QUANTITATIVE AND QUALITATIVE RESPONSES IN WHEAT RESULTING FROM PHYSICAL INJURIES TO THE PLANTS

by

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INTRODUCTION

Drought, excessive rains and the various insect pests and diseases that affect crops, and especially wheat, can to some extent be anticipated, but hail can neither be foreseen nor prevented, and its destructive effects can seldom be mitigated, except by insurance (10).

It happens that the time of the greatest hail frequency, May and June, is also the time when the enormous Kansas wheat crop is most susceptible to hail damage, so that most losses from this cause in Kansas are in wheat. Once a wheat field has been struck by heavy hail it can seldom recover. Corn and other crops that do not mature so early may recover almost completely from a moderate hailstorm (10).

Hail might be called the result of weather's most tumultuous mood. Other than frost, no other element of the weather can so quickly destroy a crop. Occurring usually in a thunderstorm, hail falls more frequently in June than any other month, and although the range of hail incidence is wide, there are extensive areas of frequent occurrence (3).

The broken tissues of the plant caused by hail afford a point of entry for more trouble in the form of insects or diseases unless a complete spray program is carried out.

When the crop is nearing maturity the most serious hail losses occur (3). Time is always a big factor in recovery, and when the crop is approaching maturity there is little that either man or nature can do to improve the quality of hail-beaten crops (3).

Very little can be done to protect crops against hailstorms. Losses caused by hail are not so large as those that come from the other weather hazards, but they probably average about $200,000 a year at present prices (24).

It is impossible to forecast when or where the next hailstorm will strike, of course, or the extent of the damage it will do, but the average crop losses in different parts of the country are now fairly well known (24).

Hail is formed in severe thunderstorms when updrafts of air carry the raindrops to higher levels where they are frozen and gather coatings of snow and frost. Then the updraft weakens or the hail moves out of line of the updraft, and the frozen drops fall to lower levels where water is condensed on them and is partly frozen. If these frozen drops again encounter strong updrafts, the cycle may be repeated until the increased weight of the hailstones brings them to earth.

In the great plains, the freezing level in the atmosphere is comparatively low so that there is frequent hail during the summer thunderstorms. Crops suffer more hail damage in the Great Plains than in any other part of the country (3, 1, 4). Some of the areas that have the highest losses from hail are in northeast Colorado, eastern Montana, and southwestern North Dakota (24).

Insurance companies apparently have formulated fairly accurate methods for estimating the loss caused by hailstorms. These methods are based upon scientific reasoning and some of them have been obtained through experimentation (12).

Actual hail damage is not infrequently one of degrees and is of course not limited to any particular part of a plant, yet different intensities of hail damage may conceivably affect certain plant structures more than others (33).

The stage of development of the plants at the time of the emergency represents an important part of hail damage and extent of recovery probable (33).

Hailstorms cannot be manufactured at will nor can the accompanying weather conditions be duplicated. In these investigations it was the objective to inflict different degrees and kinds of injury to wheat plants that approximated a combination of the various types of damage resulting from actual hail. The author studied separately different percentages of leaf, stem and head removal at different stages of plant development and determined their effect on yield and chemical composition (protein content) of the seed and on other agronomic characters. The results obtained in these simulated hail tests and their possible relationships to actual damage are presented and discussed herein.

REVIEW OF LITERATURE

In 1928, when such investigations were begun, little experimental work had been done to determine the effect of mechanical injury on the yield of crops. Since then, simulated hail studies have been conducted with several different crops. The majority reported have been with corn and small grains, but some work has been done on soybeans, flax, and onions.

Dungan (12 to 20) has reported on several phases of his artificial hail injury investigations. He inflicted what he terms "a light treatment" with a bundle of wires, shredding the leaves and bruising the stalks and ears of corn slightly. This type of injury, given when the tassels were emerging, reduced the yield 4.3 percent, while a week later when corn was in tassel, with ear shoots but no silks showing, the same type of treatment reduced the yield 15.9 percent.

Dungan (18) states that quality of grain was markedly reduced by blade removal, especially in the early milk stage. He found that blade injury reduced the yield approximately in proportion to the percentage of leaf area removed.

Hume and Fronzke (30) studied the effect of (a) total leaf removal, (b) splitting the leaves along each side of the midrib and (c) splitting the leaves and breaking the midribs. They obtained only slight reduction in yield from the two latter types of damage, but most severe injury occurring in the interval between tasseling and the milk stage.

Loomis and Burnett (36) removed various portions of leaves of corn at several stages of maturity and concluded that "any leaf removal tends to reduce yields but reduction is greatest at early silk stage".

Montgomery (37) found that removing suckers at all rates of planting from one to six kernels per hill reduced the yield. With three kernels planted per hill the reduction was 5.2 bushels per acre.

Leonard and Kiesselbach (35) in an 8-year test in which the tassels were pulled out at the top joint without injury to the leaves obtained a yield of 43.6 bushels for the detasseled plants and 42.9 bushels for the normal plants.

Eldredge (21) reviewed hail studies with corn and reported the results of a 5-year study on the effect of injury imitating hail damage on development of the corn plant. He observed that the greatest reduction in yield of grain occurred when damage (leaf stripping, leaf shredding, and stalk bruising) was inflicted during the tasseling period.

Next to corn, soybeans had attracted the attention of hail damage investigators. Dungan (20) damaged soybean plants in several ways at the following four stages: (1) first trifoliate leaf, (2) vegetative, (3) flowering and (4) seed one-half developed. At all stages then 100 percent of the leaves and cotyledons or 100 percent of the leaves and stems above the cotyledons were removed, no seed was produced. The removal of all leaves caused only slight reductions in seed yield at the first stage but much larger reductions at the last three stages.

Gibson (28), working with a defoliation experiment with soybeans, removed various quantities of leaves from two varieties at 10-, 20-, and 30-day intervals during the growing season. Reductions in seed yield were progressively greater as the amount and frequency of defoliation increased. Practically no seed was produced by one of the varieties when completely defoliated at each of the three intervals, while a small amount of seed was produced by the second variety. The smallest decrease in yield resulted when all but 6 leaves were removed from each plant at 30-day intervals.

Fuelleman (26) did work similar to that of Gibson, and observed that all rates of defoliation, when inflicted at the period of pod and seed formation, brought about severe reductions in yield.

Garner (27) studied the effect of removing a portion of the blossoms and young pods shortly after blooming. This treatment reduced the yield. The beans that developed in this case, however, were considerably larger than those of undamaged plants. Oil percentage of the seed was unaffected by this type of injury.

Eldredge (23) observed that yields of soybeans were consistently reduced most when simulated hail damage was inflicted at about the time seed began developing in the lower pods. Average decreases in yield at that stage were 27, 50 and 77 percent for light, medium and heavy damage, respectively. Yields were reduced least when plants injured were 6-12 inches tall and had from 2-5 trifoliate leaves unrolled.

He found that although protein percentage of the seed was not appreciably affected by the simulated hail injuries, oil percent was constantly decreased by heavy damage before the pods began to yellow.

The effect of several types of injury at weekly intervals during the growing season on yields of wheat, oats, and barley was measured by Eldredge (23). He found that damage inflicted during the vegetative stages resulted in less reduction in yield than damage at heading time, with the reductions being progressively less at weekly intervals before heading.

White (40) made an experiment designed to measure the effect on grasshopper damage that completely defoliated wheat plots at a number of stages of plant development. Yields were reduced most when all leaves were removed from heading to soft dough. Complete defoliation during the two weeks just prior to maturity did not affect yields. Bushels weight and plant height were reduced most by defoliation when heads were emerging.

Kiesselbach and Lyness (32) reported as an average for 9 years, plants cut off an inch above the ground level when they were 8 inches tall yielded 67 percent as much grain as untreated plants, compared with 32 percent when similarly cut off after they had attained a height of 16 inches.

Hawthorn (29), in Texas, reported that the percentage loss in onion yield due to complete removal of the foliage was significatnly greater than the percentage loss in yield due to the loss of only half of the foliage.

The most critical period for loss of foliage to occur is the week in which bulbing is beginning. The earlier in the life of the plant prior to bulbing that injury to foliage occurred, the less serious was the loss in yield. After bulbs are forming, losses in yield can occur from direct injury to the bulbs themselves, and so the total loss due to both foliage and bulb injury in the week before harvest could be very great.

Klages (33) observed that the effects of a simulated hail damage to flax were similar to those with small grains. In his studies, recovery from damage was greatest when plants were in the early stages of growth. Leaf removal was most detrimental to yield at the budding and flowering stages. The results indicated that mechanical injuries to the stems caused considerably more reduction in yield than removal of leaves.

Thatcher (39) reported the results of wheat clipping test in which he found that when wheat was clipped, the yield of grain as well as straw was reduced in every case.

Knowles (34) carried out a study regarding the effects of hail injuries to wheat, oats, and barley. He used two methods to approach the problem: first, by studying the effects of natural hail injuries and the second consisted of studying artificial hail injuries. He found that head bruises caused greater loss than either stem or leaf bruises. Spring wheat recovers fairly well if whipped at the 3 leaf stage, but ability to recover decreased rapidly towards heading stage. Breaking the stems at low levels reduced the yield more than when the injury was applied at higher levels. He concluded that the loss was not only in yield but also in quality of the kernels.

He found that hail injuries to oats and barley were very similar to wheat.

MATERIALS AND METHODS

Investigations relative to the effect of injury simulating hail damage to wheat were initiated at the Kansas Station in 1949 and continued through 1951.

The study presented in this paper represents the results of 1951 and is divided into two different phases as follows:

1. Quantitative responses of the wheat plant to simulated hail.

2. Qualitative responses (protein content) of the wheat plant to simulated hail.

In the simulated hail tests an attempt was made to simulate actual hail injury as closely as possible. This was done by using instruments to remove and break certain amounts of the leaves, stems and heads at various dates during the growing season.

In the qualitative (protein content) tests specific samples were analyzed to determine any increase or decrease in the protein content which resulted from inflicting different simulated hail injury to the wheat plant in the field.

The methods and procedures used in each of these tests are presented and discussed in succeeding sections.

All investigations reported herein were conducted in field A at the Agronomy Farm, Manhattan, Kansas. The preceding crop was oats, which had followed sweet clover.

Tillage operations began in July of 1950 and at the time of planting, the seed bed was in excellent condition. The variety of wheat selected was Pawnee and was planted under optimum conditions on October 6, 1950.

A regular drill was used to plant the seed in rows 16 inches apart at the rate of 45 pounds per acre. A good, even stand was obtained and the young plants made moderate growth during the fall. The crop went into winter dormancy in an average condition. It was intermediate in rate and vigor of emergence, and in its early growth.

Quantitative Experiments

The various injuries were inflicted at approximately weekly intervals, beginning on April 29 when plants were $12\frac{1}{2}$ inches high and ended on July 2 when wheat plants were fully ripened, and 13 days before harvest, which was delayed because of wet weather. Table 1 is an outline of the general plan of the field investigations.

Clipping Experiments. In this type of injury the plants were cut off at different heights and at different dates as shown in Table 1. This treatment was repeated six times, which made a total of six experiments, Nos. 1, 2, 3, 4, 5, 6. Three replications were included and randomized in each experiment. The size of each plot was 1½ feet long and 4 rows wide.

Whipping Experiments. Simulated hail damage was obtained by whipping the wheat plants with an Osage orange switch which was about 3 yards long. Different degrees of whipping were applied at five different dates, making a total of five separate experiments, Nos. 11, 12, 13, 14, 15. Alphabetic letters were given to denote the degree of injury out of which

"A" represents no damage

"B" represents slight whipping

"C" represents light whipping

"D" represents moderate whipping

"E" represents heavy whipping

In each of these experiments, three replications were included, and types of injury were randomized throughout the plots which were 16½ feet long and 4 drill rows wide.

Leaf Removal Experiments. This type of injury was applied to the wheat plants by removing leaves according to a certain procedure as shown in Table 1. Four replications were obtained

Table 1. Outline of the general plan of the field investigations.

Type of injury	No. of experiments	Dates of injury
A. Clipping Experiments		
1. All plants clipped off	6	April 29, May 4, 9, 18, 24, 31
2. Upper 1/4 of all plants clipped off	4	May 9, 18, 24, 31
3. Upper 1/2 of all plants clipped off	4	May 9, 18, 24, 31
4. Upper 3/4 of all plants clipped off	4	May 9, 18, 24, 31
B. Whipping Experiments		
1. Slight whipping	5	May 7, 14, 19, 25, June 1
2. Light whipping	5	May 7, 14, 19, 25, June 1
3. Moderate whipping	5	May 7, 14, 19, 25, June 1
4. Heavy whipping	5	May 7, 14, 19, 25, June 1
C. Leaf Clipping		
1. All leaves removed	4	May 28, June 4, 11, 15
2. All leaves removed from alternate stems	4	May 28, June 4, 11, 15
3. 1/2 of every leaf clipped	4	May 28, June 4, 11, 15
D. Stem Bending		
1. All stems bent low	7	May 29, June 5, 13, 15, 22, 26, July 2
2. All stems bent mid-high	7	May 29, June 5, 13, 15, 22, 26, July 2
3. Alternate stems bent mid-high	7	May 29, June 5, 13, 15, 22, 26, July 2
4. All stems bent at the neck	4	June 15, 22, 26, July 2
E. Floret Removal		
1. All spikelets removed from lower half of the head	6	June 19, 23, 25, 27, July 2
2. All spikelets removed from upper half of the head	6	June 19, 23, 25, 27, July 2
3. 1/3 of all the spikelets removed	6	June 19, 23, 25, 27, July 2
4. 2/3 of all the spikelets removed	6	June 19, 23, 25, 27, July 2

which formulated four different experiments Nos. 21, 22, 23, 24, each repeated twice at the same date. Plots were $7\frac{1}{2}$ feet long and one drill row wide.

Stem Bending Experiments. Damage was inflicted to wheat plants by bending the stems at various heights and at different dates as shown in Table 1.

The treatment was repeated seven times, making a total of seven separate experiments, Nos. 31, 32, 33, 34, 35, 36, 37, with two replications in each. The different types of stem bending injury were randomized throughout the replications. All plots were $7\frac{1}{2}$ feet long and one drill row wide.

Floret Removal Experiments. This fifty type of simulated hail damage consisted of inflicting injury to the head by removing spikelets from different parts of the head (at four different rates) as shown in Table 1.

Damage was inflicted at six different dates, making a total of six separate experiments, Nos. 41, 42, 43, 44, 45, 46, with only one replication in each. Plots of treatment were 3 feet, 9 inches long and one drill row wide. About 150 heads in each plot were treated.

In all the preceding treatments, one plot in each replication was left and marked as "no damage" in order to serve as a check when computing the data.

The Protein Content Tests

Fifty-two samples were analyzed by the author in the milling laboratory at Kansas State College to determine their protein content. These samples represented all the different types of treatment of simulated hail injury applied in the field. Only two experiments, the first and the last, of each treatment were taken into consideration; also, samples from only one replication of each experiment were analyzed. After grinding the wheat samples the Kjeldahl method for determining the protein percentage was administered and the results are expressed as percentage on a dry weight basis.[1]

Harvesting Methods and Techniques

The average date of ripening for the no damage (check) plots was July the first, and because of unfavorable weather conditions harvest started 13 days later. However, on the plots that were damaged, ripening was delayed a few days depending upon the degree of damage each plot had received. The harvesting was completed by July 26. All harvesting was done with a cycle and only the two inside rows were harvested out of each plot in the clipping and whipping experiments, so that any influence of outside factors would be eliminated.

[1] Official Methods of Analysis. AOAC, Association Official Agricultural Chemists.

The wheat in those experiments was cut approximately 2 to 3 inches above the ground, wrapped and tied in bundles which were labeled and stored. A month later the bundles were opened for counting the heads. The heads were then threshed and the total weight of grain from each plot was recorded.

In the other three types of treatments, stem bending, leaf removal, and floret removal, only enough heads, 100-150, were harvested from each plot to provide a representative sample. The head samples were placed in large paper sacks, labeled and stored.

EXPERIMENTAL RESULTS

These investigations were divided into two distinct phases, and the results for each are presented separately in the following sections. Major emphasis of the discussion is placed on yield of seed, size of head, number of kernels per head, size of hernel, and the bushel weight.

Quantitative Responses

Effect of Clipping Experiments. The main purpose of conducting this type of damage to wheat plants was to find out what re-growth plants could obtain after being clipped at certain heights and different dates, and to determine the effect on the yield and other factors such as the size of head, size of kernel, number of kernels per head, and the test weight.

In these experiments plants were clipped at four different rates: a. all plants clipped off next to ground, b. the upper $\frac{1}{4}$ of the plants clipped off, c. the upper $\frac{1}{2}$ of the plants clipped off and d. the upper 3/4 of the plants clipped off.

When inflicting the damage the four rates of injury were applied at the same data and replicated in three randomized plots to make one complete experiment.

Experiment 1 was conducted on April 29, 1951, when wheat plants were $12\frac{1}{2}$ inches high, and 22 days before the undamaged wheat began to head. Only one type of damage was inflicted, which consisted of clipping off all plants next to the ground. Beside each clipped plot one plot of the same size was left to serve as a check, four replicates were included and randomized in the same experiment. Results shown in Table 2 are the average for all replicates included.

Five days later Experiment 2 was conducted and received the same treatment as Experiment 1.

In Experiments 3, 4, and 5, which were demonstrated at different dates as shown in Table 2, four types of damage were administered as mentioned at the beginning of this section. Three replicates were included in each of which the average results are shown in Table 2 under the headings Experiments 3, 4, and 5. Experiment 5 was applied right at the full head stage May 25, while Experiment 3 was inflicted 15 days before heading

Table 2. Summary of clipping experiments.

Data	No damage	All cut off	1/4 cut off	1/2 cut off	3/4 cut off
		Experiment 1, April 29			
Acre yield bu.	46.3	5.02			
Total No. of heads per 1/1000 acre	2058	588			
Size of head, g	.457	.175			
Size of kernel, mg	24.1	15.1			
No. kernels per head	18.9	11.7			
Bushel weight, lbs.	55.1	49.1			
		Experiment 2, May 4			
Acre yield bu.	46.7	1.11			
Total No. of heads per 1/1000 acre	2098	166			
Size of head, g	.455	.122			
Size of kernel, mg	24.7	14.7			
No. kernels per head	18.4	8.3			
Bushel weight, lbs.	55.0	49.5			
		Experiment 3, May 9			
Acre yield bu.	36.3	.289	31.3	17.6	6.29
Total No. of heads per 1/1000 acre	2111	131	2043	1570	921
Size of head, g	.471	.062	.419	.302	.156
Size of kernel, mg	24.9	12.9		23.7	19.6
No. kernels per head	18.7	3.70	17.7	15.4	12.0
Bushel weight, lbs.	55.3		55	52.7	50.5
		Experiment 4, May 18			
Acre yield bu.	33.8	.046	19.6	3.37	.50
Total No. of heads per 1/1000 acre	2109	10	1669	757	289
Size of head, g	.453	.115	.345	.118	.048
Size of kernel, mg	24.7	17.0	22.8	15.8	11.7
No. kernels per head	18.3	6.70	15.1	7.45	4.16
Bushel weight, lbs.	55.3		54.5	50.7	49.0

Table 2. (concl.)

Data	No damage	All cut off	1/4 cut off	1/2 cut off	3/4 cut off
		Experiment 5, May 24			
Acre yield bu.	31.1		9.21	.739	.060
Total No. of heads per 1/1000 acre	1853		733	303	127
Size of head, g	.458		.3407	.070	.034
Size of kernel, mg	25.0		24.4	14.9	11.7
No. kernels per head	18.3		14.0	4.98	3.12
Bushel weight, lbs.	55.5		55.0	49.3	
		Experiment 6, May 31			
Acre yield bu.	30.5	.615	1.81	.094	
Total No. of heads per 1/1000 acre	1938	77	195	14	
Size of head, g	.429	.208	.253	.206	
Size of kernel, mg	24.7	22.2	23.1	20.6	
No. kernels per head	17.4	9.37	11.9	9.76	
Bushel weight, lbs.	54.5	54.5	54.3		

EXPLANATION OF PLATE I

Heads on this plate were obtained from plots in clipping experiments. They represent the gradual reduction in the size of head when different degrees of clipping were applied. Those at the top were taken from Experiment 3 which was inflicted on May 9. The heads in the bottom row were taken from Experiment 6 which was made on May 31.

In the top row, from left to right:

1. Head from No damage plots
2. Head from plots where 1/4 of the plant growth was cut off
3. Head from plots where 1/2 of the plant growth was cut off
4. Head from plots where 3/4 of the plant growth was cut off
5. Head from plots where all of the plant growth was cut off

In the bottom row from left to right:

1. Head from No damage plots
2. Head from plots where 1/4 of the plant growth was cut off
3. Head from plots where 1/2 of the plant growth was cut off
4. Head from plots where 3/4 of the plant growth was cut off

PLATE I

and Experiment 4, 7 days ahead of heading.

When Experiment 6 was made, six days after heading, it appeared clear that no re-growth could be obtained from plants clipped next to the ground, so this rate of clipping was replaced by clipping all heads off except those in the boot. Results are shown in Table 2.

In the following discussion the effect on each factor studied will be mentioned.

A. Acre Yield. The acre yield in bushels was computed from figures obtained in the different experiments. As shown in Table 3, when all plants were cut off next to the ground on April 29, the acre yield was reduced to 10.9 percent of that where no damage was inflicted. When the same damage was applied five days later it caused the yield to drop to 2.37 percent, and to .796 percent when injury was inflicted 10 days after the first experiment. Practically no production resulted where similar injuries were inflicted at later dates.

Plants with the upper 1/4 clipped off produced 86.3 percent of the yield of undamaged wheat when injury was inflicted on May 9, and it dropped to 58 percent then to 29.6 and finally to 5.92 percent as the damage was inflicted at the different later dates.

Reduction in yield dropped more severely when the upper 1/2 of the plants was cut off, making the percentages 48.5, 9.96, 2.37, .308, respectively, as damage was inflicted on successive later dates.

Table 3. Values of the summary of clipping experiments expressed as percentage of "No damage".

Data	No damage	All cut off	1/4 cut off	1/2 cut off	3/4 cut off
		Experiment 1, April 29			
Acre yield bu.	100	10.9			
Total No. of heads per 1/1000 acre	100	29.2			
Size of head, g	100	38.3			
Size of kernel, mg	100	62.6			
No. kernels per head	100	61.8			
		Experiment 2, May 4			
Acre yield bu.	100	2.37			
Total No. of heads per 1/1000 acre	100	7.92			
Size of head, g	100	26.7			
Size of kernel, mg	100	59.3			
No. kernels per head	100	45.3			
		Experiment 3, May 9			
Acre yield bu.	100	.796	86.3	48.5	17.3
Total No. of heads per 1/1000 acre	100	6.22	96.8	74.4	43.6
Size of head, g	100	13.16	88.8	64.1	39.4
Size of kernel, mg	100	51.8	95.1	78.6	61.4
No. kernels per head	100	19.8	94.6	82.4	64.5
		Experiment 4, May 18			
Acre yield bu.	100	.136	58.0	9.96	1.47
Total No. of heads per 1/1000 acre	100	.474	79.1	35.9	13.7
Size of head, g	100		76.1	26.1	10.7
Size of kernel, mg	100		92.1	63.8	47.4
No. kernels per head	100		82.6	40.6	22.7

Table 3. (concl.)

Data	No damage	All cut off	1/4 cut off	1/2 cut off	3/4 cut off
		Experiment 5, May 24			
Acre yield bu.	100		29.6	2.37	.192
Total No. of heads per 1/1000 acre	100		39.6	16.4	6.88
Size of head, g	100		74.4	15.4	8.69
Size of kernel, mg	100		97.4	59.4	47.0
No. kernels per head	100		76.3	27.2	17.0
		Experiment 6, May 31			
Acre yield bu.	100	2.01	5.92	.308	
Total No. of heads per 1/1000 acre	100	3.97	10.1	.737	
Size of head, g	100	48.4	58.9	47.8	
Size of kernel, mg	100	84.8	93.6	83.5	
No. kernels per head	100	53.9	68.7	58.2	

When 3/4 of the growth was cut off May 9, the acre yield was 17.3 percent of the no damage yield; then it dropped to 1.47 and .192 percent, respectively, in the experiments made one and two weeks later.

B. Size of Head. Tables 2 and 3 and Plate I show the effect of damage on the size of head. The reduction as expressed in percent of no damage shows that when plants were cut off next to the ground the size of head dropped to 38.3 percent. Reduction dropped respectively as damage was inflicted at later dates as follows: 26.7, 13.2. When 1/4 of the plant growth was cut off, the size of head dropped to 88.8 percent as the damage was applied on May 9; then it dropped to 76.1, 74.4 and 58.9 on successive dates of injury. The reduction trend is more pronounced when 1/2 of plants were cut off. When 3/4 of the growth was cut off at May 24 or one day before the sull-head stage the production of grain was as low as 8.69 percent of the no damage.

C. Size of Kernel. The size of kernel as shown in Table 3 was reduced to 62.6 percent of that from no damage plots when injury was administered on April 29 and when all plant growth was cut off. Later injuries did not cause very pronounced differences from that applied at the earliest, but when 1/4 of the plants were clipped off even at later dates, a very slight reduction, not exceeding 7 percent, occurred in the size of the kernel, while cutting off of the plant growth caused a reduction ranging from 21.4 percent when damage was applied on

May 9 to 40.6 when damage was inflicted on May 24. The same results were obtained when 3/4 of the plant growth was cut off except that the reduction ranged from 38.6 to 53.0 percent.

D. Number of Kernels per Head. As shown in Table 2, the number of kernels per normal head is very close to 19. When damage was inflicted at various dates and rates the number of kernels was reduced in respective proportion with the lateness and severity of injury. A drop from 19 to 11 resulted when all plants were cut off next to the ground on April 29; when damage was applied five days later, the number of kernels dropped again from 11 to 8. The most reduction resulted when injury was inflicted on May 9. This caused a drop of from 19 to 3.7 kernels per head.

Cutting off 1/4 of the plant growth at various dates caused very slight reduction compared to the undamaged heads.

Plants with the upper 1/2 and 3/4 of the growth cut off at various dates showed more pronounced reduction in the number of kernels per head, proving that the heavier and the later the damage, the less the number of kernels.

E. Bushel Weight. The same trend was obtained in the bushel weight as that of the size of kernel. However, the reduction was not as heavy as was obtained in other factors. As is noticed in Table 2, the bushel weight for no damage plots was 55 pounds, while when the latest and heaviest damage was inflicted the bushel weight dropped to only 49 pounds.

EXPLANATION OF PLATE II

Height of grain in the graduated cylinders represents the amounts of grain in the average head in injured plots expressed as percent of uninjured heads.

Fig. 1. Undamaged heads, 100 percent

Fig. 2. Heads that received slight whipping on May 7 (Experiment 11)

Fig. 3. Heads that received light whipping on May 7 (Experiment 11)

Fig. 4. Heads that received moderate whipping on May 7 (Experiment 11)

Fig. 5. Heads that received heavy whipping on May 7 (Experiment 11)

Fig. 6. Undamaged heads, 100 percent

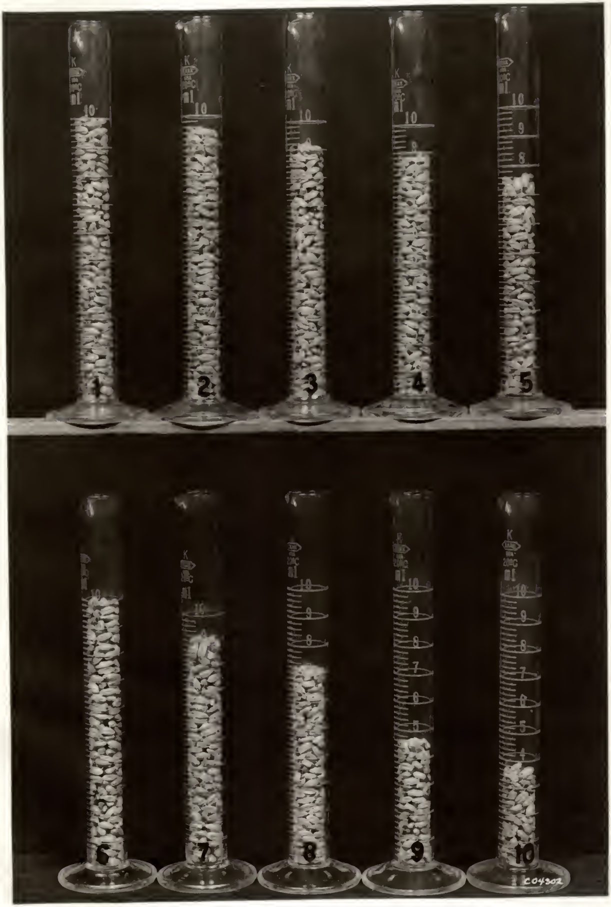
Fig. 7. Heads that received slight whipping on June 1 (Experiment 15)

Fig. 8. Heads that received light whipping on June 1 (Experiment 15)

Fig. 9. Heads that received moderate whipping on June 1 (Experiment 15)

Fig. 10. Heads that received heavy whipping on June 1 (Experiment 15)

PLATE II



Effect of Whipping Experiments. Among the different treatments, the whipping experiments seemed to most closely approximate damage from natural hailstorm. Four different degrees of whipping were applied in each experiment: 1. slight whipping which was marked by the letter B; 2. light whipping represented by C; 3. moderate whipping expressed as D; 4. heavy whipping marked as E. One plot was left with no damage and was assigned the letter A.

Five experiments were conducted at five different dates as shown in Table 4. In each experiment the four different rates of whipping were included and randomized in three replicates.

Experiment 11, the first, was begun May 7 or 18 days before full-head stage.

Experiment 12 was applied May 14, or 11 days before heading stage. Five days later (May 19) Experiment 13 was begun; by this time about 10 percent of the plants were heading. Right at the full heading date, which was May 25, Experiment 14 was applied, and 6 days later, Experiment 15 brought an end to the whipping experiments.

Plates III, IV, V, VI, and VII presented in this paper show plots in 1950 that received injuries similar to those inflicted this year. The effect of the treatments during that particular year are discussed on the Explanations of the Plates. In general the results are comparable to similar treatments inflicted in 1951.

Tables 4 and 5 present the results for the different

Table 4. Summary of whipping experiments.

Data	A	B	C	D	E
		Experiment 11, May 7			
Acre yield bu.	33.4	30.9	28.1	26.9	19.8
Total No. of heads per 1/1000 acre	2004	1940	1891	1739	1513
Size of head, g	.448	.434	.406	.421	.358
Size of kernel, mg	24.2	23.0	22.7	22.6	21.4
No. kernels per head	16.6	19.2	17.9	18.7	16.7
Bushel weight, lbs.	55.3	54.0	53.5	54.3	53.5
		Experiment 12, May 14			
Acre yield bu.	31.3	28.6	23.7	20.7	13.1
Total No. of heads per 1/1000 acre	1905	1850	1543	1487	1096
Size of head, g	.448	.421	.420	.381	.328
Size of kernel, mg	24.3	23.5	22.4	22.0	20.0
No. kernels per head	18.4	18.0	18.8	17.3	16.4
Bushel weight,lbs.	54.7	54.0	53.8	53.8	52.5
		Experiment 13, May 19			
Acre yield bu.	32.0	21.9	18.0	7.9	3.9
Total No. of heads per 1/1000 acre	1803	1609	1291	1039	618
Size of head, g	.487	.372	.383	.196	.173
Size of kernel, mg	24.5	22.9	22.7	20.9	17.6
No. kernels per head	19.8	16.3	16.9	9.24	9.82
Bushel weight, lbs.	55.2	54.2	54.3	52.5	50.2
		Experiment 14, May 25			
Acre yield bu.	29.2	16.5	10.3	5.5	2.9
Total No. of heads per 1/1000 acre	1875	1370	1057	770	403
Size of head, g	.425	.327	.265	.196	.150
Size of kernel, mg	23.0	22.1	20.5	19.0	17.4
No. kernels per head	18.5	14.8	12.9	10.4	8.65
Bushel weight, lbs.	54.2	54.2	53.8	51.8	49.5

Table 4. (concl.)

Data	A	B	C	D	E
		Experiment 15, June 1			
Acre yield bu.	25.6	21.4	16.9	8.8	4.3
Total No. of heads per 1/1000 acre	1692	1570	1545	1199	767
Size of head, g	.412	.372	.299	.192	.144
Size of kernel, mg	23.1	22.3	19.1	18.1	16.7
No. kernels per head	17.8	16.7	15.8	10.5	8.65
Bushel weight, lbs.	54.2	54.3	53.2	51.2	51.0

Table 5. Summary of whipping experiments expressed as percentages of "No damage".

Data	A	B	C	D	E
		Experiment 11, May 7			
Acre yield bu.	100	92.5	84.1	80.5	54.3
Total No. of heads per 1/1000 acre	100	96.8	94.4	86.8	75.5
Size of head, g	100	96.8	90.5	44.0	79.8
Size of kernel, mg	100	95.0	03.0	94.4	88.4
No. kernels per head	100	103.6	92.6	100.0	90.0
Bushel weight, lbs.	100	97.6	96.7	98.1	96.7
		Experiment 12, May 14			
Acre yield bu.	100	91.4	75.7	66.1	41.9
Total No. of heads per 1/1000 acre	100	97.1	81.0	78.1	57.5
Size of head, g	100	93.9	93.7	85.0	73.1
Size of kernel, mg	100	96.7	92.0	90.3	82.3
No. kernels per head	100	97.1	102.0	94.1	88.9
Bushel weight, lbs.	100	98.7	98.4	98.4	96.0
		Experiment 13, May 19			
Acre yield bu.	100	68.4	56.3	24.7	12.2
Total No. of heads per 1/1000 acre	100	89.2	71.6	57.6	34.3
Size of head, g	100	76.4	78.5	40.3	35.4
Size of kernel, mg	100	93.6	92.8	85.5	72.1
No. kernels per head	100	81.8	89.9	46.5	49.5
Bushel weight, lbs.	100	98.1	98.3	95.1	90.9
		Experiment 14, May 25			
Acre yield bu.	100	56.5	35.3	18.8	10.0
Total No. of heads per 1/1000 acre	100	73.1	56.4	41.1	21.5
Size of head, g	100	76.8	62.2	45.0	35.2
Size of kernel, mg	100	96.0	89.1	82.4	75.8
No. kernels per head	100	80.1	69.9	56.1	46.9
Bushel weight, lbs.	100	100.0	99.3	95.5	91.3

Table 5. (concl.)

Data	A	B	C	D	E
		Experiment 15, June 1			
Acre yield bu.	100	83.6	66.0	34.4	16.8
Total No. of heads per 1/1000 acre	100	92.8	91.3	70.9	45.3
Size of head, g	100	90.1	72.5	46.5	34.9
Size of kernel, mg	100	96.3	82.5	78.1	72.2
No. kernels per head	100	93.6	87.8	58.7	48.6
Bushel weight, lbs.	100	100.0	98.2	94.4	94.1

EXPLANATION OF PLATE III

Pawnee wheat in the "No damage" plots

Photographed on May 5

PLATE III

EXPLANATION OF PLATE IV

Pawnee wheat on plots that received the smallest amount of whipping (designated "B") on April 24. Photographed on May 5.

Compared with the undamaged wheat (Plate III) the percentage reduction for this treatment was:

Yield	2 %
Number of heads per acre	+3 %
Weight of grain in head	5 %
Number of kernels per head	2 %
Size of kernel	2 %

PLATE IV

EXPLANATION OF PLATE V

Pawnee wheat in plots that received slight whipping (designated "C") on April 24. Photographed on May 5.

The percentage decrease of this treatment compared with undamaged wheat was:

Yield	17 %
Number of heads per acre	6 %
Weight of grain in head	12 %
Number of kernels per head	8 %
Size of kernel	2 %

PLATE V

EXPLANATION OF PLATE VI

Pawnee wheat in plots that received light whipping (designated "D") on April 24. Photographed May 5.

The percentage decrease of this wheat compared with undamaged wheat was:

Yield	21 %
Number of heads per acre	8 %
Weight of grain per head	14 %
Number of kernels per head	4 %
Size of kernel	11 %

PLATE VI

EXPLANATION OF PLATE VII

Pawnee wheat in plots that received the heaviest amount of whipping (designated "E") on April 24. Photographed May 5.

The percentage decrease of this wheat compared with undamaged wheat was:

Yield	34%
Number of heads per acre	12%
Weight of grain in head	25%
Number of kernels per head	11%
Size of kernel	16%
Heads below 7 inches, increase	2.4%
Delay in heading	4 days

PLATE VII

factors discussed as an average for the three replicates included in each experiment. The whipping at different dates and degrees and its effect on the apparent factors are presented as follows:

A. Acre Yield. Before discussing this section it should be mentioned that reductions in acre yield were due to the combined effects of injury which resulted from reductions in different factors; e.g., number of heads per 1/1000 acre, size of head, or size of kernel.

The slight whipping applied at earlier dates resulted in very small reductions in the percentage of acre yield compared with slight whipping applied right at the heading stage. When applied after heading was completed and grains had formed, slight injury seemed to cause pronounced reduction in the acre yield but not as much as that applied at heading time.

A gradual reduction following the lateness of whipping applications resulted in the yield from plots whipped lightly. As shown in Table 5 under C, the acre yield dropped to 84.1 then to 75.7, 56.3, and to 35.3 right at the heading stage, but when applied a week later light whipping caused a reduction of only 66.0 percent of the no damage plots.

Moderate whipping showed the same trend as that of light whipping except the reduction was more pronounced when damage was inflicted from date to date.

The heavy whipping seemed to have a steep trend in its reduction of acre yield. The yield dropped from 54.3 percent of no damage when whipped May 7 to 10.0 percent when whipped right at heading stage. When heavy whipping was inflicted six days after heading, as shown in Table 5, the acre yield was 16.8 percent of no damage plots compared to 10 percent for the same injury applied at the heading stage.

B. Size of Head. Only moderate reduction in size of head occurred when plants were slightly and lightly whipped at different dates, but a pronounced reduction occurred when moderate whipping was applied even at an early date of May 7.

Reduction in the size of head was most important when plants received heavy whipping at the different dates. The weight of grain per head was reduced to 79.8 percent of no damage heads when injury was inflicted May 7, then it dropped to 73.1, 35.4 and 35.2 as injuries were inflicted on later dates. All results for size of head indicated that injuries inflicted after heading seemed to have less pronounced effect than those before or right at the heading stage.

C. Size of Kernel. The least reduction in terms of percentage from no damage was obtained in the size of kernel. As shown in Tables 4 and 5, the later the damage and the more severe, the more the reduction in the size of kernel. But even when heavy damage was inflicted at the heading stage a reduction to only 75.8 percent was secured while the acre yield from the same plots was reduced to 10.0 percent of that from no damage plots.

D. Number of Kernels per Head. Experiments 11, 12, applied May 7 and 14 had but little effect on the number of kernels per head. But when damage was administered at the heading stage or a few days earlier the reduction was much more pronounced, as shown for example in the heavy whipping at the heading date. The number of kernels per head dropped to 46.9 percent of the normal head. Whipping plants after heading had smaller effect on number of kernels per head than that applied at heading date or 6 days earlier.

E. Bushel Weight. Again as in the clipping experiments, whipping showed but little effect on the bushel weight. No damage plots had a bushel weight as high as 56.3, while when the heavy damage was applied right at the heading stage, it caused the bushel weight to drop down to 49.5. Other results due to different rates and dates of whipping as shown in Table 4 indicate a variation in the bushel weight due mainly to the severity of the damage and not to the lateness of inflicting the damage.

Effect of Leaf Removal Experiments. When natural hailstones hit the wheat plants from a vertical direction, the leaves, which extend horizontally, are more exposed to injury than other parts of the plant. Experiments 21, 22, 23, and 24 were designed and conducted to study the effect of losing leaves from the plant on the different factors taken into consideration as size of head, size of kernel, number of kernels per head and bushel weight.

Three different degrees of damage were applied and randomized in two replications in each experiment: A. Clipping of the terminal 1/2 of every leaf on the plant; B. Removing all leaves from alternate stems; C. Removing all leaves from all of the stems.

Four experiments, Nos. 21, 22, 23, and 24 were conducted on May 28, June 4, 11, and 15, respectively. Table 6 shows all the results obtained from the leaf removal experiments expressed as an average for the two replications in each experiment. Table 7 shows the same results expressed as percentages of no damage plots.

A. Size of Head. Applying this type of treatment at early and late dates shows but little effect on the size of head. When all leaves were removed from plants on May 28 or 3 days after the full heading stage, the size of head dropped to 83.2 percent of that from no damage plots, while when the experiment was applied on June 4, the size of head dropped to only 92.4 percent of normal heads. Experiments at later dates seemed to have no influence on the size of head as shown in Tables 6 and 7.

When removing 1/2 of every leaf in the first experiment on May 28, the size of head was 87.2 percent of that from undamaged plots. Later experiments showed an increase in the size of head from 87.2 to 96.5 and finally to 98.3 percent.

When all leaves were removed from alternate stems on May 28, the size of head was 92.7 percent of that from undam-

Table 6. Summary of leaf removal experiments.

Type of damage	Size of head, g	Size of kernel mg	No. kernels per head	Bu. weight lbs.
		Experiment 21, May 28		
No damage	.5299	26.74	19.8	57.25
1/2 of all leaves removed	.4623	25.20	18.3	56.0
All leaves removed from alternate stems	.4912	24.70	19.9	56.25
All leaves removed	.4410	23.14	19.1	56.25
		Experiment 22, June 4		
No damage	.5274	26.62	19.8	56.5
1/2 of all leaves removed	.5090	24.73	20.6	56.0
All leaves removed from alternate stems	.5252	25.51	20.6	56.5
All leaves removed	.4871	24.42	20.3	56.5
		Experiment 23, June 11		
No damage	.5286	26.10	20.3	56.5
1/2 of all leaves removed	.5195	25.90	20.0	56.5
All leaves removed from alternate stems	.5303	25.16	21.1	56.0
All leaves removed	.5578	25.60	21.7	55.7
		Experiment 24, June 15		
No damage	.4848	26.37	18.8	56.25
1/2 of all leaves removed				
All leaves removed from alternate stems				
All leaves removed	.5062	28.13	19.4	56.25

Table 7. Values of summary of leaf removal experiments expressed as percentages of "no damage".

Type of damage	Size of head, g	Size of kernel mg	No. kernels per head	Bu. weight lbs.
		Experiment 21, May 28		
No damage	100	100	100	100
1/2 of all leaves removed	87.24	94.24	92.4	97.81
All leaves removed from alternate stems	92.69	92.37	100.1	98.25
All leaves removed	83.22	86.53	96.6	98.25
		Experiment 22, June 4		
No damage	100	100	100	100
1/2 of all leaves removed	96.51	92.90	103.7	99.1
All leaves removed from alternate stems	99.50	95.83	103.9	100
All leaves removed	92.35	91.73	102.5	100
		Experiment 23, June 11		
No damage	100	100	100	100
1/2 of all leaves removed	98.27	99.23	98.9	100
All leaves removed from alternate stems	100.3	96.39	104.0	99.11
All leaves removed	105.5	98.08	107.3	98.51
		Experiment 24, June 15		
No damage	100	100	100	100
1/2 of all leaves removed				
All leaves removed from alternate stems				
All leaves removed	104.4	99.08	103.0	100

aged plots, while in later experiments the size of head showed no change.

B. Size of Kernel. Very similar results were obtained regarding the size of kernel as those of the size of head. Early treatment on May 28 by removing all leaves reduced the size of kernel to 86.5 percent of those from undamaged heads. When applying the same injury on June 4, the size of head was 91.7 percent, and later experiments showed but a very small reduction.

Removing 1/2 of every leaf on May 28 reduced the size of kernel to 94.2 percent of normal heads. In Experiments 22 and 23, applied on June 4 and 11, the size of kernel was brought to 92.9 and 99.2 percent of normal kernels, respectively.

The same trend as shown in Tables 6 and 7 was obtained when all leaves were removed from alternate stems. Early experiment on May 28 reduced the size of kernel to 9.24 percent, while applying the same damage on June 4 and 11 caused an increase to 95.8 and 96.4 percent of undamaged kernels.

C. Number of Kernels per Head. Only 4 percent reduction was obtained in the number of kernels when all leaves were removed on May 28. Later injuries, on June 4, 11 and 15, showed no influence on the number of kernels per head.

Only an 8 percent reduction was observed in number of kernels per head when damage was applied by cutting 1/2 of every leaf on May 28. Later injuries on June 4 and 11 showed no apparent influence.

Removing all leaves from alternate stems kept the number of kernels per head the same as normal regardless of the date of injury.

D. Bushel Weight. Tables 6 and 7 show that, regardless of the damages inflicted, the bushel weight remained as normal except for a few instances, as in Experiments 21 and 23 when a small reduction not exceeding 2 percent was observed.

Effect of Stem Bending Experiments. One common feature of hailstorm damage to wheat is to bend, bruise, or break the stems at different heights causing difficulty in the translocation process and possibly making photosynthesis less efficient.

This type of damage was inflicted in order to imitate the hazards of nature and to observe its effect on different factors that we are interested in learning.

Seven experiments, each of two replications, were conducted at seven different dates. Four different bending treatments were included in each experiment as follows: A. all plants bent low or right above the first node; B. all plants bent mid-high or right above the upper node; C. alternate stems bent mid-high; D. all stems bent at the neck or in between the head and the flag leaf. Dates and kinds of injury are shown in Tables 8 and 9. In the following discussion the effect on each factor studied will be considered.

A. Size of Head. When all plants were bent low at an early date, as May 29 or June 5 and 13, the size of the head; i.e., weight of grain, was very much affected and it dropped

Table 8. Summary of stem bending experiments.

Type of damage	Size of head, g	Size of kernel mg	No. kernels per head	Bu. weight lbs.
		Experiment 31, May 29		
No damage	.492	26.1	18.9	57.5
Bent at the neck	.403	25.1	18.0	53.5
Bent mid-high	.419	26.7	15.7	56.8
Alternate stems(Not bent	.388	23.0	17.0	54.0
bent mid-high (Bent	.260	20.0	13.1	51.3
Bent low				
		Experiment 32, June 5		
No damage	.521	25.6	19.6	56.5
Bent at the neck	.340	19.6	17.3	52.2
Bent mid-high	.512	26.5	19.3	56.2
Alternate stems(Not bent	.363	20.3	18.0	52.2
bent mid-high (Bent	.244	14.9	12.9	49.0
Bent low				
		Experiment 33, June 13		
No damage	.534	26.3	20.3	55.5
Bent at the neck	.398	22.2	17.9	53.5
Bent mid-high	.598	27.1	22.1	56.5
Alternate stems(Not bent	.582	22.9	18.3	55.2
bent mid-high (Bent	.270	17.8	14.9	49.7
Bent low				
		Experiment 34, June 15		
No damage	.500	25.7	19.3	54.7
Bent at the neck	.398	21.7	18.1	53.7
Bent mid-high	.446	25.6	17.4	55.7
Alternate stems(not bent	.458	23.1	19.8	55.2
bent mid-high (Bent	.340	19.5	17.4	49.7
All bent low				

Table 8. (concl.)

Type of damage	Size of head, g	Size of kernel mg	No. kernels per head	Bu. weight lbs.
		Experiment 35, June 22		
No damage	.500	25.6	19.4	56.0
Bent at the neck	.500	23.7	21.1	55.5
Bent mid-high	.444	24.5	18.1	55.0
Alternate stems (Not bent	.492	24.9	19.9	55.7
bent mid-high (Bent	.427	24.0	17.8	54.7
All bent low	.477	23.9	20.0	54.0
		Experiment 36, June 26		
No damage	.513	26.2	19.6	55.0
Bent at the neck	.474	25.3	18.7	54.7
Bent mid-high	.449	24.3	18.5	52.7
Alternate stems (Not bent	.454	25.0	18.1	55.5
bent mid-high (Bent	.471	24.1	19.6	56.0
All bent low	.504	25.3	19.9	52.7
		Experiment 37, July 2		
No damage	.489	24.9	19.6	55.5
Bent at the neck	.532	25.7	20.7	55.5
Bent mid-high	.480	24.5	19.5	53.7
Alternate stems (Not bent	.502	24.7	20.4	54.5
bent mid-high (Bent	.535	24.3	21.9	55.0
Bent low	.467	25.2	18.5	54.5

to about half of the size of a normal one. But later damages, as June 15, 22, and 26, showed much less damage in the size of the head compared to earlier experiments. The results indicate that late injuries on June 22 and 26 have but a very slight effect on the size of head.

It was late in the season before bending at the neck was included and administered in these experiments; however, when applying it on June 22 and later experiments, size of head did not show any change.

Bending all plants mid-high caused a reduction in the size of head when inflicted early. Later experiments proved the later the damage, the less the drop in the size of head.

When harvesting heads from stems alternately bent mid-high they were separated into two groups, via., those from bent stems, and those from erect stems. The data were computed and presented separately as shown in Tables 9 and 10.

Size of head from bent stems showed a fairly big reduction when damage was inflicted on May 29 and June 5, while later damages showed but a small reduction not exceeding 14 percent less than the normal head. Heads from unbent stems were bigger in size than heads from damaged stems but they did not, except in two experiments, show any increase above the normal heads.

B. Size of Kernel. The same trend was observed as in the size of head. When all plants were bent low, results in Tables 8 and 9 show a pronounced reduction in the size of kernel when

EXPLANATION OF PLATE VIII

Height of grain in the graduated cylinders represents the average amount of grain in the heads from stems that were injured by bending expressed as percentage of amount in heads from undamaged stems.

Fig. 1. Stems were not damaged

Fig. 2. Stems bent at the neck on June 22 (Experiment 35)

Fig. 3. Stems bent mid-high on May 29 (Experiment 31)

Fig. 4. Stems bent low on May 29 (Experiment 31)

Fig. 5. Stems were not damaged

Fig. 6. Stems bent at the neck on June 26 (Experiment 36)

Fig. 7. Stems bent mid-high on June 26 (Experiment 36)

Fig. 8. Stems bent low on June 26 (Experiment 36)

PLATE VIII

Table 9. Values of the summary of stem bending experiments expressed as percentages of "No damage".

Type of damage	Size of head, g	Size of kernel mg	No. kernels per head	Bu. weight lbs.
		Experiment 31, May 29		
No damage	100	100	100	100
Bent at the neck				
Bent mid-high	81.8	95.9	84.9	93.0
Alternate stems (Not bent	85.0	102.2	83.1	98.7
bent mid-high (Bent	78.8	87.9	90.3	93.9
Bent low	52.9	76.5	69.2	89.1
		Experiment 32, June 5		
No damage	100	100	100	100
Bent at the neck				
Bent mid-high	65.2	73.6	88.4	92.5
Alternate stems (Not bent	98.1	99.6	98.4	99.6
bent mid-high (Bent	69.7	76.1	91.7	92.5
Bent low	46.8	56.0	65.9	86.7
		Experiment 33, June 13		
No damage	100	100	100	100
Bent at the neck				
Bent mid-high	74.4	84.2	87.9	96.3
Alternate stems (Not bent	111.9	102.8	108.7	101.8
bent mid-high (Bent	108.9	87.0	90.2	99.5
Bent low	50.5	67.6	73.5	89.5
		Experiment 34, June 15		
No damage	100	100	100	100
Bent at the neck				
Bent mid-high	83.6	84.5	93.9	98.1
Alternate stems (Not bent	89.9	99.6	90.2	101.8
bent mid-high (Bent	92.2	89.9	102.4	100.9
Bent low	68.5	75.9	89.9	90.8

Table 9. (concl.)

Type of damage	Size of head, g	Size of kernel mg	No. kernels per head	Bu. weight lbs.
		Experiment 35, June 22		
No damage	100	100	100	100
Bent at the neck	100.2	92.3	109.0	99.1
Bent mid-high	89.4	95.4	93.6	98.2
Alternate stems (Not bent	99.1	96.6	102.4	99.5
bent mid-high (Bent	86.0	93.7	91.6	97.7
Bent low	96.0	93.0	103.0	96.4
		Experiment 36, June 26		
No damage	100	100	100	100
Bent at the neck	92.3	96.6	95.6	99.4
Bent mid-high	87.4	92.6	94.3	95.8
Alternate stems (Not bent	88.3	95.5	92.4	100.9
bent mid-high (Bent	91.7	92.0	99.8	101.8
Bent low	98.2	96.6	101.6	95.8
		Experiment 37, July 2		
No damage	100	100	100	100
Bent at the neck	108.9	103.0	105.6	100
Bent mid-high	98.2	98.5	99.6	96.7
Alternate stems (Not bent	102.8	98.9	103.8	98.1
bent mid-high (Bent	109.4	97.3	111.8	99.1
Bent low	95.6	101.2	94.4	98.2

damage was inflicted at early dates, but less damage was noted with the later applications of damage.

Plants bent at the neck showed a small drop in the size of kernel when the injury was inflicted on June 22, but later injuries on June 26 and July 2 seemed to have slight effect.

Bending the stems mid-high on May 29 caused a reduction in size of kernel to 95.0 percent from the normal kernels, but when damage was inflicted one week later, a reduction to 73.6 percent was observed. Injuries at later dates caused less reduction in the size of kernel compared with the size secured when damage was administered on June 5.

In the treatment when alternate stems were bent mid-high the non-bent stems showed no change in the size of kernel regardless of the time of damage, while size of kernel from those stems that were bent dropped to 87.9 and then to 76.1 percent of the normal kernels when damages were inflicted on May 29 and June 5. Later applications of injury showed suscessively larger kernels from 76.1 percent to 87.0, 89.9, 93.7, 92.0, and 97.3, denoting that the later the damage the less the effect of injury.

C. Number of Kernels per Head. When stems were bent low on May 29, June 5, 13, and 15, a reduction of 30.7, 34.1, 26.5, and 10.1 percent from a normal head was observed in number of kernels per head. Later injuries showed practically no effect on the number of kernels per head.

Bending the stems at the neck on June 22 and July 2 seemed to have a slight effect in increasing the number of kernels per head.

As shown in Tables 8 and 9, when plants were bent mid-high on May 29, a reduction down to 84.9 percent from normal was observed in the number of kernels per head. The later the damage was inflicted the less was the reduction in the number of kernels, and as we notice in Table 9, when injury was administered on July 2, the number of kernels per head was normal.

Number of kernels per head from undamaged stems in plots in which stems alternately were bent mid-high showed a decrease when injury was applied on May 29, Later injuries showed an irregular increase, while number of kernels per head from bent stems, although it showed a drop to 90.3 percent of normal showed a steady increase in later experiments.

D. Bushel Weight. Bending all plants low at the first four experiments reduced the bushel weight about 10 percent below the normal weight, while later experiments seemed to have less effect. Neither bending at the neck nor mid-high caused any appreciable reduction in the bushel weight. A slight but insignificant drop was observed at the first two experiments in test weight of grain from bent stems compared with grain from alternate stems that were not injured.

<u>Effect of Floret Removal Experiments</u>. In many cases after the head is completely developed a hailstorm might cause damage to it by removing a certain number of spikelets. This type of

EXPLANATION OF PLATE IX

Heads from floret removal experiments showing how the heads were treated. Starting from the left as Fig. 1 to the right:

Fig. 1. Head from undamaged plots

Fig. 2. Head from which 1/3 of the spikelets were removed

Fig. 3. Head from which 2/3 of the spikelets were removed

Fig. 4. Head from which the upper half of the head was removed

Fig. 5. Head from which spikelets from the lower half of the head were removed

PLATE IX

Table 10. Summary of floret removal experiments.

Type of damage	Size of head, g	kernel mg	No. kernels per head	Test weight
	Experiment 41, June 19			
No damage	.504	26.2	19.2	59.5
Upper half of head removed	.308	28.5	10.8	58.5
Lower half of head removed	.339	26.7	12.7	59.5
1/3 of spikelets removed	.360	26.4	13.6	59.0
2/3 of spikelets removed	.168	24.8	6.76	58.5
	Experiment 42, June 21			
No damage	.456	25.8	17.7	59.0
Upper half of head removed	.314	26.4	11.9	59.0
Lower half of head removed	.245	24.4	10.1	58.0
1/3 of spikelets removed	.284	25.5	11.2	59.0
2/3 of spikelets removed	.147	24.5	6.0	59.5
	Experiment 43, June 21			
No damage	.566	25.5	22.2	58.5
Upper half of head removed	.360	29.7	12.1	58.0
Lower half of head removed	.318	26.9	11.8	60.0
1/3 of spikelets removed	.367	26.0	14.1	58.5
2/3 of spikelets removed	.160	26.9	6.0	57.5
	Experiment 44, June 25			
No damage	.428	24.9	17.2	59.0
Upper half of head removed	.279	26.2	10.6	58.0
Lower half of head removed	.193	24.1	8.6	58.5
1/3 of spikelets removed	.293	23.9	12.2	58.0
2/3 of spikelets removed	.172	23.7	7.28	58.0

Table 10. (concl.)

Type of damage	Size of head, g	Size of kernel mg	No. kernels per head	Test weight
	Experiment 45, June 27			
No damage	.422	25.1	16.8	58.0
Upper half of head removed	.310	26.1	11.8	58.5
Lower half of head removed	.225	21.7	9.66	57.5
1/3 of spikelets removed	.310	24.3	12.8	57.0
2/3 of spikelets removed	.112	23.9	4.68	59.0
	Experiment 46, July 2			
No damage	.455	24.8	18.8	59.0
Upper half of head removed	.320	25.7	12.5	58.5
Lower half of head removed	.167	22.9	7.31	58.0
1/3 of spikelets removed	.477	26.0	18.3	57.0
2/3 of spikelets removed	.159	24.2	6.57	58.0

experiment was arranged to study the effect of this certain damage on other factors, particularly size of kernel and bushel weight.

To obtain observations on different injuries to the head caused by a hailstorm, four different types of damage were inflicted at six different dates, making a total of six experiments, each with one replication. The different injuries were randomized throughout the experiment.

In each experiment the four different injuries to the head were: A. removing the upper half of the head; B. removing all spikelets from the lower half of the head; C. removing 1/3 of the spikelets from the head by starting from the bottom to the top, removing one spikelet and leaving two; D. removing 2/3 of the spikelets as in C, leaving one spikelet and removing two.

Results of these experiments are shown in Tables 10 and 11. The effect of this type of injury on the coming factors is presented as follows:

A. Size of Head. The most apparent effect as it will appeal to the reader by looking at Tables 10 and 11 is the change in the size of head and number of kernels per head. As for the former, when removing the upper half of the head the percentage compared to a normal head fluctuated between 61.1 and 73.5. There is a very slight evidence that the later the damage the bigger the size of head. But removing the lower half of the head showed a gradual reduction in its size. When damage was demonstrated on June 19 the size of head was reduced to 67.3 percent of a normal head, while damages at later dates, as on June 21, 25, 27, and July 2 made the percentages drop to 54.0, 45.2, 53.3, and 35.9.

When 1/3 of the spikelets were removed a trend showing an increase in the size of head as experiments were applied at later dates was observed as it is shown in Tables 10 and 11.

Removing 2/3 of the spikelets showed but an irregular trend, because lateness of damage applications seemed to have no effect on the size of head in this particular kind of injury.

B. Size of Kernel. Removing the upper half of the head and leaving the lower half showed an increase in the size of kernel compared to kernels from normal heads. When damage was applied as early as June 19, the size of kernel was 109 percent, and all treatments at later dates showed an increase of the same nature.

When the lower half of the head was removed on June 19 and 21, size of kernels from the upper half in general were below the size of kernels from the entire undamaged head. (Note relation of size of kernels from lower 1/2 and upper 1/2 of undamaged heads.)

As 1/3 of the spikelets was removed a very similar trend to that when the lower half was removed was obtained.

A reduction of about 5 percent below the normal size of the kernel was observed when 2/3 of spikelets were removed at

Table 11. Values of the summary of floret removal experiments expressed as percentages of "No damage".

Type of damage	Size of head, g	Size of kernel mg	No. kernels per head	Test weight
		Experiment 41, June 19		
No damage	100	100	100	100
Upper half of head removed	61.1	109.0	56.1	98.3
Lower half of head removed	67.3	102.0	66.2	100
1/3 of spikelets removed	71.3	101.0	71.0	99.1
2/3 of spikelets removed	33.3	94.6	35.2	98.3
		Experiment 42, June 21		
No damage	100	100	100	100
Upper half of head removed	68.9	102.0	67.3	100
Lower half of head removed	54.0	94.6	57.0	98.3
1/3 of spikelets removed	62.3	98.7	63.1	100
2/3 of spikelets removed	32.2	94.9	33.8	101.0
		Experiment 43, June 21		
No damage	100	100	100	100
Upper half of head removed	63.6	117.0	54.5	99.1
Lower half of head removed	56.3	105.0	53.3	103.0
1/3 of spikelets removed	64.8	102.0	63.7	100
2/3 of spikelets removed	28.3	105.0	26.8	98.3
		Experiment 44, June 25		
No damage	100	100	100	100
Upper half of head removed	65.1	105.0	52.0	98.3
Lower half of head removed	45.2	96.9	46.7	99.2
1/3 of spikelets removed	68.6	96.1	71.4	98.3
2/3 of spikelets removed	40.3	94.3	42.4	98.3

Table 11. (concl.)

Type of damage	Size of head, g	Size of kernel mg	No. kernels per head	Test weight
		Experiment 45, June 27		
No damage	100	100	100	100
Upper half of head removed	73.5	104.0	70.8	101.0
Lower half of head removed	53.3	86.5	57.5	98.2
1/3 of spikelets removed	73.6	96.7	76.2	98.3
2/3 of spikelets removed	26.5	95.2	27.9	102.0
		Experiment 46, July 2		
No damage	100	100	100	100
Upper half of head removed	68.7	104.0	66.3	99.2
Lower half of head removed	35.9	92.4	38.8	98.3
1/3 of spikelets removed	102.0	105.0	97.3	96.6
2/3 of spikelets removed	34.1	97.7	34.9	98.3

different dates.

C. Number of Kernels per Head. Removing the upper half of the head on June 19 reduced the number of kernels per head to 56.1 percent of the normal number of kernels, but applying the same damage at later dates as June 21, 25, 27, and July 2 gave different results as 67.3, 54.5, 52, 70.8 and 66.3 percentages denoting an irregular trend.

When the lower half of the head was removed a gradual reduction following the lateness of injury applications was obtained in the number of kernels per head, the reduction was between 66 and 38.8 percent of the normal number of kernels.

When 1/3 of the spikelets were removed, the number of kernels was reduced to 71.0 percent of normal as damage was inflicted on June 19. Later experiments on June 21, 25, 27 and July 2 resulted in reduction down to 63.1, 63.7, 71.4 and 76.2 percent.

Removing 2/3 of the spikelets showed a slight gradual reduction trend in the number of kernels per head as experiments were carried on at later dates.

D. Bushel Weight. As the reader will notice from Tables 10 and 11, the bushel weight was hardly affected by this type of injury. A very slight reduction of about 2 percent was mostly obtained when different injuries were inflicted.

Qualitative Responses

Protein Content of Grain from Clipping Experiments. As mentioned in a previous section, the main purpose of this study was to determine the effect of different simulated hail injuries on the protein content of the grain produced. In discussing the obtained results, two points are taken into consideration: 1. Whether or not the degree of the severity of damage had any proportional effect; 2. If so, how important is the date of application of the injuries.

Table 12 represents the results of protein analyses of the grain from the first and the last experiments included in the plant clipping treatments. As indicated in the table, samples from the four different degrees of injury are presented with one sample from plots that received no damage to serve as a check.

Table 12. Protein content of samples from clipping experiment.

Type of damage	Protein percentage & date of injury		
	April 29	May 9	May 31
No damage	12.3	12.7	
All cut off	14.4	14.8	
1/4 cut off		12.6	14.2
1/2 cut off		12.7	17.8
3/4 cut off		14.4	17.0

When injury was inflicted by clipping off 1/4 and 1/2 of the plant's growth, the protein percentage of the grain that was produced showed no change from that of no damage plots. But when 3/4 and all the plants were cut off, the protein percentage increased up to 14.4 in both cases, while check samples were only 12.8.

Later injuries on May 31 caused a considerable increase in the protein percentage in all plots that were treated. Results show that the heavier the damage the higher the protein.

Protein Content of Grain from Whipping Treatments. Table 13 revealed that injuries inflicted as early as May 7 had no effect except when the heavy damage was applied, a small increase not exceeding 1 percent was obtained.

Table 13. Protein content of samples from whipping experiments.

Type of damage	Protein percentage & date of injury	
	May 7	June 1
A	12.3	12.6
B	12.7	13.4
C	12.7	14.4
D	12.4	15.2
E	13.3	15.4

Administering the same degrees of injury on June 1 caused a considerable increase in the percentage of protein. It was also observed that the heavier the injury the more the increase in percentage of protein.

Protein Content of Grain from Leaf Removal Treatments. Examining Table 14, the reader could hardly notice any significant effect for inflicting different degrees of this injury at an early or late date; however, a small decrease in protein percentage was noticed when all leaves were removed on May 28. Also later injuries applied on June 11 showed but a very little increase above those damaged early.

Table 14. Protein content of samples from leaf removal experiments.

Type of damage	Protein percentages & date of injury	
	May 28	June 11
No damage	11.9	11.8
1/2 of all leaves removed	11.6	11.8
All leaves removed from alternate stems	11.5	11.9
All leaves removed	11.2	11.4

Protein Content of Grain from Stem Bending Treatments. As indicated in Table 15, when stems were bent at different heights on May 29, an apparent increase was obtained in the protein percentage of the harvested grain. Plants that were bent low showed the highest protein percentage, while other treatments showed a variable increase ranging from 12.2 to 13.9 compared to 11.5 that was obtained in the no damage samples.

Table 15. Protein content of samples from stem bending experiments.

Type of damage	Protein percentage & date of injury		
	May 29	June 15	July 2
No damage	11.5		11.7
All bent at the neck		13.3	12.1
All bent mid-high	13.9		12.1
Alternate stems(Not bent	13.4		12.0
bent mid-high (Bent	12.2		12.1
All bent low	15.0		11.8

<u>Protein Content of Grain from Floret Removal Treatments.</u> Results of protein analyses for samples that were taken from plants injured on June 19 showed an increase in the protein percentage for all plants that were treated. Samples from plants from which 2/3 of the spikelets were removed seemed to have the highest protein content, followed by samples from plants on which the lower half of the head was removed.

Table 16. Protein content of samples from floret removal experiments.

Type of injury	Protein percentage & date of injury	
	June 19	July 2
No damage	12.0	12.1
Upper half removed	13.0	12.4
Lower half removed	13.4	11.8
1/3 of spikelets removed	12.5	12.1
2/3 of spikelets removed	14.2	11.5

Inflicting the damage as late as July 2 showed practically no pronounced difference among samples from different plots denoting that injuries applied to the head at such a date do not change the protein percentage of its kernel.

SUMMARY AND DISCUSSION

Discussions in this paper were derived from data which present a one-year period of study. Trends that are mentioned are presented as they were observed regardless of their similarity to results from this study in other seasons.

Significant trends that were observed and the possible explanations for their occurrence are discussed here.

Some of the clipping experiments were made during the second week of May when the growing point of the plant was above the surface of the ground. So, when all of a plant's growth was clipped, the growing point was destroyed. In these experiments there was no further growth of the plant and consequently no yield of the grain.

Other degrees of clipping showed the relationship between leaf area and yield since no injury was inflicted on the culms. The size of head, the size of kernel and the number of kernels per head were reduced in accordance with the proportion of plant growth clipped off and the stage of development of the crop. The amount of damage increased as the crop advanced toward maturity.

The results of whipping experiments are necessarily somewhat erratic because it was very difficult to inflict the same degree of injury at succeeding weekly intervals and in the different plots.

In the early part of the season the probable reason for yield reduction was mostly due to loss of leaves. Later after the stems had developed, their injury was more important than loss of leaves, and the yield that was obtained where injury was severe came chiefly from heads of new tillers rather than heads on broken stems. When plants were whipped at different dates and varying degrees of injury the acre yield of grain was reduced in proportion with the severity of treatment and with later dates of whipping. Early damage showed much less effect compared with late injuries.

The reduction in yield of grain can apparently be accounted for in part by decrease in the number of heads as well as decrease in the size of head expressed in weight of grain. Reduction in the size of head is due to decrease in either or both size of kernel and number of kernels per head.

In all whipping experiments, size of kernel was the least affected compared with other factors. It showed slight reduction when plants were whipped at an early stage while the heavy damage at the latest date caused a reduction of 28 percent below normal. Number of kernels per head followed the same trend as size of kernel but was more important especially in the later experiments.

The importance of leaves and their function as food manufacturing agents was investigated further in leaf removal experiments. When all leaves were removed from plants as early as May 28, which was 3 days after heading, the weight of grain from the head and the size of kernel were reduced 14 to 17 percent below normal. This was due to the removal of leaves while they were still functioning and because the head was not yet completely developed.

Stems that are bruised or bent, sometimes referred to as "breaks" are often the cause of considerable concern in a hail damage settlement. Bending the stems at different heights before heads are completely developed causes difficulty in the translocation process and possibly makes photosynthesis less efficient; besides when plants are bent low many of the heads will be on the ground and will be subject to rot. Keeping these facts in mind one notices that when stems were bent low at different dates a pronounced reduction in yield, size of head, size of kernel, number of kernels per head and bushel weight was observed. Early damages reflect the most effect, while later injuries hardly show any response because they were made when heads were completely developed and partly ripened. About the same trend was obtained when plants were bent mid-high, except that reductions were not as severe.

When heads were damaged by removing certain percentages of the florets, the kernels were well developed and in the process of filling and maturing. Removal of some of the florets did not affect the size of the remaining kernels. However, the size of head and number of kernels per head obviously were affected because removal of any kernels from the head simply meant a reduction in its weight and a reduction in number of kernels it contained. Essentially the same results were obtained when these injuries were inflicted on different dates.

In some experiments all the plant growth was cut next to the ground on April 29 and May 9. Those dates might have been early enough to give the plants a chance to make some regrowth and to produce limited yields; however, subsequent weather conditions were not as favorable to carbohydrate accumulation as they were to protein formation. For this reason, the yields were low and the protein content was higher in grain from damaged plots. Other injuries on May 31, which was 6 days after heading, caused very similar results for the same reason.

When plants were whipped at early dates practically no increase in protein percentage was obtained, while later injuries on June 1 showed an intermediate increase in the protein content. This probably was due to the fact that when injuries were applied early in the season there was enough time for plants to recover and to accumulate enough carbohydrates to make the C/N ratio normal, while later in the season, as June 1, the protein was already stored in the kernels and the plants failed to accumulate and store the normal required amounts of carbohydrates.

It is known that proteins are deposited in the kernels during the early stages of kernel development, while carbohydrates are stored gradually at later stages. Therefore, when plants were bent at early dates right after the heading stage the injury caused an increase in the protein percentage, apparently because the translocation process and synthesis of carbohydrates were limited while the major part of the nitrogen was already deposited in the grain. Later bending when heads were completely developed did not cause any changes.

Only early injuries in the spikelet removal experiments caused a slight increase in protein percentages in the grain.

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QUANTITATIVE AND QUALITATIVE RESPONSES IN WHEAT RESULTING FROM PHYSICAL INJURIES TO THE PLANTS

by

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Hail as one of Nature's hazards was and still is a problem facing both the farmer and the insurance companies.

The purpose of this study was to find out the effect of hail damage on wheat particularly yield per acre and various features of growth that might be associated with yield, such as number of heads per acre, weight of grain per head, size of kernel, and bushel weight. Also the protein content of the wheat from plants that were damaged was compared with grain from undamaged plants. The wheat was grown on the Agronomy farm in 1951.

To imitate the effect of hail of different intensities five different treatments were applied. In each treatment experiments were inflicted on different dates in order to study the effect of the stage of growth and the ability of the plant to recover.

In the first experiments portionsof the leaf growth were clipped off to determine the importance of leaves and how the plant would respond when leaf area was reduced. These treatments included:

1. Where all plants were clipped next to ground
2. Three-fourths of the plant growth was clipped off
3. One-half of the plant growth was clipped off
4. One-fourth of the plant growth was clipped off

The second type of damage was inflicted by whipping the plants. In these treatments four degrees of injury were inflicted; viz., slight, light, moderate, and heavy.

Another type of damage consisted of removing leaves at intervals after the plants had headed. Three different treatments were applied:

1. All leaves were removed

2. All leaves were removed from alternate stems

3. The terminal half of every leaf was clipped off

The fourth type of injury was inflicted by bending the stems. Stems were bent at three different heights;

1. Low or next to ground

2. Mid high

3. High; i.e., above the flag leaf or at the neck

In some experiments alternate stems were bent mid high for comparison with plots in which all of the stems were bent at that height.

The last type of treatment consisted of removing some of the florets or spikelets from the heads. Four different treatments were employed:

1. All spikelets were removed from the lower half of the head

2. All spikelets were removed from the upper half of the head

3. One-third of the spikelets in the head were removed

4. Two-thirds of the spikelets of the head were removed

In the protein tests samples of grain representing all kinds of damage were analyzed by the Kjeldahl method.

Significant effects and trends in the growth, yield and quality of wheat were observed as the result of treatments applied in these studies.

1. When the plants were clipped near the ground during the second week of May destroying the young heads that had then formed there was no further growth of the plant and consequently no yield of grain. Where the plant was cut at higher levels the size of the head, the size of the kernel and the number of kernels per head were reduced, the extent of damage increasing with the proportion of the plant growth that was clipped off and with the stage of development of the crop.

2. When plants were whipped at different dates and varying degrees of injury the acre yield of grain was reduced in proportion with the severity of treatment and with later dates of whipping. Early damage showed much less effect than later injuries. In all whipping experiments, the size of kernel was the least affected.

3. When all leaves were removed from plants at the heading stage, May 28, the weight of grain from the head and the size of kernel were reduced to about 17 per cent below normal. It is believed that this was due to the removal of leaves while they were still functioning and when the head was not yet completely developed.

4. When stems were bent low at different dates a pronounced reduction in yield, size of head, size of kernel, and number of kernels per head were observed. Early damages showed the most effect, while later injuries made when heads were completely developed and partly ripened hardly showed any response.

Reductions were not as great where stems were bent mid-high as at low level.

5. Removal of florets from the head obviously decreased the number of kernels proportionately and would be expected to decrease the weight of grain nearly in proportion. However, this type of injury did not show any change in the size of kernel.

6. In the protein analyses, grain from plants that were clipped at different heights showed higher protein percentage than normal; probably because subsequent weather conditions under which plants recovered were not as favorable to carbohydrate accumulation as they were to protein formation.

7. Grain from plants whipped at early dates showed no increase in protein content probably because when injuries were applied early in the season there was enough time for plants to recover and to function normally. Injuries applied soon after heading, June 1, showed an intermediate increase in the protein content because by that time considerable of amounts of the nitrogen were already stored in the kernels and the plants apparently failed to accumulate and store the normal required amounts of carbohydrates.

8. When plants were bent at early dates right after the heading stage the injury caused an increase in protein percentage, apparently because the translocation process and synthesis of carbohydrates were limited while the major part of the nitrogen was already deposited in the grain.

9. Only early injuries in the spikelets' removal experiment influenced protein percentage of the grain and then only slight increases were observed.