a field caliper (figure 6), with final measurements being made on January 25. Measurements were made to the nearest one-fourth inch. Head measurements for the spring planting were made on May 26, 1958, with the field calipers.

The weights were obtained by the use of hand scales with a 10-quart pail attached. Ten heads were cut from each treatment and placed in the pail. The weight for the heads could be read to the nearest tenth of a pound. The heads were weighed on the day following the head measurements on May 27, 1958.

Computations: The analysis of variance (18) was computed for the tables of means which were summarized from the following: (1) Fall planting--head size (table 2); (2) Spring planting--head size (table 4); (3) Spring planting--head weight (table 6); (4) Spring planting--head size (table 8). The measurements for the fall planting were not replicated. At the time of measurement only the heads in one block were in a satisfactory condition due to insect infestations and climatic conditions. The error term used

in the analysis of variance (table 2) may not have been true because of an interaction. Analysis of variance (table 4) showed no interaction, therefore the correct error was probably used in table 2.

Figure 6. Measurement of head diameter with field caliper

RESULTS AND DISCUSSION

Effect of Reducing Leaf Area on Heading and Head Size: For the fall planting there was no significant effect on reducing the head size as a result of removing 50 percent of the leaf area. This is shown by comparing the overall mean values of 3.72 inches and 3.66 inches for the two methods of removing 50 percent of the leaf area with the value for the overall mean for no leaf removal of 3.88 inches. Also, there was no difference found between the overall mean values for removing 50 percent of the leaf area by two methods. The complete removal of leaves reduced the size of the heads at all stages of growth (figure 7). Plants that were not injured headed somewhat faster (figure 10); but, due to the extended time of seven weeks from heading until final measurement, the injured plants from 50 percent removal had time to develop as much as the plants from no removal of leaves.

Due to the fact that there is no difference in the method of removing leaf area, the method of reducing leaf area 50 percent by removal of one-half of each leaf was used for the spring planting. Differences between 50 percent removal and 100 percent removal of the leaf area

appear to be quite large so the removal of 75 percent of the leaf area was added to the spring planting.

Significant reductions in the head size were recorded for all degrees of leaf removal from the spring planting. The greater the amount of leaf area removed the greater the reduction in size, with significant differences between 50 and 75 percent and 75 and 100 percent. This is shown by comparing the overall mean values of 3.01, 3.21, 3.41, and 3.84 for removal of 100, 75, 50 percent and no leaf removal, respectively (table 3). There was only a three-week period from the beginning of heading until final measurements were made. All plants began to form heads within a one-week period so percentage of heading by weeks could not be used to compare with the fall planting. There was not as much difference in the sizes from complete removal of leaves to no leaf removal as was found in the fall planting. Overall mean for complete removal for fall planting was 1.67 compared to 3.01 for the spring planting. The overall means for no leaf removal were much the same for both plantings with a value of 3.88 for the fall planting and 3.84 for the spring planting.

Differences between leaf removal treatments in any one stage of growth is not significant in all cases. In the first stage of growth (figure 8) there is no difference between the three degrees of leaf removal. Also, there is no difference between 75 and 100 percent removal of leaf area

at the second and fourth stages of growth and between 50 and 75 percent at the fourth stage. The analysis of the head weights (table 5) gave the same results as the analysis of the head size. There were no significant interactions found from the analysis of variance of either the size or the weight of the heads; therefore, there is no relation between leaf removal and stage of growth. All plants, whether injured in early stages of growth or later stages, produced significantly smaller heads.

Effect of Stage of Growth on Heading and Head Size: Plants on which all leaf area was removed in the fall planting did not have time to recover at the last stage of growth (table 1) with the result that no heads were formed at the time of measurement. The plants from this treatment did eventually form heads after measurements had been completed. The differences between head sizes for the stages of growth for the fall planting were not significant (table 2).

For the spring planting significant differences were found between stages of growth, with the larger heads being produced from the first stage of growth. Smaller sized heads were produced with damage inflicted at later stages of growth as shown in tables 3 and 5 by comparing overall means for stage of growth. There was no difference between damage inflicted when the plant had 8 or 10 leaves and little difference between the 6- and 8-stages of growth.

Table 1. Mean Head Diameters Resulting from 50 Percent and 100 Percent Leaf Area Removal at Four Stages of Growth Fall Planting, 1957.

Stage of Growth	Percent Leaf Removal				Average for all treatments
	100	50[a]	50[b]	0	
1st	2.16*	3.76	3.73	3.84	3.37
2nd	2.36	4.08	3.85	3.97	3.56
3rd	2.16	3.48	3.52	3.97	3.28
4th	0.00	3.54	3.53	3.74	2.70
Average	1.67	3.72	3.66	3.88	

[a]Removal of alternate leaves.
[b]Removal of one-half of each leaf.
*Each value is a mean in inches for 20 heads.

L.S.D. at 5% level for treatment means 1.28.
L.S.D. at 5% level for overall means .64.

Table 2. Analysis of Variance for Values in Table 1

Source	Degrees of Freedom	Sums of Squares	Mean Square	"F" Value
Leaf Removal	3	13.8823	4.6274	28.90*
Stage of Growth	3	1.6542	.5514	3.44
Error	9	1.6410	.1601	
Total	15	17.1775		

*Significant at 1% level.

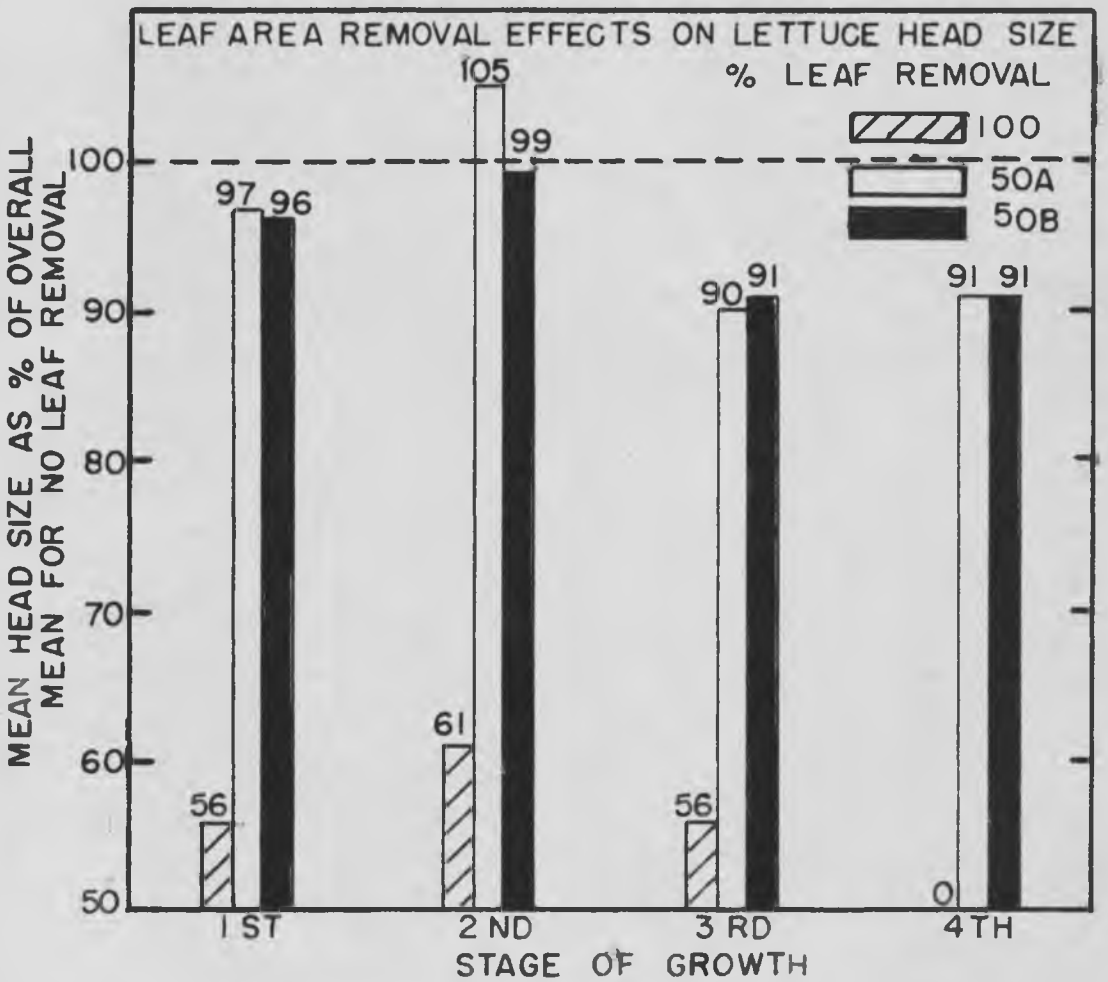

Figure 7. Effects of removing 50 and 100 percent of the leaf area at four stages of growth (1st stage--4 leaves, 2nd stage--6 leaves, 3rd stage--8 leaves, and 4th stage--10 leaves) on lettuce head size, fall planting, 1957. Overall mean head diameter of no leaf removal plants--3.88 inches. 50A is removal by alternate leaves and 50B is removal of one-half of each leaf.

Table 3. Mean Head Diameters Resulting from 50 Percent, 75 Percent, and 100 Percent Leaf Area Removal at Four Stages of Growth, Spring Planting, 1958.

Stage of Growth	Percent Leaf Removal				Average for all treatments
	100	75	50	0	
1st	3.24*	3.35	3.44	3.94	3.49
2nd	3.03	3.19	3.52	3.77	3.38
3rd	2.84	3.23	3.49	3.81	3.34
4th	2.93	3.06	3.19	3.82	3.25
Average	3.01	3.21	3.41	3.84	

*Each value is a mean in inches for 30 heads.

L.S.D. at 5% level for overall means .10.
L.S.D. at 5% level for treatment means .20.

Table 4. Analysis of Variance for Values in Table 3.

Source	Degrees of Freedom	Sums of Squares	Mean Square	"F" Value
Blocks	2	.0397	.0198	1.40
Leaf Removal	3	4.4535	1.4845	105.30*
Stage of Growth	3	.3556	.1185	8.40*
Interaction	9	.2780	.0309	2.19
Error	30	.4225	.0141	
Total	47	5.5493		

*Significant at 1% level.

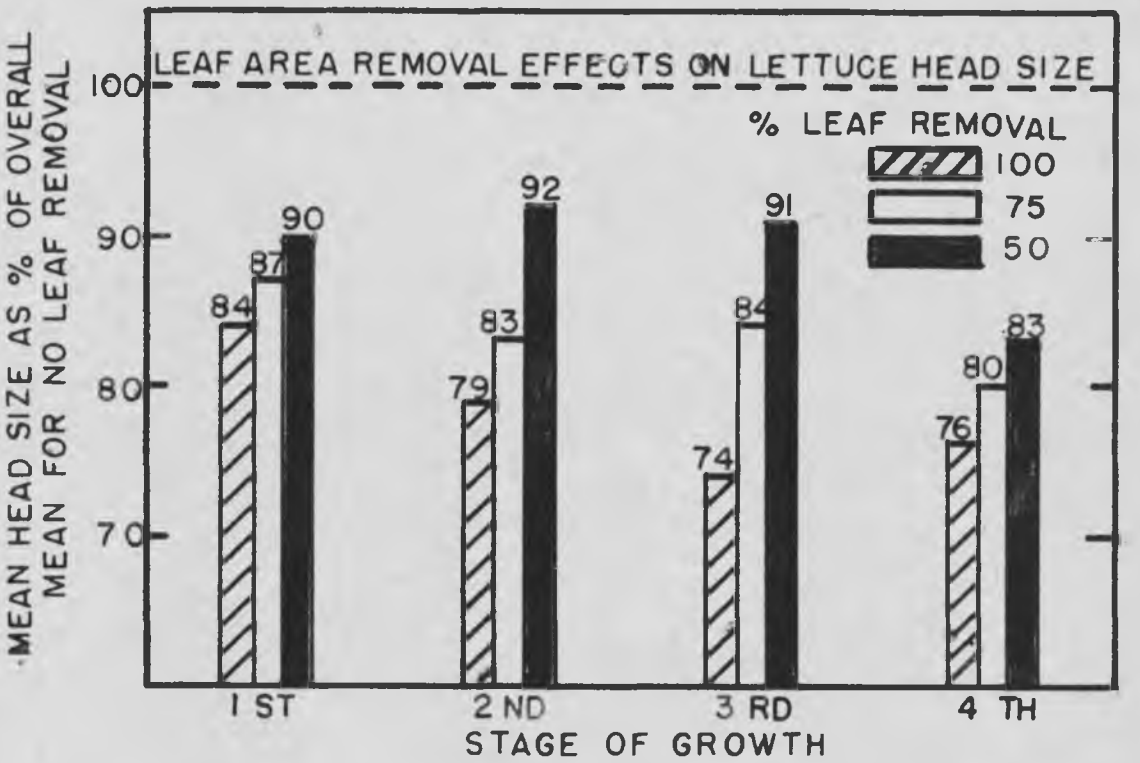

Figure 8. Effects of removing 50, 75, and 100 percent of the leaf area at four stages of growth (1st stage--4 leaves, 2nd stage--6 leaves, 3rd stage--8 leaves, and 4th stage--10 leaves) on lettuce head size, spring planting, 1958. Overall mean head diameter of no leaf removal plants--3.84 inches.

Table 5. Mean Head Weight Resulting from 50 Percent, 75 Percent, and 100 Percent Leaf Area Removal at Four Stages of Growth, Spring Planting, 1958.

Stage of Growth	Percent Leaf Removal				Average for all treatments
	100	75	50	0	
1st	.457*	.487	.507	.580	.509
2nd	.357	.430	.513	.537	.459
3rd	.273	.370	.450	.537	.408
4th	.287	.353	.437	.553	.409
Average	.345	.412	.477	.552	

*Each value is a mean in pounds for 30 heads.

L.S.D. at 5% level for treatment means .098.
L.S.D. at 5% level for overall means .0495.

Table 6. Analysis of Variance for Values in Table 5.

Source	Degrees of Freedom	Sums of Squares	Mean Square	"F" Value
Blocks	2	.01361	.006806	1.93
Leaf Removal	3	.28182	.093941	26.69*
Stage of Growth	3	.08402	.028007	7.96*
Interaction	9	.03108	.003453	0.98
Error	30	.10559	.003520	
Total	47	.51612		

*Significant at 1% level.

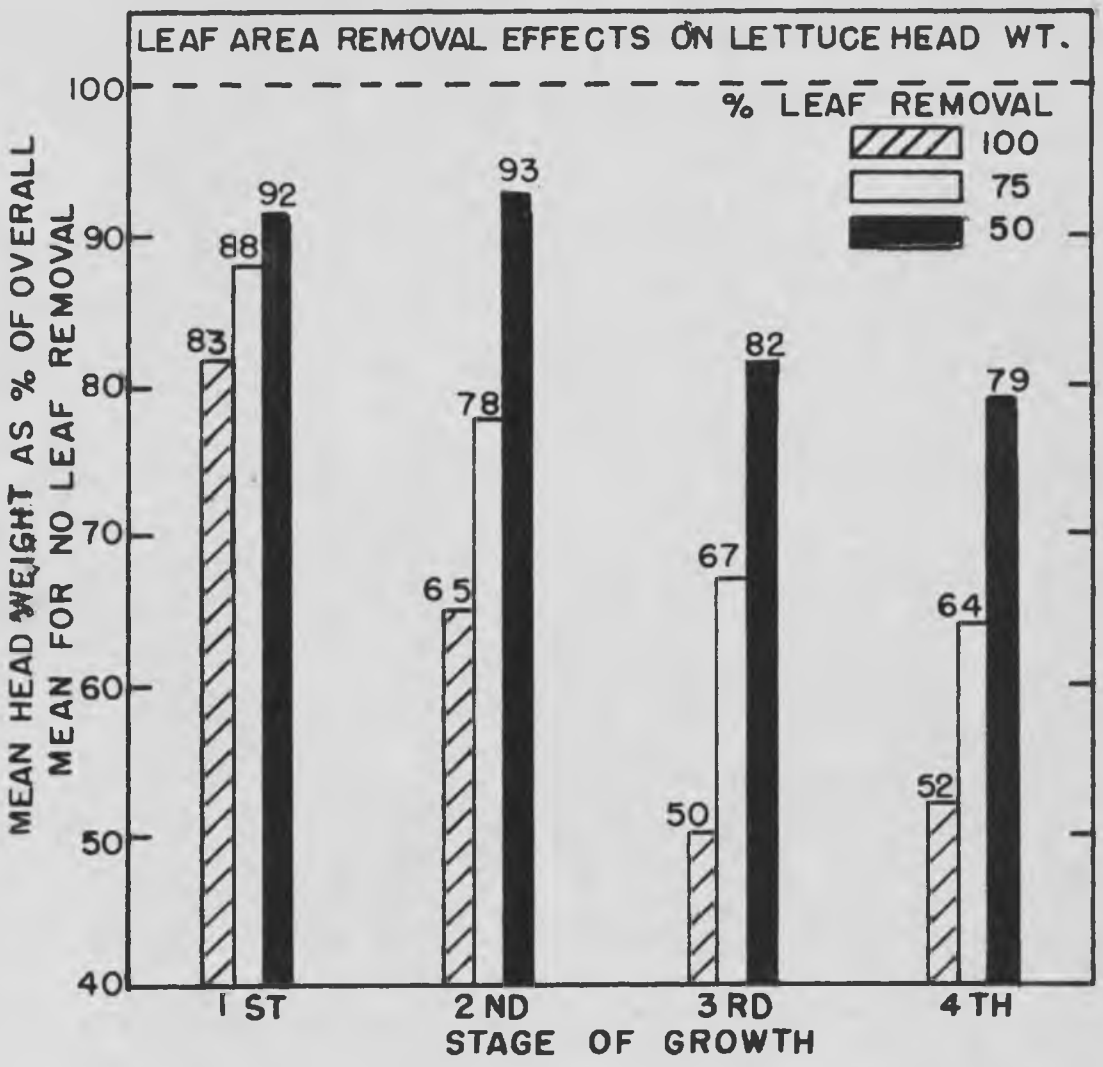

Figure 9. Effects of removing 50, 75, and 100 percent of the leaf area at four stages of growth (1st stage--4 leaves, 2nd stage--6 leaves, 3rd stage--8 leaves, and 4th stage--10 leaves) on lettuce head weight, spring planting, 1958. Overall mean head weight of no leaf removal plants--.552 pounds.

Effect of Tip Injury on Head Size and Production of Multiple Heads: Significant differences were found between treatments, but no differences were found between stages of growth (table 7). Besides smaller heads being produced after injury of the growing tip, many plants produced multiple heads.

Stage of Growth	Number of Ball Drops Per Plant	Plants with Multiple Heads Per 20 Plants
1st	1	0
	3	3
2nd	1	0
	3	1
3rd	1	3
	3	9
4th	1	4
	3	8

In the early stages of growth the plant outgrows injury and produces one head, but multiple heads are formed when the plant is more mature. The growing tip on a plant of 8 to 10 leaves is well protected and in order to drop the ball on the tip the outer leaves had to be pulled back. It was very difficult to inflict injury with one drop on a plant with 10 leaves. After the tip has been damaged, the plant did not produce any new leaves for approximately 7 to 10 days. The steel ball drop experiment was not replicated and was carried out in areas that were replanted so results are only an indication of what damage might be expected.

Table 7. Mean Head Diameter Resulting from Tip Injury by One and Three Steel Ball Drops at Four Stages of Growth, Spring Planting, 1958.

Stage of Growth	Number of Steel Ball Drops			Average for all treatments
	3	1	0	
1st	2.75*	2.86	3.50	3.04
2nd	2.52	2.81	3.33	2.89
3rd	2.89	3.09	3.72	3.23
4th	2.09	3.25	3.53	2.96
Average	2.56	3.00	3.52	

*Each value is a mean in inches for 10 heads.

L.S.D. at 5% level for treatment means .90.
L.S.D. at 5% level for overall means .45.

Table 8. Analysis of Variance for Values in Table 7.

Source	Degrees of Freedom	Sums of Squares	Mean Square	"F" Value
No. of Ball Drops	2	1.8376	.9188	14.96*
Stage of Growth	3	.2019	.0673	1.10
Error	6	.3684	.0614	
Total	11	2.4079		

*Significant at 1% level.

Effect of Climatic Factors on Recovery and Resulting Yields after Injury: The fall planting was made during warm temperatures and germination was completed in four days. The plants were thinned on October 18 and treatment interval was approximately 10 days. Because of rains and resulting insect infestations, plants from the first series of treatments recovered slowly. The second and third series of treatments recovered much faster from leaf removal injury. By the time of the fourth stage of growth treatment series, the plants in the second series of treatments appeared to be as far along as the plants in the first. Following the fourth series of treatments, night temperatures began to drop to below freezing. Growth of all lettuce plants was greatly slowed down and recovery from complete removal of leaves on the fourth series of treatments was very slow. There was some separation of the epidermial tissue on December 3, when the temperature dropped to 21°F. (figure 11). Warm temperatures and rain followed the freeze and the plants recovered and showed no signs of injury from cold.

The warmest weekly average beginning December 9, since the last week of October, brought about head formation. Nearly all plants began to head regardless of their size resulting from leaf removal. The treatments that accounted for the greatest retarded head formation were the

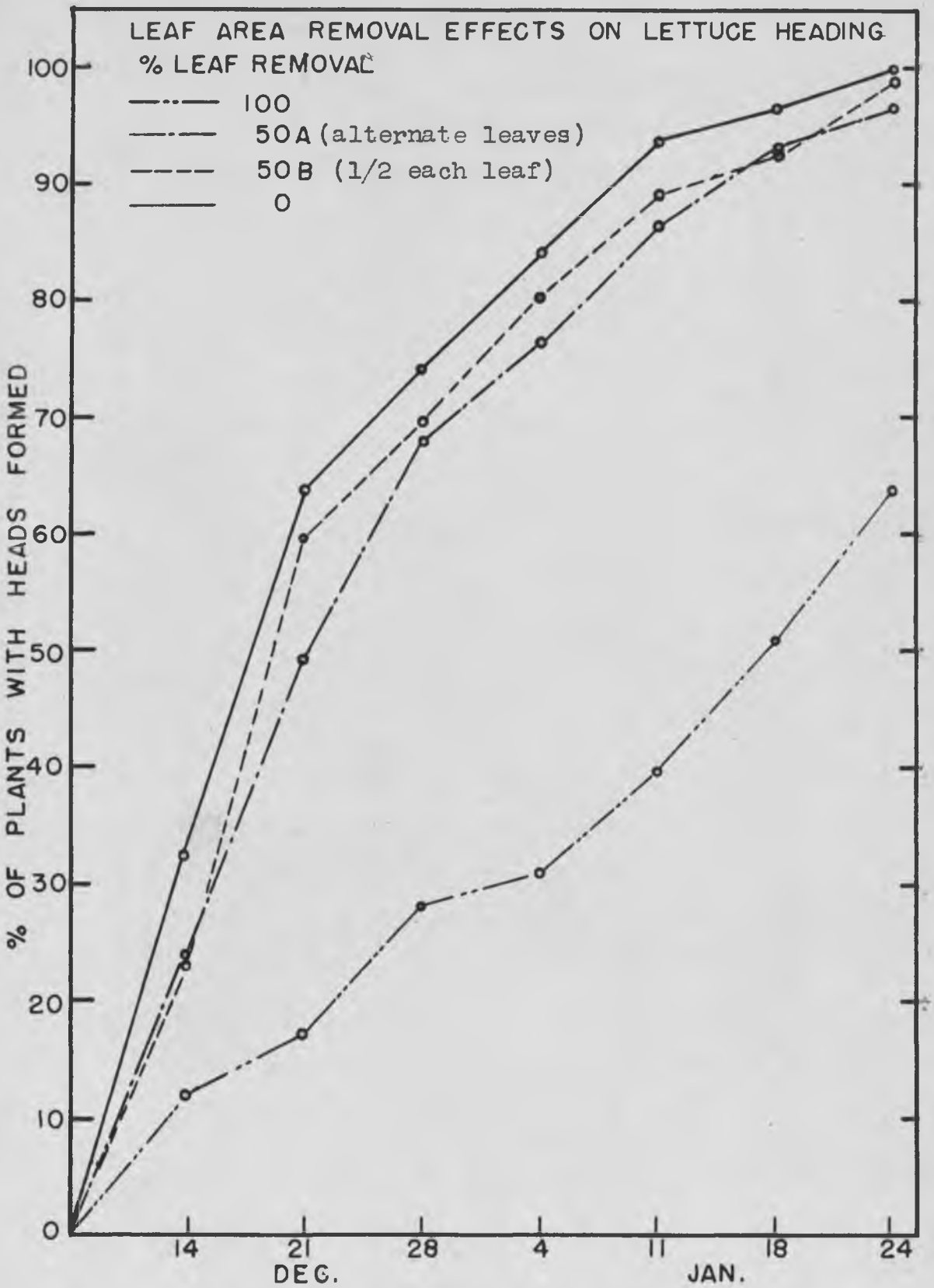

Figure 10. Effects of removing 50 and 100 percent of the leaf area on lettuce heading over a seven week period, December 14, 1957, to January 24, 1958

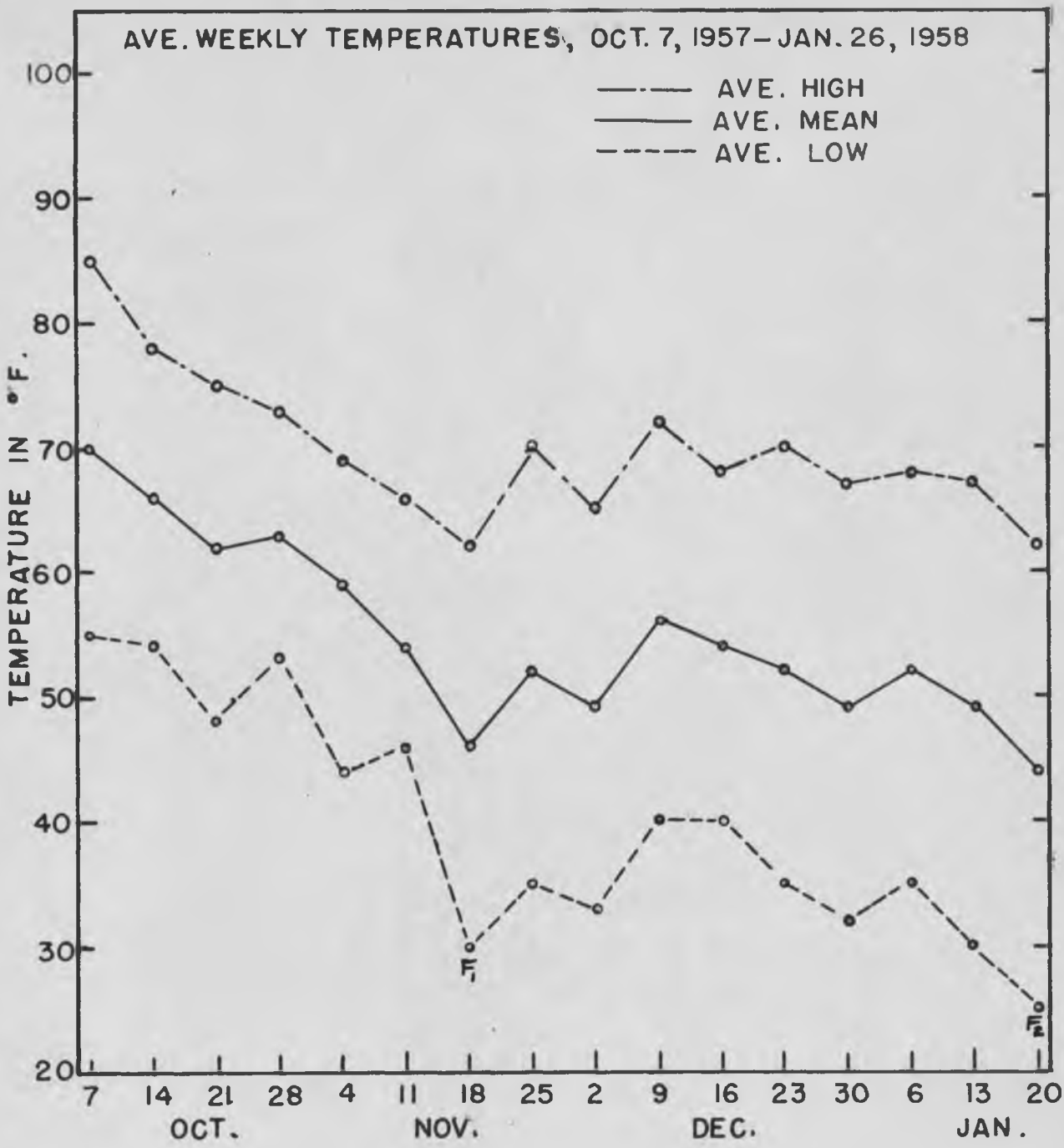

Figure 11. Average weekly high, mean, and low temperatures from September 30, 1957, to January 26, 1958, University of Arizona Campbell Avenue Farm. F_1 (low of 21° F. on Dec. 3) caused separation of epidermial layers of plant. F_2 (low of 20° F. on Jan. 23) caused permanent injury to heads.

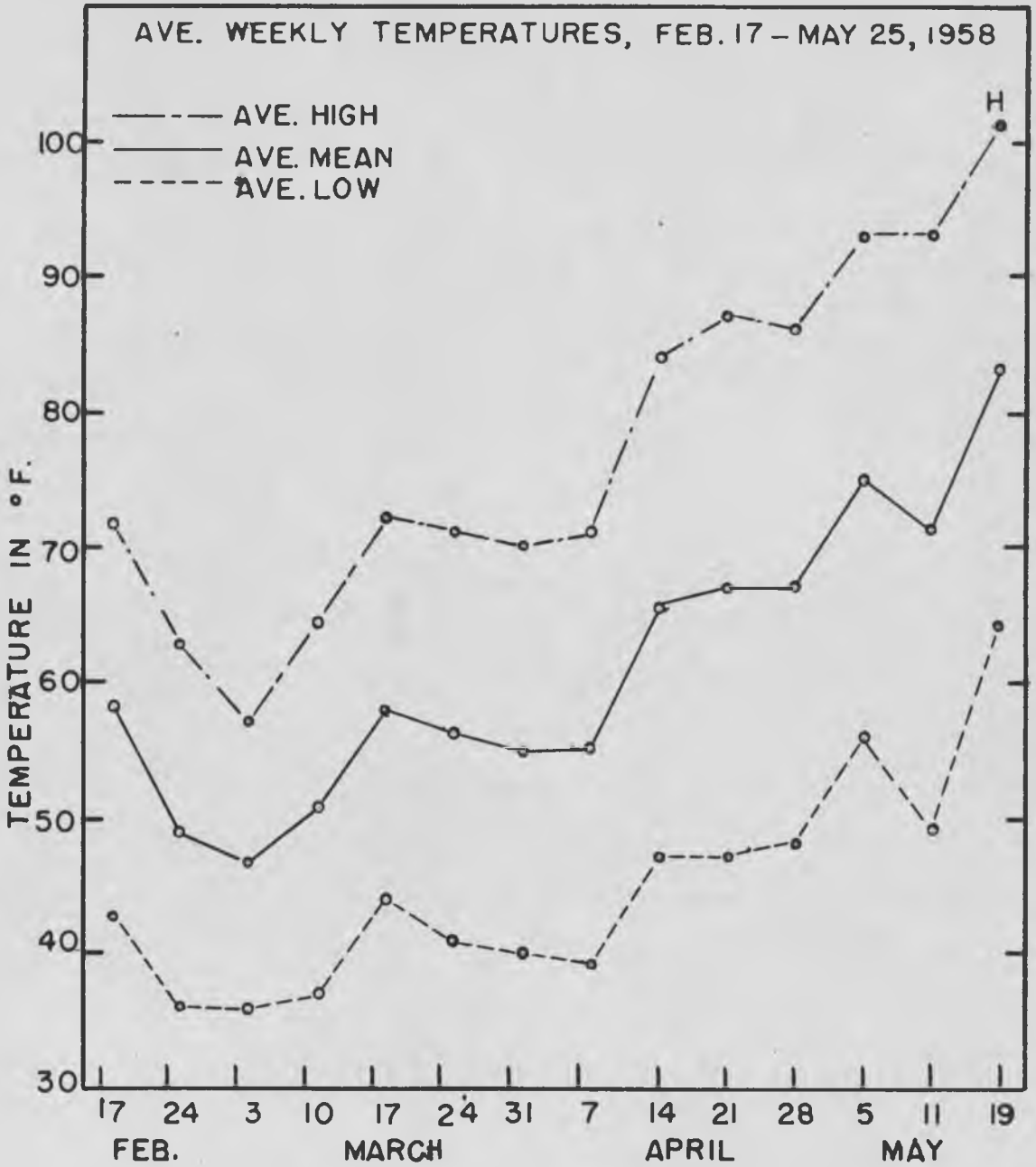

Figure 12. Average weekly high, mean, and low temperatures from February 17, 1958, to May 25, 1958, University of Arizona Campbell Avenue Farm. H is week in which bolting began.

plots with complete leaf removal (figure 10). The complete removal of leaves of plants with eight leaves produced the highest percentage of the heads of all the plants during the first week of heading. Temperatures remained mild through December and the first part of January. Lows of 26° to 27° F. were recorded in early January when heads were fairly well formed, but no damage resulted. Growth was very slow during periods of cold nights. A very cold spell began on January 20 with the temperature falling below 25° F. at night and continuing until January 23 when 20° F. was recorded. The next morning, following the low temperature reading of 20° F., the heads were frozen solid and did not thaw out until noon. Head size measurements were made in the afternoon. It was noted that heads were becoming mushy and many of them had turned dark in color. Slime developed shortly after the temperature rose above the freezing point.

The spring planting was made during a week of fairly warm temperatures with no freezing temperatures recorded (figure 12). Germination was very slow and many of the emerging seedlings were eaten by birds. Rain and cool temperatures during the first week of March prevented seedlings from growing. Re-planting areas of poor stand was made on March 11. Rain and cool temperatures continued through March and the lettuce did not reach thinning stage

until March 25. The lettuce began to make rapid growth in April and time between treatments was reduced to eight-day intervals. Recovery from the severe treatments was much more rapid than during the fall treatments.

The first indication of heading was observed on May 10. Beginning May 15, temperatures averaged about 10 degrees above normal. Plants began to show signs of bolting on May 21 and were no longer edible due to the development of a bitter taste. Temperatures after May 21 remained about 100° F. so head measurements were made on May 26, 1958. Many of the plants in the no removal plots were already distorted due to the elongation of the seed-stalk. The heads were weighed on May 27 and it was noted all heads were bitter and had a seedstalk forming. Some plants were left in tact and examination one week later showed many seedstalks had broken through the heads.

Effect of Insects: Cabbage looper worms were observed feeding on the plants at the time of the first series of leaf removal treatments, on October 19, and Malathion was sprayed on the plants. A heavy rain on October 22 washed most of the insecticide off the plant foliage and the cabbage loopers inflicted heavy damage to the plants in the treatment that had all leaves removed. The loopers fed on the growing tips and completely destroyed nearly half the number of plants in the complete removal

section at the first stage of growth. Plants with no leaf removal or those with partial leaf surface were not badly damaged since feeding of the worms was restricted to the leaves and tips were not injured. Rains also washed off the insecticide that was sprayed on October 26, so a third spraying was made on October 30.

Need for Further Study: The different results obtained from the two plantings are due mainly to climatic factors. Because lettuce is greatly influenced by climatic factors, this experiment should be carried on at least one more year to compare the results of the two different plantings.

The indication that tip injury may result in multiple head formation should be further explored. Possibly a split-plot design could be used. The present block system would remain the same and under each treatment several plants could be used for tip injury. In this way, the effect of leaf removal and tip injury could be used to simulate hail damage.

The fall planting at Tucson should be made by September 1 to allow sufficient time for the plants to form heads and mature before freezing temperatures begin.

By using tables 3 and 5, the density and weight per unit volume for the mean head in each treatment was computed. It was found that the complete removal treatment produced a

more dense head than those from plants with no leaf removal. Measurements were made on the head when it was still intact on the plant. The following day the head was cut off and weighed so the difference may be due to the method used. If the same results were obtained by cutting off the head, measuring with a tape, and then weighing, it may be that leaf removal does produce a more compact head.

SUMMARY AND CONCLUSIONS

1. Removal of leaf surface to simulate hail damage reduced yields with higher reductions from increasingly greater percentages of leaf surface removed.

2. Removal of 50 percent of the leaf area by the method of alternate leaves or one-half of each leaf produced similar effects.

3. Injury of the tip, especially as the plant matures, produced multiple head formation. Plants that produce multiple heads have no marketable value so yields would be greatly reduced.

4. Insect infestations were found to be an important factor after hail when the plants were in a weakened condition.

5. Climatic conditions following simulated hail damage appear to be as important as the damage inflicted. Under conditions of warm temperatures the plants recover rapidly from injury. Yield is definitely reduced when cold, wet conditions follow severe leaf removal. Heads produced from plants damaged are smaller than heads from plants with no injury.

LITERATURE CITED

1. Camery, M. P. and C. R. Weber. 1953. Effects of certain components of simulated hail injury on soybeans and corn. Iowa Agri. Exp. Sta. Bull. 400.

2. Dungan, G. H. 1928. Effect of hail injury on the development of the corn plant. J. Amer. Soc. Agronomy 20:51-54.

3. Dungan, G. H. 1930. Hail damages corn worst when plants are tasseling. Ill. Agri. Exp. Sta. Annual Report 44:57-59.

4. Eldredge, J. C. 1935. The effect of injury in imitation of hail damage on the development of the corn plant. Iowa Agri. Exp. Sta. Bull. 185.

5. Eldredge, J. C. 1937. The effect of injury in imitation of hail damage on the development of small grain. Iowa Agri. Exp. Sta. Bull. 219.

6. Fazio, S. 1951. Effects of nitrogen sprays on the growth of lettuce. Masters Thesis, University of Arizona.

7. Fisher, W. D. 1955. Hail injury in cotton. The Cotton Gin and Oil Mill Press, Dallas, Texas. Vol. 56(10): 44, May.

8. Hawthorn, L. R. 1946. Defoliation studies as a basis for the estimation of hail losses in onions. Texas Agri. Exp. Sta. Bull. 682.

9. Hubbard, O. D. 1957. Western lettuce--an industry in transition. Ariz. Agri. Exp. Sta. Report 151, Feb.

10. Kalton, R. R., C. R. Weber, and J. C. Eldredge. 1949. The effect of injury simulating hail damage to soybeans. Iowa Agri. Exp. Sta Bull. 359.

11. Kiesselbach, T. A. and W. E. Lyness. 1945. Simulated hail injury of corn. Neb. Agri. Exp. Sta. Bull. 377.

12. Klages, K. H. 1933. The effects of simulated hail injuries on flax. J. Amer. Soc. of Agronomy. 25:534-540.

13. Lane, H. C. 1958. Simulated hail damage. Texas Agri. Progress. Vol. 4(1):14-15, Jan.-Feb.

14. Morris, H. E. 1950. Simulated hail damage to sugar beets 1948-49. Proc. Am. Soc Sugar Beet Technologists. pp 302-304.

15. Pew, W. D., R. B. Marlatt, and L. Hopkins. 1956. Growing head lettuce in Arizona. Ariz. Agri. Exp. Sta. Bull. 278.

16. Pointer, J. P. and W. G. Woltz. 1956. Investigations of hail damaged tobacco. N.C. Agri. Exp. Sta. Tech. Bull. 123.

17. Smith, H. V. 1956. The climate of Arizona. Ariz. Agri. Exp. Sta. Bull.279.

18. Snedecor, G. W. 1956. Statistical Methods, Fifth Ed. The Iowa State College Press, Ames, Iowa.

19. Snyder, G. B. 1955. The effect of simulated hail damage to selected vegetable crops. Mass. Agri. Exp. Sta. Annual Report Bull. 490. pp 52.

20. Sparks, W. C., G. W. Woodbury, and Takatori. 1957. Estimating hail injury in potatoes. Idaho Agri. Exp. Sta. Bull. 274.

21. U. S. Weather Bureau. 1940-1958. Climatological data, Arizona. U. S. Department of Commerce. Vols. 44-62

22. Weber, C. R. 1955. Effects of defoliation and topping simulating hail injury to soybeans. Agronomy J. Vol. 47(6):262-266.

Appendix

Table 1. Weekly Mean Head Diameters Resulting from 50 Percent and 100 Percent Leaf Area Removal at Four Stages of Growth, Fall Planting, 1957.

Stage of Growth	Percent Leaf Removal	Date of Measurement		
		Jan. 11	Jan. 18	Jan. 24
4 Leaves	100	1.96*	2.08	2.16
	50[a]	3.52	3.65	3.76
	50[b]	3.43	3.52	3.73
	0	3.70	3.78	3.84
6 Leaves	100	1.93	2.25	2.36
	50[a]	3.47	3.81	4.08
	50[b]	3.40	3.57	3.85
	0	3.61	3.72	3.97
8 Leaves	100	1.60	2.09	2.16
	50[a]	2.92	3.08	3.48
	50[b]	2.94	3.30	3.52
	0	3.73	3.81	3.97
10 Leaves	100	0.00	0.00	0.00
	50[a]	2.53	3.15	3.54
	50[b]	2.71	3.41	3.53
	0	3.47	3.63	3.74

*Each value is a mean in inches for 20 heads.
[a]Removal of alternate leaves.
[b]Removal of one-half of each leaf.

Appendix

Table II. Block Mean Head Diameters Resulting from 50 Percent, 75 Percent, and 100 Percent Leaf Area Removal at Four Stages of Growth, Spring Planting, 1958.

Stage of Growth	Percent Leaf Removal	Block		
		I	II	III
4 Leaves	100	3.29*	3.31	3.12
	75	3.47	3.39	3.19
	50	3.49	3.50	3.33
	0	3.98	3.93	3.90
6 Leaves	100	3.15	3.02	2.93
	75	3.24	3.12	3.22
	50	3.75	3.50	3.32
	0	3.94	3.70	3.68
8 Leaves	100	2.75	2.91	2.87
	75	3.07	3.29	3.32
	50	3.48	3.50	3.48
	0	3.83	3.77	3.84
10 Leaves	100	3.00	2.70	3.11
	75	3.11	2.88	3.20
	50	3.16	3.27	3.14
	0	3.80	3.84	3.81

*Each value is a mean in inches for 10 heads.

Appendix

Table III. Block Mean Head Weights Resulting from 50 Percent, 75 Percent, and 100 Percent Leaf Area Removal at Four Stages of Growth, Spring Planting, 1958.

Stage of Growth	Percent Leaf Removal	Block		
		I	II	III
4 Leaves	100	.51*	.48	.38
	75	.53	.50	.45
	50	.45	.59	.48
	0	.55	.63	.56
6 Leaves	100	.45	.34	.28
	75	.52	.39	.38
	50	.59	.50	.45
	0	.62	.52	.47
8 Leaves	100	.22	.34	.26
	75	.33	.36	.42
	50	.42	.47	.46
	0	.50	.53	.58
10 Leaves	100	.37	.25	.26
	75	.39	.33	.34
	50	.40	.45	.46
	0	.62	.46	.58

*Each value is a mean in pounds for 10 heads.

Appendix

Table IV. Percentage of Heads Formed in Each Treatment at Four Stages of Growth at Weekly Intervals December 14, 1957, to January 24, 1958.

Stage of Growth	Percent Leaf Removal	Date						
		12/14	12/21	12/28	1/4	1/11	1/18	1/24
1st	100	0.0	8.2	21.3	31.2	41.0	67.3	85.3
	50[a]	21.9	48.8	63.4	76.8	84.2	96.4	96.4
	50[b]	14.6	50.0	69.5	87.8	90.3	96.4	100.0
	0	33.8	58.5	75.4	84.6	92.3	92.3	100.0
2nd	100	0.0	9.2	29.0	30.3	57.9	73.7	90.8
	50[a]	24.7	44.2	71.5	79.2	90.9	93.5	97.4
	50[b]	19.3	55.5	60.2	74.6	86.7	90.3	100.0
	0	27.0	66.3	74.3	85.1	96.0	98.7	100.0
3rd	100	46.2	50.0	62.5	62.5	62.5	68.7	87.5
	50[a]	23.8	45.0	56.2	67.5	77.5	86.3	92.5
	50[b]	34.2	69.6	78.5	81.0	83.6	89.8	96.2
	0	33.8	53.2	62.4	75.3	89.5	97.4	100.0
4th	100	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	50[a]	26.5	57.8	80.7	80.7	93.9	96.4	100.0
	50[b]	25.0	63.6	69.9	77.5	92.5	93.8	100.0
	0	33.8	75.0	83.6	90.0	96.2	96.2	100.0

[a]Removal by alternate leaves.
[b]Removal of one-half of each leaf.

Appendix

Table V. Daily High-Low Temperatures from October 7, 1957, to January 26, 1958, University of Arizona Campbell Avenue Farm

	October	November	December	January
1		73-49	70-33	68-42
2		75-48	64-31	72-33
3		76-53	71-21	64-30
4		66-50	73-29	61-26
5		68-42	59-46	60-36
6		61-45	57-40	67-48
7	88-56*	64-33	60-32	69-48
8	91-48	73-32	67-32	74-37
9	93-54	77-36	75-36	70-27
10	93-68	75-37	75-35	68-29
11	85-59	76-39	67-43	60-32
12	70-54	69-37	74-32	65-27
13	72-46	68-35	75-36	67-29
14	61-56	72-40	77-42	64-25
15	77-55	72-39	63-59	71-23
16	78-55	56-50	72-62	74-26
17	83-53	52-45	64-49	69-38
18	83-54	58-31	66-42	69-42
19	85-50	64-31	64-33	56-28
20	81-54	68-33	65-30	58-24
21	79-53	65-33	73-31	59-23
22	66-49	52-30	71-32	53-23
23	76-41	56-24	73-41	61-20
24	79-40	72-26	67-49	65-25
25	79-43	79-37	68-30	65-29
26	76-49	76-36	68-34	73-31
27	72-60	68-37	70-29	
28	65-58	67-28	70-29	
29	76-51	64-25	72-29	
30	80-52	65-48	69-29	
31	69-57		73-29	

*Degrees Fahrenheit

Appendix

TAble VI. Daily High-Low Temperatures from February 17, 1958, to May 25, 1958, University of Arizona Campbell Avenue Farm

	February	March	April	May
1		59-31	73-39	83-47
2		60-37	64-50	80-50
3		55-40	73-39	85-50
4		57-42	59-46	95-49
5		64-35	65-33	99-53
6		62-38	81-33	100-55
7		46-34	74-40	93-61
8		60-31	58-40	86-58
9		57-32	67-37	90-50
10		63-29	75-37	94-52
11		61-38	77-40	89-65
12		52-39	72-39	85-45
13		61-37	75-38	88-48
14		67-37	80-38	91-48
15		72-38	87-43	97-48
16		72-41	76-52	95-52
17	82-33*	65-42	78-48	97-51
18	83-40	68-41	87-48	100-53
19	78-46	75-38	89-49	102-68
20	61-48	78-41	91-51	97-70
21	68-44	75-46	93-41	100-68
22	73-44	70-58	95-54	100-63
23	71-45	74-41	85-55	101-58
24	72-42	66-48	82-47	105-59
25	70-44	70-38	85-46	104-63
26	60-45	69-45	84-44	
27	58-28	85-38	86-45	
28	60-24	64-42	87-45	
29		70-39	88-47	
30		76-39	86-46	
31		73-40		

*Degrees Fahrenheit.