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The Effect of Simulated Hail Damage on Oats

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THE EFFECT OF SIMULATED HAIL DAMAGE ON OATS

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This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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INTRODUCTION

With all of the advances in science and technology, the farmer is still helpless against the powers of nature. A natural disaster, such as a hail storm, can seriously affect an individual farmer, or a small region. During the course of a growing season, the sum of these hail storms can result in a substantial loss to the total farm economy. Hail insurance provides a way for farmers to protect themselves from losses due to hail, but the estimation of losses in a hailed field is a difficult job since the entire field is often hit leaving no check area from which to determine actual yield. It is to the benefit of farmers and insurers alike to have accurate and uniform adjusting procedures. The improvement of adjusting procedures has come a long way in small grains, especially in the case of wheat and barley. There are still several questions left unanswered in the case of oats, however.

The major objective of this study was to determine the effect of simulated hail damage on oats at various stages of growth. This information may lead to the development of an adjustment table for use solely on oats; at the present time, there is one adjustment table for all small grains. In addition to providing a more factual basis for the adjustment of hail damage on oats, it will also increase our knowledge on the growth and development of the oat plant.

Several treatments applied at various stages of growth were examined in an attempt to answer several of the questions raised about the adjustment of oats. The specific objectives were: 1) to determine the amount of blast caused by hail, 2) to determine whether a reduction in kernel weight occurs when the culm is broken below the head, and 3) to determine the percent of heads that fall prior to harvest. Answers to these objectives will help insurers make more accurate and uniform adjustments and provide farmers with just compensation for their losses.

LITERATURE REVIEW

Simulated Hail Studies on Small Grain

Most of the literature on simulated hail studies or actual hail damage of small grains is on wheat, but Eldredge (10) and Knowles (19) have both studied the effect of simulated hail damage on oats and barley, as well as wheat. Eldredge, working in Iowa, inflicted five types of injury: 1) plants beaten off at the surface, 2) cut off at the surface of the ground or above the growing point, 3) whipped lightly, 4) heads bruised, and 5) straws broken.

The first type of injury resulted in the complete destruction of all above-ground plant material. There was good correlation for all three crops with this treatment. Declining partial recovery from the injury was reported until the boot stage when all recovery ceased. Damage done in the vegetative stage prior to extension of the growing point above the surface resulted in a 10 to 50% loss in yield, depending on the crop, stage of injury, and environmental factors. Once the growing point was 1 to 2 inches above the surface, the yield was reduced by about 70% for all crops.

When plants were cut off above the growing point, there was less damage done, in all crops, than with the preceding treatment. When the growing point was still below the surface, however, there was more damage done with the second treatment on oats and barley. This probably would be true for winter wheat as well, but the treatments were applied on the same date for all crops, regardless of stage, so winter wheat was well into the jointing stage.

The losses due to the light whipping tended to increase as injury was inflicted at advanced stages of maturity. An increasing amount of the yield came from new tillers as the injury was inflicted at later stages of development. Other simulated hail studies support the finding that as injury is inflicted from the early leaf stages through the heading stage, the plant's ability to recover decreases with advanced maturity (1) (15) (19) (22). Test weight and 1000 kernel weight declined in a similar manner in the wheat treated by Hella and Stoa (15).

The head bruising injury was not as severe on oats as barley and wheat probably due to its loose panicle. This type of injury was not as severe as the others, but the yield reductions were significant for barley and wheat. Hella and Stoa (15), working in North Dakota on wheat, simulated head, as Eldredge (10) did, by holding a board beside the head and striking the other side of the head with the edge of a thin board. This treatment applied in boot, heading, and milk stages resulted in about a 21% loss for all three stages.

Stem breakage has been simulated by breaking stems over a lath, using clay marbles and hand bending. Regardless of the method used, the most severe injury occurs during the period from boot through milk stages (1) (15) (19) (22). Eldredge (10) reported a 46.6% loss for oats when bent in the boot stage and a 22.1% loss when bent at maturity. Low breaks averaged between 23 and 28% losses for all years in Laude and Pauli's study on wheat (22), indicating little influence due to environmental conditions. At 5 days before heading, the kernel number was decreased by 15% and the kernel size by 5%. The influence of kernel size on yield increased with increasing maturity, having an effect as late as 25 days after heading.

It has been found that the amount of damage done by stem breakage is dependent upon the location of the break. Low breaks were found to be about 1.5 times more severe than the mid and upper injuries by Laude and Pauli (22), working on winter wheat in Kansas. Knowles (19) also found low breaks to be more severe. In 1930, Eldredge (10) collected heads of wheat from a field which had been struck by hail when the plants were in the bloom stage. If the culms were broken near the head, with the head still attached, there was a 31.2% reduction in yield and if broken closer to the ground so that the head actually rested on the ground, although still attached, there was a 65.2% yield reduction. Busch (3), working with wheat, and Deckard and Peterson (7), working with barley in North Dakota, found that bending the stems below the flag leaf reduced the yield less than bending the stems above the flag leaf. For wheat, this was due in part to a decreased number of kernels per head. For barley, the grain quality (as measured by test weight, % plump and % thin kernels) was reduced at the various bending treatments, especially in soft dough.

Much of the loss due to stem breakage can often be attributed to the complete loss of heads. Knowles (19) found that in the case of wheat, 16% of the heads dropped when stems were bent 6 days after heading and 10% dropped when bent 11 days after heading. He found the same general trends for oats and barley. Afanasiev (1) also found the greatest loss occurred in the heading and milk stages, but yield losses could not be attributed solely to loss of heads. In hailed fields of wheat where the average droppage was 27.8%, Knowles (19) found that the yield was decreased by 23% due to the loss of hanging heads, and there was an 18% loss in kernel weight. Dry, windy weather was also found to increase the amount of droppage. Laude and Pauli (22) bent stems above and below the flag leaf as Busch (3) did; both studies showed a higher frequency of head droppage when stems were bent above the flag leaf. When Laude and Pauli bent stems above the flag leaf 17 to 21 days after heading, they had 44% head droppage. This loss was magnified even more by the fact that the heads that fell were 13% heavier than the heads still attached. They also noticed an apparent varietal difference in head droppage.

Some attempts have been made to simulate stem bruising. In 1953 and 1954, Hella and Stoa (15) applied treatments to spring wheat which resulted in yield losses of 10%. Test weights and 1000 kernel weights were decreased similarly. Ripening was delayed about 5 days when treatments were applied in jointing and boot stages and about 2 days when applied at later stages. Plants that had stems bruised by hail were collected by Knowles (19), and he found that these bruises caused little or no reduction in yield or kernel weight.

At Carrington, North Dakota, Busch (3) inflicted injury under both dryland and "post wet" (application of water following injury) conditions. The "post wet" condition was thought to be more representative of actual hail conditions. Trends for yield were similar under these two situations, but some of the other parameters varied somewhat. Test weights varied more by treatment under dryland than "post wet." One thousand kernel weights were similar for dryland and "post wet" as was the percentage of fallen heads. Yield reductions by stage of development were from most to least damaged: milk, heading, soft dough, boot, and hard dough. The milk stage was the most critical, since yield, test weight, and 1000 kernel weight were all reduced severely at this stage.

There have been other studies done on wheat that applied treatments similar to those applied in simulated hail studies. One of these was done by White (31) who artificially defoliated wheat plants. He found that defoliation caused the greatest yield reduction when done in the heading stage. Defoliated plants were slightly shorter, required about 1.9 days longer to mature, had fewer heads, and were lower in test weight. Defoliation was detrimental at any stage except the last two weeks prior to ripening. The effect of lodging on yield was studied by Laude and Pauli (21) by artificially bending the stems by hand. Yields were reduced by one-third one to two weeks before heading and also one to two weeks after heading. Early lodging reduced the number of kernels and late lodging reduced the size of kernels.

Blast in Oats

Blast in oats has had several common names, such as blindness, blight, white ear, deafness and sterility (11, 27). Johnson and Brown (18) defined blast of oats as "a condition in which the growth of some of the spikelets is inhibited during the development of the panicle so that when the panicle emerges, the blasted spikelets are sterile and have a white, papery appearance." Typical blast in oats, according to Sheals (26) is 85.3% of the blast on the lower third of the panicle, 14.1% on the middle third, and 0.6% on the upper third. Three general causes for the condition have been listed by Eldredge (10): 1) a varietal characteristic; 2) unfavorable growing conditions, such as extremes in temperature, moisture, light, and nutrients; and 3) injury to the developing spikelets while still in an early stage of growth. The most common forms of injury are insect damage, disease, and hail.

Some of the first evidence for varietal differences was found by Elliott (12). She suspected a relationship between halo blight and blast but found none; instead, she found a great deal of variability in the amount of blast among varieties. The occurrence of blast in several varieties was observed and it was found that the percentage of blast in each variety varied from year to year, but variability between varieties was consistent (11). In 1922, the blast percentage ranged from 6 to 28%, in 1923 from 17 to 46%, and in 1924 from 11 to 45%. She also noted that the varieties with the highest blast percentages were either known or suspected to be of hybrid origin. Huskins (16), on the other hand, found no indication of hybridity having anything to do with blast; he, therefore, believed that blast-resistant varieties could be produced by breeding.

Varietal differences were also found by Derick and Hamilton (9), but they felt these differences could be due to maturity since early-maturing varieties might escape the environmental conditions favoring blast. No consistent association was found, however, so environmental factors cannot be the sole explanation of varietal resistance to blast. Genetic factors must play a part in blast resistance.

Observations were made on over 300 varieties by Mackie (23) and varietal resistance was found to be quite stable. He concluded from his studies that there was a single factor for blast resistance, but other researchers, such as Wakabayashi (29), believed multiple factors were involved.

No varietal differences were found by Sheals (26) in spring oats, but varietal differences were found for winter oats. The average blast percentage for spring oats was 25.9% and that for winter oats was 27.7%.

Several studies have found that drought increases blast (8, 11, 18). Johnson and Brown in two separate studies found late drought (drought during the time of active panicle elongation) to cause more blast than an earlier period of drought. The early drought periods reduced the total number of spikelets produced.

Frey and Browning (14) studied blast in Iowa in 1957 when an epiphytotic of blast occurred. Two distinct types of blast were found--normal blast as described by Sheals (26), and an atypical type. The atypical type had all spikelets on a panicle or portion of a panicle blasted. They felt this atypical condition was probably due to a period of cool and cloudy weather 30 to 40 days before heading. They found that 100 seed weights from blasted panicles were heavier than seeds from normal panicles. This finding is in contrast to that of Derick and Hamilton (9) and Johnson and Brown (18) who found no significant increase in seed weight on blasted heads.

The influence of light on blast was studied by Derick and Forsyth (8) by placing plants under different combinations of light and water treatments. Normal light always gave a lower blast percentage than excess or reduced light under all water treatments. Excess light produced significantly higher blast percentages under all moisture conditions. Excess water treatments were significantly lower in causing blast than other water treatments.

The effect of mineral nutrients on blast was included in Johnson and Brown's study (18). Nutrient conditions prior to spikelet development had an influence on the number of spikelets per panicle, and nutrient conditions after spikelet initiation had an influence on the percentage of blast.

Late seedings were reported significantly higher in blast than early seedings by Derick and Forsyth (8), but only the variety Gopher showed an increase in the frequency of blast with late seeding in Johnson and Brown's study (18). Late seeding did decrease panicle size and reduce yields, however. Johnson and Brown also found that the frequency of blast decreased with increased seeding rates. At the lower seeding rates, the plants were probably growing under more favorable conditions early in development which allowed more spikelets to be initiated than could be carried through to maturity. Often, conditions are drier as a plant approaches maturity which would limit the plant's ability to develop a large number of spikelets.

Frit flies and thrips are two insects most commonly associated with blast. Sheals (26) concluded that their "activity in the developing panicle was of little importance in relation to the blindness condition found in North Wales."

Elliott (12) studied the association of blast and halo blight. On some plants, she sprayed the bacterial suspension and on others sterile water. Check plants had 21% blast, those sprayed with sterile water had 40 to 52%, and those sprayed with the bacterial suspension had 44 to 63%. She concluded that "the amount of sterility does not appear to be in proportion to susceptibility to halo blight."

The effect of rust on the occurrence of blast was studied by Johnson and Brown (18). They increased blast from 23% on the check to 52% on plants inoculated with rust. They felt "it would probably be erroneous to include either stem rust or crown rust among the common causes of blast in Western Canada, as these rusts rarely cause severe injury to oat plants until after the panicle has emerged, at which stage the amount of blast has already been determined."

Hail has been found to increase the amount of blast in two separate studies. In association with his head bruising treatments, Eldredge (10) found that primary panicles from check plots were 16.4% sterile, and primary panicles from bruised plots were 35.3% sterile. Secondary panicles from check plots were 40.0% sterile; this was probably due to the main stems having an advantage in moisture and nutrients. Knowles (19) used clay marbles to simulate hail damage while plants were in the boot stage. He found that "ordinary blast seldom occurs at the top of the panicle, among the first formed spikelets, whereas blast due to hail is distributed fairly evenly." In 1938, check plots averaged 37.1% blast and bruised plots 46.8%, and in 1939 check plots averaged 9.6% blast and bruised plots 14.0%.

Defoliation studies were conducted by Johnson and Brown (18) and Empson (13). Johnson and Brown conducted two studies under greenhouse conditions, one in the fall and one in the spring. They removed all of the leaves at the 7-leaf stage in the fall study and increased blast from 50% in the check to 86% in the defoliated plants. Repeating this in the spring at the 6-leaf stage, they increased blast from 10% in the check to 34% in the defoliated plants. They attributed the difference in blast frequency in spring and fall to light conditions. In a field study, they defoliated plants at the 5-leaf stage. The percent blast on the check was 44%, plants with 4 leaves removed had 47%, and complete defoliation resulted in 63% blast. Empson found in his study on defoliation that the most severe damage occurred when defoliation was done in the boot stage, and moderate damage was done in the 5- to 6-leaf stage and after the panicle was fully emerged.

There is agreement among most researchers that blast can be caused by adverse conditions or injury occurring during the period of active spikelet differentiation and panicle elongation (18, 26). This critical period usually occurs 6 to 8 weeks after seeding (8, 14). It is also known that varieties vary in their susceptibility (9, 11, 18, 26).

MATERIALS AND METHODS

The study was conducted during the 1973 and 1974 growing seasons at two South Dakota Experiment Stations: Brookings and 15 miles north of Watertown. The varieties (Chief, a midseason oat, and Froker, a late maturity oat for the region involved) were used at both locations. A randomized complete block design was used with four replications per treatment. Each plot consisted of four fourteen-foot rows one foot apart. All four rows of each plot were treated; the center rows were shortened to twelve feet and machine harvested.

The hail damage was simulated by hitting or bending the plants at four different developmental stages. The hitting treatments were meant to bruise the head while the plants were in the boot stages. These treatments were included so the effect of hail damage on blast could be studied. The hitting treatments were applied by using the "hail gun" pictured in Fig. 1. The leaf sheath was positioned on the center of the pad, and the solenoid was triggered once for each sheath so the dowel would bruise the head within the sheath. Two 12-volt lantern batteries were the source of power for the 24-volt, direct current, intermittent solenoid. The dowel length was 8 inches. The bending treatments were done by bending the culm or peduncle by hand so that the terminal portion of the culm or head hung downward. The plants were considered to be in a specific stage when fifty percent had entered or passed through that stage. A plant was considered to be in early boot when the distance from the collar of the second leaf to the collar of the flag leaf was 5 to 10 cm. (25). A plant was considered to be in the late boot stage when the tip of the head was located at the terminal portion of the flag

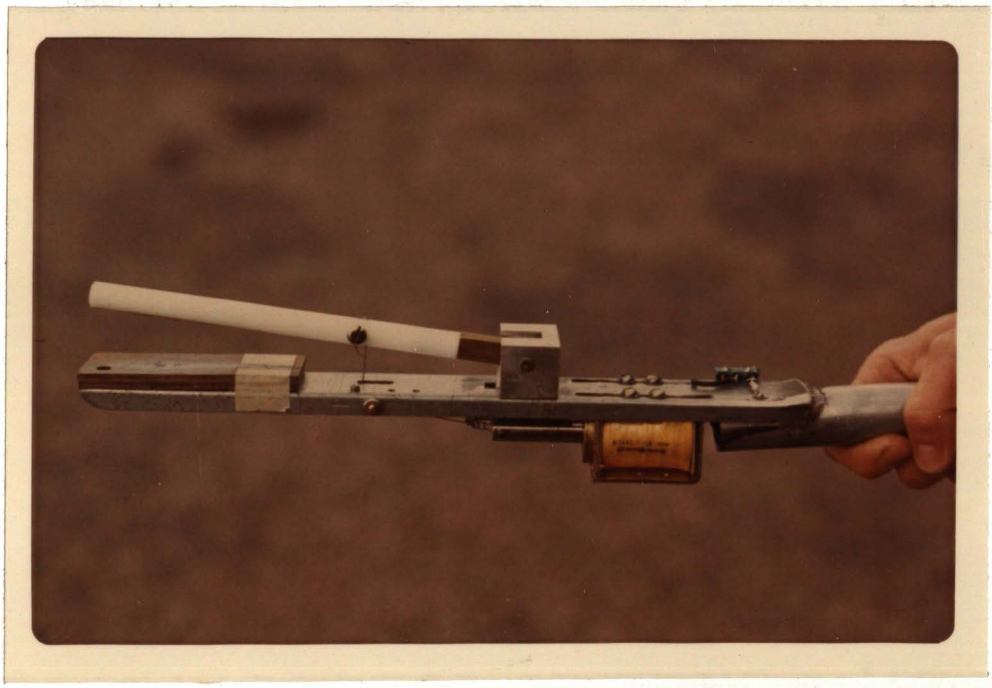

Figure 1. "Hail gun" used for hitting treatments.

leaf's sheath. The various treatments are listed below.

A. Control (no treatment)

B. Treatments applied at early boot.

1. Leaf sheaths bent just below the collar of the flag leaf (3/3 intensity).

2. Sheath of the flag leaf hit near the center of the head (3/3 intensity).

C. Treatments applied at late boot. Three intensities were used (1/3, 2/3, and 3/3 intensities).

1. Stems bent where the base of the head was located.

2. Sheath of the flag leaf hit near the center of the head.

D. Treatments applied at the heading stage (when heads were completely emerged from the boot). Intensities were 1/3, 2/3, and 3/3.

1. Stems bent two inches below the flag leaf collar.

2. Stems bent 1½ to 2 inches below the bottom joint of the head.

E. Treatments applied when the peduncle was fully extended (near soft dough). Intensities were 1/3, 2/3, and 3/3.

1. Stems bent two inches below the flag leaf collar.

2. Stems bent about 3/4 the distance from the flag collar to the head.

In treatments B and C where blast was likely to be a significant factor, the culms were tagged (10 tags per plot) for later identification. The tagged heads were collected in the soft dough stage, and the amount of blast was determined.

The number of fallen heads was determined for treatments D and E in 1973 and for all bending treatments in 1974 by tagging individual culms at the time of treatment and counting the fallen heads prior to harvest. Tags were applied at the same frequency as the simulated hail treatments (1/3 intensity equals 10 tags per plot, 2/3 intensity equals 20 tags per plot, and 3/3 intensity equals 30 tags per plot). Grain yield (bushels/acre), test weight (pounds/bushel), percent thin kernels (0.0640 X 3/8 inch screen as used for commercial grading), percent intermediate kernels (going through the plump screen size but not through the thin screen size), percent plump kernels (5½/64 X 3/8 inch screen), and 1,000 kernel weight were determined for all plots.

When the results were statistically analyzed, all treatments were compared with the control; therefore, the Dunnett procedure was used. It is a more conservative test than the Least Significant Difference (LSD); therefore, any significant difference is more likely to be a valid difference.

Figure 2. Blast of oat panicle caused by simulated hail treatments.

RESULTS AND DISCUSSION

The years during which this study was conducted were dry at both locations, but the effects of these dry conditions on production were especially noticeable the second year. The temperature and precipitation data for the 1973 and 1974 growing seasons at the Brookings and Watertown Experiment Stations are given in Tables 1 and 2. In 1973, both stations were below normal for both temperature and precipitation. Temperatures were a little warmer in 1974, especially later in the growing season, but precipitation was again below normal. The effects of simulated hail treatments may be quite different on plants growing under conditions of adequate rainfall. This data may apply to conditions of adequate or surplus rainfall as well, but no work has been done in this study to substantiate this. The results and conclusions, therefore, are limited in application to oats grown under dry conditions.

A comparison of sowing, treatment, and harvest dates are presented in Table 3. The early boot treatment at Watertown was not done in 1973 on the variety Chief.

Yield

Of the parameters included in this study, grain yield is the most important. The potential yield of a field is an important factor in hail adjustment. The effects of hail on yield of oats will vary with the stage of development when damaged. This was demonstrated by the effects of simulated hail treatments on grain yield in 1973 and 1974 which is summarized in Table 4 for both varieties at both locations. The greatest yield reductions occurred when stems were bent below the head at the late boot and heading stages at the 3/3 intensity treatment.

Table 1. Temperature and Precipitation Data at the Brookings Experiment Station During the 1973 and 1974 Growing Seasons.

	Temperature (°F)		Precipitation (inches)	
	Monthly Average	Deviation from Average	Monthly Total	Deviation from Average
1973				
April	42.5	-2.7	0.72	-1.05
May	53.2	-4.4	1.78	-1.01
June	66.4	-0.7	1.22	-2.73
July	70.1	-3.1	2.54	+0.39
1974				
April	44.6	0.0	1.44	-0.61
May	52.2	-4.0	4.46	+1.26
June	63.5	-2.2	1.57	-3.01
July	74.4	+3.3	1.96	-0.88

Table 2. Temperature and Precipitation Data at the Watertown Experiment Station During the 1973 and 1974 Growing Seasons.

	Temperature (°F)		Precipitation (inches)	
	Monthly Average	Deviation from Average	Monthly Total	Deviation from Average
1973				
April	42.3	-0.9	1.14	-0.92
May	55.1	-0.9	2.87	0.00
June	66.8	+1.1	1.00	-2.70
July	71.2	-1.1	2.05	-0.62
1974				
April	45.0	+2.3	1.22	-0.90
May	52.5	-2.2	3.37	+0.18
June	65.3	+0.6	1.45	-2.30
July	76.0	+5.3	2.09	-1.08

Table 3. Dates of Sowing, Treatment Application, and Harvest for Two Oat Varieties at Brookings and Watertown, South Dakota, in 1973 and 1974.

	Brookings		Watertown	
	Chief	Froker	Chief	Froker
1973				
Sowing	4/5	4/5	4/18	4/18
Early Boot Treatments	6/8	6/12	--*	6/18
Late Boot Treatments	6/11	6/14	6/15	6/21
Heading Treatments	6/18	6/21	6/25	6/27
Soft Dough Treatments	7/2	7/6	7/11	7/16
Harvest	7/23	7/27	7/26	7/26
1974				
Sowing	4/16	4/16	4/19	4/19
Early Boot Treatments	6/14	6/18	6/24	6/24
Late Boot Treatments	6/17	6/21	6/26	6/27
Heading Treatments	6/25	7/1	7/8	7/9
Soft Dough Treatments	7/12	7/15	7/18	7/22
Harvest	7/24	7/25	7/23	7/26

*No treatment applied

There was also a large yield loss when stems were bent below the flag leaf at the heading stage. Treatments applied at the soft dough stage did not reduce yields as greatly as at the late boot and heading stages, but yields still were reduced up to 18% when stems were bent below the flag leaf. When bending treatments applied below the head and below the flag leaf were compared at the heading stage, yields were reduced more by bending below the head. When the same treatments were compared at the soft dough stage, yields were reduced more by bending below the flag leaf. Bending stems at the early boot stage reduced yields only slightly. Hitting heads in the sheath at early and late boot also had little effect on yield. As the intensity of the treatment increased, so did the reductions in yield. This trend was absent only at the late boot stage when heads were hit in the sheath.

When all of the data for yield were analyzed, there were significant differences among years, varieties, locations, and treatments (Appendix 2). The trends, however, were quite consistent over the two years for both varieties at both locations. The largest losses occurred at the heading stage with considerable losses also at the late boot stage. There were significant differences in yield losses for both years at Watertown. Most of the plots at Brookings in 1974 were severely lodged, and yields were, therefore, much lower than normal. The lodging may also be a contributing factor in the absence of any significant differences at that location in 1974.

The actual reductions in yield were higher in 1973 than 1974. Losses at the late boot and heading stages were in the range from 19 to 49% for the 3/3 intensity treatments at those stages in 1973 and +1 to 17% in 1974. The greatest reduction of 49% occurred at the late boot stage at Brookings for the variety Froker. Much of the loss was due to head droppage.

Test Weight

Test weight contributes directly to yield, therefore, if test weights are low, the yield will be reduced. The effect of simulated hail damage on test weight in 1973 and 1974 is summarized in Table 5 for both varieties at both locations. The greatest reductions in test weight were found when stems were bent below the head or flag leaf at the heading stage. The reduction increased as the intensity of treatment increased. There was little change for treatments at the other

Table 4. Grain Yield as Affected by Simulated Hail Treatments on Oats. The yields are an average of two varieties grown at two locations in 1973 and 1974.

	Time of Treatment							
	Early Boot[1]		Late Boot		Heading		Soft Dough	
Treatment	Bu/A	% Loss	Bu/A	% Loss	Bu/A	% Loss	Bu/A	% Loss
Check	57.0	0	58.3	0	58.3	0	58.3	0
1/3 bent below flag leaf					53.6	8.1	57.1	2.1
2/3 bent below flag leaf					49.6	14.9	52.1	10.6
3/3 bent below flag leaf	55.8	2.1			46.1	20.9	48.0	17.7
1/3 bent below head			57.0	2.2	52.2	10.5	54.1	7.2
2/3 bent below head			47.9	17.8	47.7	18.2	53.8	7.7
3/3 bent below head			43.6	25.2	42.6	26.9	51.6	11.5
1/3 hit center head			58.6	+0.5				
2/3 hit center head			56.1	3.8				
3/3 hit center head	57.5	+0.9	56.7	2.8				

[1]No data for Chief at Watertown in 1973.

stages of development. There was a slight reduction (about half of that found at the heading stage) when stems were bent below the head at the 3/3 intensity at the late boot stage. Test weight was affected very little by bending treatments at the early boot or soft dough stages. Hitting treatments in early and late boot were also not very influential.

When all of the data for test weight were analyzed, there were significant differences among years, varieties, locations, and treatments (Appendix 4). The trends are similar for 1973 and 1974, but the loss was greater in 1973. The range for 3/3 intensity treatments in 1973 was +3 to 19% and in 1974 it was +5 to 4%. The majority of losses in both years were from treatments in the heading stage when stems were bent below the head. Losses were also common when stems were bent below the flag leaf in the heading stage. There was a tendency to increase test weight when treatments were applied at early boot and late boot, especially when heads were hit in the sheath. Bending stems below the head at the late boot stage resulted in several losses in 1973, but in 1974 at Watertown, test weight was significantly increased by bending at this stage and early boot for Froker. The same is true for treatments at soft dough. In 1973 at Watertown (and 1974 at Brookings), test weights were reduced. Test weights were also reduced for Chief at Watertown in 1974, but for Froker, test weight increased after treatment. Froker probably had more favorable conditions than Chief at some critical periods of development at Watertown.

<u>1000 Kernel Weight</u>

One thousand kernel weight helps judge the quality of the grain, since the heavier the sample, the larger the kernels. The effect of simulated

Table 5. Test Weight as Affected by Simulated Hail Treatments on Oats. The weights are an average of two varieties grown at two locations in 1973 and 1974.

	Time of Treatment							
	Early Boot[1]		Late Boot		Heading		Soft Dough	
Treatment	Lb/Bu	% Loss	Lb/Bu	% Loss	Lb/Bu	% Loss	Lb/Bu	% Loss
Check	30.3	0	30.5	0	30.5	0	30.5	0
1/3 bent below flag leaf					30.1	1.3	31.0	+1.6
2/3 bent below flag leaf					29.1	4.6	30.3	0.7
3/3 bent below flag leaf	31.2	+3.0			27.7	9.2	29.5	3.3
1/3 bent below head			30.8	+1.0	29.8	2.0	30.5	0
2/3 bent below head			30.0	1.6	28.5	6.6	30.7	+0.7
3/3 bent below head			29.0	4.9	27.1	11.2	29.8	2.3
1/3 hit center head			30.8	+1.0				
2/3 hit center head			31.1	+2.0				
3/3 hit center head	30.7	+1.3	31.1	+2.0				

[1]No data for Chief at Watertown in 1973.

hail treatments on 1000 kernel weight in 1973 and 1974 are summarized in Table 6 for both varieties at both locations. The greatest reductions in kernel weight occurred at the heading stage, especially when stems were bent below the head, and also when stems were bent below the flag leaf. Losses at the soft dough stage were only about half those of the heading stage. Both bending and hitting treatments at early boot and late boot resulted in slight increases in kernel weight rather than decreases as found at heading and soft dough.

When the data were analyzed, there were significant differences among years, varieties, locations and treatments (Appendix 6). When years, varieties, and locations were observed individually, the trends were much the same with the greater reductions occurring in 1973. The range in percent loss for 3/3 intensity treatments was +7 to 22% in 1973 and +3 to 2% in 1974. The greatest losses occurred at the heading stage, especially when bent below the head, except in 1974 when significant increases in kernel weight at Brookings for both varieties resulted from the late boot treatment. At the late boot stage some of the lower spikelets must have been damaged, therefore, providing more available nutrients for the remaining spikelets. Due to the increased supply of materials, the remaining spikelets developed larger than those of the control accounting for the significant increase in 1000 kernel weight.

The varieties responded similarly to all treatments at the same location in both years except at Brookings in 1973. Froker was affected more than Chief in this case.

Table 6. 1000 Kernel Weight as Affected by Simulated Hail Treatments on Oats. The weights are an average of two varieties grown at two locations in 1973 and 1974.

	Time of Treatment							
	Early Boot[1]		Late Boot		Heading		Soft Dough	
Treatment	Gms	% Loss	Gms	% Loss	Gms	% Loss	Gms	% Loss
Check	25.8	0	25.6	0	25.6	0	25.6	0
1/3 bent below flag leaf					25.4	0.8	25.5	0.4
2/3 bent below flag leaf					24.3	5.1	24.9	2.7
3/3 bent below flag leaf	26.2	+1.6			24.0	6.3	25.3	1.2
1/3 bent below head			26.2	+2.3	25.2	1.6	25.1	2.0
2/3 bent below head			25.7	+0.4	24.1	5.9	24.7	3.5
3/3 bent below head			25.7	+0.4	23.1	9.8	25.4	0.8
1/3 hit center head			25.4	0.8				
2/3 hit center head			25.8	+0.8				
3/3 hit center head	26.6	+3.1	26.1	+2.0				

[1]No data for Chief at Watertown in 1973.

Kernel Sizes

In evaluating the effect of simulated hail damage, the quality of the grain is an important consideration. One of the factors in oat quality is the plumpness of the kernel. When Laude and Pauli simulated hail damage on wheat in Kansas, they found kernel sizes were reduced, especially from treatment in the heading stage (22). The effects of simulated hail treatments on Chief and Froker oats in 1973 and 1974 is summarized in Table 7 for both locations. The two varieties differ in kernel size; Froker is a plumper oat than Chief, so the percentages of the various kernel sizes differ considerably for the two varieties.

In the summary table for Chief oats, the largest deviations from the control occurred at the late boot stage when stems were bent below the head and at the heading stage when stems were bent below the flag leaf. The percent plump kernels increased, the percent intermediate kernels decreased, and the percent thin kernels decreased from the late boot treatment, but increased when treated at the heading stage. Kernel sizes from oats treated at the other stages of development and under other treatments varied little from the control.

When the percentages of various kernel sizes were summarized for Froker oats, the largest deviations from the control occurred at the heading and soft dough stages when stems were bent below the head. In these treatments, the percent plump kernels decreased, the percent intermediate kernels increased, and the percent thin kernels tended to increase slightly from heading treatments but did not change for soft dough.

The effect of simulated hail treatments varied between the two varieties not only in the time and location the varieties were most susceptible to influence, but also in the expression of that influence on kernel size. The percentage of plump kernels decreased with treatment for Froker oats and increased for Chief oats, while the quantity of intermediate kernels increased for Froker oats and decreased for Chief oats.

Kernel size varied greatly from year to year, and also varied between locations in the same year. The data for 1973 and 1974 is presented in appendix tables 7-10. In 1973, the percentage of plump kernels for Chief at Brookings was 60%; in 1974 it was 19%. In 1973, Chief at Watertown had a plump kernel percentage of 16%, which was about one-fourth that at Brookings. Froker demonstrated a fluctuation between years and locations also.

In addition to the trends noted for Chief from the summary table, there were significant differences in kernel size when stems were bent below the head at the heading stage in 1973 at Brookings and in 1974 at Watertown. In addition to the large deviations mentioned for Froker, there were also significant differences at the heading stage when stems were bent below the flag leaf for all locations and years. There were also significant differences at late boot when stems were bent below the head and in 1974 at Watertown when stems were bent below the flag leaf at soft dough.

Overall, the most critical period for influencing kernel size was the period from late boot to heading. At the heading stage, bending the stem below the head seemed to be especially critical, although bends below the flag leaf were influential also.

It was observed from the data on individual years and locations that when considering plump and intermediate kernels, the kernel size

Table 7. Kernel Size as Affected by Simulated Hail Treatments on Chief and Froker Oats. The percentages are an average of two locations in 1973 and 1974.

	Time of Treatment											
	Early Boot[1]			Late Boot			Heading			Soft Dough		
	P[2]	I[3]	T[4]	P	I	T	P	I	T	P	I	T
Chief												
Check	34.4	62.6	3.0	29.7	67.4	2.9	29.7	67.4	2.9	29.7	67.4	2.9
1/3 bent below flag leaf							31.8	65.1	3.1	36.1	61.6	2.3
2/3 bent below flag leaf							33.6	63.5	2.9	29.4	67.4	3.2
3/3 bent below flag leaf	37.5	60.2	2.3				36.9	59.6	3.5	31.9	65.0	3.1
1/3 bent below head				34.7	62.8	2.5	31.0	66.2	2.8	28.7	68.3	3.0
2/3 bent below head				37.3	60.9	1.8	31.1	65.1	3.8	29.3	67.3	3.1
3/3 bent below head				38.9	59.7	1.4	31.2	65.4	3.4	28.6	68.2	3.2
1/3 hit center head				31.4	66.0	2.6						
2/3 hit center head				32.2	65.7	2.1						
3/3 hit center head	37.3	60.1	2.6	33.5	64.3	2.2						
Froker												
Check	67.0	32.1	0.9	67.0	32.1	0.9	67.0	32.1	0.9	67.0	32.1	0.9
1/3 bent below flag leaf							63.9	35.1	1.0	64.0	35.0	1.0
2/3 bent below flag leaf							62.6	36.3	1.1	61.9	37.2	0.9
3/3 bent below flag leaf	67.6	31.6	0.8				62.6	36.2	1.2	64.6	34.5	0.9
1/3 bent below head				67.1	32.1	0.8	63.0	35.9	1.1	64.9	34.3	0.8
2/3 bent below head				62.7	36.6	0.7	61.8	37.1	1.1	62.0	37.2	0.8
3/3 bent below head				67.7	32.5	0.8	58.0	40.7	1.3	61.8	37.2	1.0
1/3 hit center head				66.2	33.0	0.8						
2/3 hit center head				66.9	32.2	0.9						
3/3 hit center head	68.0	31.2	0.8	67.1	32.1	0.8						

1 No data for Chief at Watertown in 1973.
2 P-Plump; kernels remaining on top of a 5½/64 x 3/8 inch screen.
3 I-Intermediate; kernels going through the plump screen size but not the thin screen size.
4 T-Thin; kernels going through a 0.064 x 3/8 inch screen.

present in the greatest amount always decreased after treatment while the kernel size present in the smallest amount always increased. The percentage of thin kernels tended to decrease from treatments at early and late boot, increase from treatments at heading and increase slightly or remain unchanged from treatments at soft dough.

Blast

Since blast has often been associated with hail damage to oats, an evaluation of simulated hail treatments on oats must consider the problem of blast. The effect of simulated hail treatments on blast for Chief and Froker oats in 1973 and 1974 is summarized in Table 8 for both locations. There was a big difference between the varieties Chief and Froker in their susceptibility to blast. Chief had two to four times more blast than Froker. The percentage of blast was increased 57% at early boot and 62% at late boot for Chief by hitting treatments. Froker, on the other hand, increased 20 and 16%, for early and late boot, respectively.

In 1973, the amount of natural blast and the amount of blast caused by simulated hail treatments were less in Watertown than Brookings, but the percent increase in blast was greater for Watertown. Statistically, significant differences were found only for the variety Chief at both locations, however, blast was increased 39% by treating Froker at the late boot stage at Watertown (Appendix 11).

In 1974, the plots at Brookings responded much the same as they did in 1973. The percent increase in blast was only about half that of 1973, but the trends were similar. Blast due to simulated hail treatments increased greatly at the early boot stage for Chief at Brookings;

in fact, this was the only significant difference found in 1974. Both varieties at Watertown, showed reductions in the amount of blast after treatment rather than increases. The reductions were not statistically significant, but were as high as 13% for Chief at the late boot stage (Appendix 12).

Blast is affected greatly by environmental factors which make it very difficult to find exact causes of increases or decreases in the blast percentages. The increases in blast as a result of simulated hail treatments certainly demonstrated the positive association of hail and blast at the early and late boot stages. The lower percentages of blast at Watertown in 1974 might be explained by a loss of spikelets prior to harvest. A reduced number of total spikelets would account for lower blast percentages if some of the blasted spikelets were lost due to high winds, which are common at the Watertown station. However, total spikelet numbers were not in all cases less than those for the check. Some environmental factor or combination of factors must have been involved.

The variability of blast among varieties and between locations is evident when thirty oat selections from the Standard Variety Trials grown at Brookings and Watertown are compared (Appendix 15). Characterization of hail's effect on blast is not enough. Information on individual varieties, locations, and environmental factors is also essential to an understanding of blast in oats.

Head Droppage

Head droppage has been a major cause of yield reductions due to hail, especially in wheat and barley. The effects of simulated hail treatments on head droppage for Chief and Froker oats in 1973 and 1974

Table 8. Blast as Affected by Simulated Hail Treatments on Chief and Froker Oats. The blast percentages are an average of two locations in 1973 and 1974.

	Time of Treatment			
	Early Boot[1]		Late Boot	
	% Blast	% Increase	% Blast	% Increase
Chief				
Check	12.7	0	12.7	0
1/3 hit center head			14.1	11.0
2/3 hit center head			15.0	18.1
3/3 hit center head	19.9	56.7	20.6	62.2
Froker				
Check	14.3	0	14.3	0
1/3 hit center head			14.7	2.8
2/3 hit center head			15.6	9.1
3/3 hit center head	17.2	20.3	16.6	16.1

[1] No data for Chief at Watertown in 1973.

are summarized in Table 9 for both varieties at both locations.

In the case of oats, unlike wheat and barley, there was no natural problem with head droppage. This is probably due in part to the open panicle which allows individual spikelets to entangle with spikelets of their neighboring panicles. If the peduncle should break, many times the head will not fall but will remain entangled with another panicle.

When simulated hail treatments were applied at the various stages of growth, the stage most susceptible to head droppage was the late boot stage. The amount of droppage caused by bending the stems below the head in this stage was almost twice that of a similar treatment in the heading stage.

There were varietal differences in head droppage, but they were not consistent from one year to the next. Froker at Brookings had the greatest droppage in 1973; this was especially true for the late boot stage where actual counts of dropped heads revealed a 56% drop for the 3/3 intensity treatment of bending stems below the head. In 1974, however, Chief had a higher frequency of droppage than Froker, and at Brookings, most of the droppage occurred from heading treatments while at Watertown most resulted from late boot treatments (Appendix 13 and 14).

The highest frequency of droppage usually occurred at the 2/3 intensity. When all stems were bent, the heads clustered together not allowing for much movement, but when 2/3 of the stems were bent, the wind could move and twist those hanging heads until many finally fell.

As was evident in 1973, head droppage can be a problem in oats during certain years if the oats are hit by hail at an especially vulnerable time. However, normally head droppage is usually not nearly the problem in oats that it is in wheat and barley.

Table 9. Head Droppage as Affected by Simulated Hail Treatments on Oats. The percentages are an average of two varieties grown at two locations in 1973 and 1974.

	Time of Treatment			
	Early Boot*	Late Boot*	Heading	Soft Dough
Treatment	% Drop	% Drop	% Drop	% Drop
Check	0	0	0	0
1/3 below flag leaf			1.6	0
2/3 below flag leaf			0.6	0.4
3/3 below flag leaf			1.5	0.4
1/3 below head		4.0	5.8	1.6
2/3 below head		14.0	8.2	3.4
3/3 below head	0.6	12.9	6.2	2.9

* average of two varieties in 1974

SUMMARY AND CONCLUSIONS

The effects of simulated hail treatments on oats have been shown to vary between years, varieties, and locations. The effects are, therefore, very dependent on environmental factors. A summary of 3/3 intensity simulated hail treatments is presented in Table 10. Bending the stem below the head at the heading stage resulted in the greatest losses in yield, test weight, 1000 kernel weight and plump kernels. About one-quarter of the yield reduction was accounted for by head droppage. Bending the stem below the head at the late boot stage also resulted in a large yield reduction. About one-half of this loss was due to head droppage and about one-fifth was due to a reduction in test weight.

Yield reductions and reductions in test weight, 1000 kernel weight, and plump kernels were also found at the soft dough stage, but they were less than those for either treatment at the heading stage. By the time a plant had reached soft dough, it was far enough along in development to avoid great losses from the bending treatments which simulated hail damage. The early boot stage, on the other hand, was early enough in development to allow some recovery from hail damage. The critical period for grain development of an oat plant was the period from late boot through the heading stage.

The location of damage at the heading stage was important. Bending the stem below the head, but above the flag leaf resulted in greater losses primarily because of the amount of head droppage that occurred at that site on the plant. If the stem was bent below the flag leaf collar, there was apparently enough sheath material to support the broken culm and keep it from falling. That was also true at the soft dough stage. However, at the soft dough stage, bending the stem below the flag leaf resulted in greater losses in yield. Head droppage was not much of a factor from those treatments, because harvest was usually completed before heads had a chance to fall. Losses in yield at this stage must have been due to a reduction in translocation. The translocating vessels must have been damaged, thus not allowing as great a supply of materials to the head. The vessels could be more rigid at advanced maturity, therefore, being more susceptible to damage. The younger tissue below the head was probably more flexible and not as susceptible to injury.

Although blast was affected by simulated hail treatments, it had little effect on the final yield. The plant was apparently able to supply the undamaged kernels with additional materials resulting in increases in test weight, 1000 kernel weight and in the early boot stage, increases in plump kernels.

Table 10. The Effects of 3/3 Intensity Simulated Hail Treatments on Oats. The values are an average of two varieties grown at two locations in 1973 and 1974.

Stage	Treatment	Percent Reduction Yield	Test Weight	1000 Kernel Weight	Plump Kernels	Increase in Blast (%)	Head Droppage[2] (%)
Check		0	0	0	0	0	0
Early Boot[1]	Bend below flag leaf	4.3	+2.3	+2.3	+3.7	--	0.6
Early Boot[1]	Hit center head	1.4	+0.7	+3.9	+3.9	38.5	--
Late Boot	Bend below head	25.2	4.9	+0.4	+5.1	--	12.9
Late Boot	Hit center head	2.8	+2.0	+2.0	0.8	39.2	--
Heading	Bend below flag leaf	20.8	9.2	6.3	1.8	--	1.5
Heading	Bend below head	26.9	11.2	9.8	12.0	--	6.2
Soft Dough	Bend below flag leaf	17.7	3.3	1.2	4.7	--	0.4
Soft Dough	Bend below head	11.3	2.0	0.8	10.8	--	2.9

[1] No data for Chief at Watertown in 1973.
[2] Counts for early and late boot were taken only in 1974.

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Appendix 1. Partial Analysis of Variance of the Effects of Simulated Hail Treatments on Grain Yield of Chief and Froker Oats at Brookings and Watertown in 1973 and 1974.

	1973				1974			
	Brookings		Watertown		Brookings		Watertown	
Stage and Treatment	Chief	Froker	Chief	Froker	Chief	Froker	Chief	Froker
Early Boot-3/3 bent below flag leaf	n.s.	n.s.	--[1]	n.s.	n.s.	n.s.	n.s.	* I
Early Boot-3/3 hit center head	n.s.	n.s.	--[1]	n.s.	n.s.	n.s.	n.s.	n.s.
Late Boot - 1/3 bent below head	n.s.	*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Late Boot - 2/3 bent below head	**	**	n.s.	**	n.s.	n.s.	**	*
Late Boot - 3/3 bent below head	n.s.	**	*	**	n.s.	n.s.	**	**
Late Boot - 1/3 hit center head	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	** I
Late Boot - 2/3 hit center head	n.s.	n.s.	n.s.	*	n.s.	n.s.	n.s.	n.s.
Late Boot - 3/3 hit center head	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Heading - 1/3 bent below flag leaf	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Heading - 2/3 bent below flag leaf	**	*	**	**	n.s.	n.s.	*	n.s.
Heading - 3/3 bent below flag leaf	**	*	**	**	n.s.	n.s.	n.s.	*
Heading - 1/3 bent below head	n.s.	**	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Heading - 2/3 bent below head	**	**	n.s.	**	n.s.	n.s.	**	n.s.
Heading - 3/3 bent below head	**	**	**	**	n.s.	n.s.	**	**
Soft Dough-1/3 bent below flag leaf	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Soft Dough-2/3 bent below flag leaf	**	n.s.	**	*	n.s.	n.s.	n.s.	n.s.
Soft Dough-3/3 bent below flag leaf	**	*	**	**	n.s.	n.s.	n.s.	n.s.
Soft Dough-1/3 bent below head	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Soft Dough-2/3 bent below head	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Soft Dough-3/3 bent below head	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

[1]No treatment applied.

*, ** significant at 5 and 1% level, respectively

n.s. Not significantly different

I Increase in yield rather than decrease

Appendix 2. Analysis of Variance for all Yield Data for 1973 and 1974.

Source of Variation	Degrees of Freedom	Mean Squares	
Locations	1	16,652.06	**
Replications	3	39.34	ns
LxR	3	135.35	**
Treatments	18	762.34	**
LxT	18	98.74	**
RxT	54	37.07	**
LxRxT	54	22.58	ns
Varieties	1	1,519.28	*
LxV	1	1,547.21	**
RxV	3	244.15	**
LxRxV	3	73.37	ns
TxV	18	90.95	**
LxTxV	18	57.97	*
RxTxV	54	24.84	ns
LxRxTxV	54	31.30	ns
Years	1	71,572.88	**
LxY	1	381.64	**
RxY	3	134.32	**
LxRxY	3	170.60	**
TxY	18	193.19	**
LxTxY	18	84.89	**
RxTxY	54	25.91	ns
LxRxTxY	54	31.79	ns
VxY	1	7,071.41	**
LxVxY	1	5,785.34	**
RxVxY	3	20.04	ns
LxRxVxY	3	213.26	**
TxVxY	18	138.97	**
LxTxVxY	18	49.10	ns
RxTxVxY	54	27.95	ns
LxRxTxVxY	54	30.65	
TOTAL	607		

*, ** significant at 5 and 1% level, respectively
n.s. Not significantly different

Appendix 3. Partial Analysis of Variance of the Effects of Simulated Hail Treatments on Test Weight of Chief and Froker Oats at Brookings and Watertown in 1973 and 1974.

	1973				1974			
	Brookings		Watertown		Brookings		Watertown	
Stage and Treatment	Chief	Froker	Chief	Froker	Chief	Froker	Chief	Froker
Early Boot - 3/3 bent below flag leaf	n.s.	n.s.	--[1]	n.s.	n.s.	n.s.	n.s.	** I
Early Boot - 3/3 hit center head	n.s.	n.s.	--[1]	n.s.	n.s.	n.s.	n.s.	n.s.
Late Boot - 1/3 bent below head	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	** I
Late Boot - 2/3 bent below head	n.s.	*	*	*	n.s.	n.s.	n.s.	** I
Late Boot - 3/3 bent below head	n.s.	**	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Late Boot - 1/3 hit center head	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	** I
Late Boot - 2/3 hit center head	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	** I	* I
Late Boot - 3/3 hit center head	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	* I
Heading - 1/3 bent below flag leaf	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	* I
Heading - 2/3 bent below flag leaf	n.s.	n.s.	n.s.	*	*	n.s.	n.s.	n.s.
Heading - 3/3 bent below flag leaf	n.s.	n.s.	**	**	*	**	*	*
Heading - 1/3 bent below head	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Heading - 2/3 bent below head	n.s.	**	**	n.s.	n.s.	n.s.	**	n.s.
Heading - 3/3 bent below head	**	**	**	**	**	**	*	*
Soft Dough-1/3 bent below flag leaf	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	**	** I
Soft Dough-2/3 bent below flag leaf	n.s.	n.s.	**	n.s.	n.s.	n.s.	n.s.	n.s.
Soft Dough-3/3 bent below flag leaf	n.s.	n.s.	**	n.s.	n.s.	n.s.	n.s.	n.s.
Soft Dough-1/3 bent below head	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	** I
Soft Dough-2/3 bent below head	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	*	** I
Soft Dough-3/3 bent below head	n.s.	n.s.	*	n.s.	*	n.s.	n.s.	n.s.

[1] No treatment applied.

*, ** significant at 5 and 1% level, respectively.

n.s. Not significantly different

I Increase in test weight rather than decrease.

Appendix 4. Analysis of Variance for all Test Weight Data for 1973 and 1974.

Source of Variation	Degrees of Freedom	Mean Squares	
Locations	1	16.28	*
Replications	3	5.28	**
LxR	3	2.91	ns
Treatments	18	42.14	**
LxT	18	2.45	*
RxT	54	0.95	ns
LxRxT	54	1.75	ns
Varieties	1	8.17	**
LxV	1	0.91	ns
RxV	3	0.64	ns
LxRxV	3	7.16	**
TxV	18	4.57	**
LxTxV	18	3.29	**
RxTxV	54	1.42	ns
LxRxTxV	54	1.52	ns
Years	1	1,064.51	**
LxY	1	1,009.65	**
RxY	3	13.53	**
LxRxY	3	1.11	ns
TxY	18	6.05	**
LxTxY	18	4.48	**
RxTxY	54	0.87	ns
LxRxTxY	54	1.38	ns
VxY	1	51.24	**
LxVxY	1	15.00	**
RxVxY	3	1.47	ns
LxRxVxY	3	1.68	ns
TxVxY	18	3.85	**
LxTxVxY	18	3.18	**
RxTxVxY	54	1.69	ns
LxRxTxVxY	54	1.35	
TOTAL	607		

*, ** significant at 5 and 1% level, respectively
n.s. Not significantly different

Appendix 5. Partial Analysis of Variance of the Effects of Simulated Hail Treatments on 1000 Kernel Weight of Chief and Froker Oats at Brookings and Watertown in 1973 and 1974.

	1973				1974			
	Brookings		Watertown		Brookings		Watertown	
State and Treatment	Chief	Froker	Chief	Froker	Chief	Froker	Chief	Froker
Early Boot - 3/3 bent below flag leaf	n.s.	n.s.	--[1]	n.s.	n.s.	n.s.	n.s.	n.s.
Early Boot - 3/3 hit center head	n.s.	n.s.	--[1]	n.s.	n.s.	n.s.	n.s.	n.s.
Late Boot - 1/3 bent below flag leaf	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Late Boot - 2/3 bent below flag leaf	n.s.	n.s.	n.s.	n.s.	** I	** I	n.s.	n.s.
Late Boot - 3/3 bent below flag leaf	n.s.	*	n.s.	n.s.	** I	** I	n.s.	n.s.
Late Boot - 1/3 hit center head	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Late Boot - 2/3 hit center head	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Late Boot - 3/3 hit center head	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Heading - 1/3 bent below flag leaf	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Heading - 2/3 bent below flag leaf	n.s.	**	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Heading - 3/3 bent below flag leaf	n.s.	*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Heading - 1/3 bent below head	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Heading - 2/3 bent below head	n.s.	**	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Heading - 3/3 bent below head	**	**	n.s.	n.s.	n.s.	n.s.	*	**
Soft Dough - 1/3 bent below flag leaf	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Soft Dough - 2/3 bent below flag leaf	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Soft Dough - 3/3 bent below flag leaf	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Soft Dough - 1/3 bent below head	n.s.	*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Soft Dough - 2/3 bent below head	n.s.	*	n.s.	n.s.	n.s.	n.s.	*	n.s.
Soft Dough - 3/3 bent below head	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

[1] No treatment applied.
*, ** significant at 5 and 1% level, respectively
n.s. Not significantly different
I Increase in 1000 kernel weight rather than decrease.

Appendix 6. Analysis of Variance for all 1000 Kernel Weight Data for 1973 and 1974.

Source of Variation	Degrees of Freedom	Mean Squares	
Locations	1	486.02	**
Replications	3	0.54	ns
LxR	3	6.84	**
Treatments	18	19.52	**
LxT	18	3.42	*
RxT	54	1.29	ns
LxRxT	54	1.55	ns
Varieties	1	1,315.10	**
LxV	1	0.75	ns
RxV	3	8.07	**
LxRxV	3	4.45	ns
TxV	18	4.78	**
LxTxV	18	2.25	ns
RxTxV	54	1.50	ns
LxRxTxV	54	1.92	ns
Years	1	13,012.83	**
LxY	1	4,840.91	**
RxY	3	1.70	ns
LxRxY	3	8.74	**
TxY	18	7.13	**
LxTxY	18	8.86	**
RxTxY	54	1.36	ns
LxRxTxY	54	1.94	ns
VxY	1	487.80	**
LxVxY	1	24.72	**
RxVxY	3	3.37	ns
LxRxVxY	3	1.21	ns
TxVxY	18	4.40	ns
LxTxVxY	18	1.78	ns
RxTxVxY	54	1.38	ns
LxRxTxVxY	54	1.80	
TOTAL	607		

*, ** significant at 5 and 1% level, respectively
n.s. Not significantly different

Appendix 7. Percentage of Grain in Various Kernel Sizes as Affected by Simulated Hail Treatments on Chief and Froker Oats at Brookings in 1973.

	Time of Treatment											
	Early Boot			Late Boot			Heading			Soft Dough		
	P[1]	I[2]	T[3]	P	I	T	P	I	T	P	I	T
Chief												
Check	59.9	39.7	0.4	59.9	39.7	0.4	59.9	39.7	0.4	59.9	39.7	0.4
1/3 bent below flag leaf							63.8	35.9	0.3	60.5	39.1	0.4
2/3 bent below flag leaf							60.4	39.2	0.4	60.8	38.9	0.3
3/3 bent below flag leaf	64.2	35.5	0.3				63.6	36.1	0.3	62.1	37.6	0.3
1/3 bent below head				64.8	34.9	0.3	60.3	39.1	0.6	59.7	40.0	0.3
2/3 bent below head				61.6	37.8	0.6*	49.9**	49.5*	0.6*	61.7	38.0	0.3
3/3 bent below head				63.5	36.2	0.3	43.9**	55.4**	0.7*	52.4	47.2	0.4
1/3 hit center head				61.2	38.4	0.4						
2/3 hit center head				67.2	32.5	0.3						
3/3 hit center head	63.5	36.1	0.4	64.5	35.2	0.3						
P-Dunnett	(.05)= 7.8	(.01)= 9.0		I- Dunnett	(.05)= 8.6	(.01)= 10.3		T- Dunnett	(.05)= 0.2	(.01)= 0.4		
Froker												
Check	90.6	9.0	0.4	90.6	9.0	0.4	90.6	9.0	0.4	90.6	9.0	0.4
1/3 bent below flag leaf							89.1	10.6	0.3	89.2	10.4	0.4
2/3 bent below flag leaf							85.7**	13.9**	0.4	89.4	10.3	0.3
3/3 bent below flag leaf	91.3	8.4	0.3				83.9**	15.6**	0.5	87.8	11.8	0.4
1/3 bent below head				89.4	10.3	0.3	82.9**	16.5**	0.6*	88.0	11.6	0.4
2/3 bent below head				88.5	11.1	0.4	79.8**	19.3**	0.9**	89.4	10.3	0.3
3/3 bent below head				83.9**	15.3**	0.8	64.4**	34.3**	1.3**	86.6**	13.0**	0.4
1/3 hit center head				91.1	8.6	0.3						
2/3 hit center head				91.5	8.3	0.2						
3/3 hit center head	90.5	9.2	0.3	90.7	9.0	0.3						
P-Dunnett	(.05)= 3.0	(.01)= 3.5		I- Dunnett	(.05)= 3.4	(.01)= 4.0		T- Dunnett	(.05)=0.2	(.01)=0.4		

1 P-Plump; kernels remaining on top of a 5½/64 x 3/8 inch screen.
2 I-Intermediate; kernels going through the plump screen size but not the thin screen size.
3 T-Thin; kernels going through a 0.064 x 3/8 inch screen.
*, ** Significant at 5 and 1% level, respectively.

Appendix 8. Percentage of Grain in Various Kernel Sizes as Affected by Simulated Hail Treatments on Chief and Froker Oats at Watertown in 1973.

	Time of Treatment											
	Early Boot[1]			Late Boot			Heading			Soft Dough		
	P	I	T	P	I	T	P	I	T	P	I	T
Chief												
Check				15.6	81.9	2.5	15.6	81.9	2.5	15.6	81.9	2.5
1/3 bent below flag leaf							16.8	80.5	2.7	35.9**	61.8**	2.3
2/3 bent below flag leaf							19.7	77.8	2.5	19.3	78.1	2.6
3/3 bent below flag leaf							24.3	71.8	3.9*	23.3	74.6	2.1
1/3 bent below head				26.0	72.5	1.5	18.3	78.8	2.9	14.5	82.9	2.6
2/3 bent below head				26.3	72.4	1.3	20.4	76.0	3.6	19.2	78.2	2.6
3/3 bent below head				30.7*	67.8*	1.5	22.3	74.4	3.3	19.8	77.2	3.0
1/3 hit center head				22.6	75.5	1.9						
2/3 hit center head				21.8	76.4	1.8						
3/3 hit center head				21.8	76.3	1.9						
	P- Dunnett (.05)= 13.1 (.01)= 15.8			I- Dunnett (.05)= 13.1 (.01)= 15.8						T- Dunnett (.05)= 1.2 (.01)= 1.4		
Froker												
Check	65.1	34.4	0.5	65.1	34.4	0.5	65.1	34.3	0.5	65.1	34.4	0.5
1/3 bent below flag leaf							58.7	40.6	0.7	63.8	35.5	0.7
2/3 bent below flag leaf							52.8**	46.5*	0.7	54.6	44.8	0.6
3/3 bent below flag leaf	72.3	27.2	0.5				56.6	42.4	1.0	59.3	40.2	0.5
1/3 bent below head				70.0	29.5	0.5	63.0	36.5	0.5	61.2	38.1	0.7
2/3 bent below head				71.3	28.2	0.5	59.8	39.5	0.7	52.3**	47.1*	0.6
3/3 bent below head				75.6	23.8	0.6	56.6	42.6	0.8*	56.7	42.6	0.7
1/3 hit center head				69.1	30.4	0.5						
2/3 hit center head				63.6	35.7	0.7						
3/3 hit center head	69.3	30.2	0.5	68.6	30.8	0.6						
	P- Dunnett (.05)= 9.8 (.01)= 11.4			I- Dunnett (.05)= 11.4 (.01)= 13.6						T- Dunnett (.05)= 0.3 (.01)= 0.4		

1 No treatment applied for Chief

*, ** Significant at 5 and 1% level, respectively.

Appendix 9. Percentage of Grain in Various Kernel Sizes as Affected by Simulated Hail Treatments on Chief and Froker Oats at Brookings in 1974.

	Time of Treatment											
	Early Boot			Late Boot			Heading			Soft Dough		
	P	I	T	P	I	T	P	I	T	P	I	T
Chief												
Check	19.1	74.7	6.2	19.1	74.7	6.2	19.1	74.7	6.2	19.1	74.7	6.2
1/3 bent below flag leaf							17.4	75.6	7.0	22.0	73.5	4.5
2/3 bent below flag leaf							21.1	72.0	6.9	16.9	76.2	6.9
3/3 bent below flag leaf	19.1	76.1	4.8				23.8	68.9	7.3	18.8	74.1	7.1
1/3 bent below head				19.8	74.0	6.2	20.8	74.5	4.7	19.4	74.2	6.4
2/3 bent below head				25.7*	70.8	3.5*	18.9	73.4	7.7	18.2	75.3	6.5
3/3 bent below head				32.2**	65.6*	2.2**	26.0	68.5	5.5	17.8	75.6	6.6
1/3 hit center head				16.4	77.7	5.9						
2/3 hit center head				18.8	76.5	4.7						
3/3 hit center head	18.2	76.0	5.8	17.3	77.6	5.1						

P- Dunnett (.05)= 6.1 (0.1)= 7.1 I- Dunnett (.05)= 7.0 (.01)= 8.2 T- Dunnett (.05)= 2.5 (.01)= 2.9

	Early Boot			Late Boot			Heading			Soft Dough		
	P	I	T	P	I	T	P	I	T	P	I	T
Froker												
Check	40.3	57.8	1.9	40.3	57.8	1.9	40.3	57.8	1.9	40.3	57.8	1.9
1/3 bent below flag leaf							42.1	55.7	2.2	39.3	58.2	2.5
2/3 bent below flag leaf							43.5	54.0	2.5	39.7	58.1	2.2
3/3 bent below flag leaf	40.9	57.3	1.8				49.1*	48.7**	2.2	42.5	55.8	1.7
1/3 bent below head				43.7	54.6	1.7	42.3	55.1	2.6	43.5	54.7	1.8
2/3 bent below head				51.6**	47.1**	1.3	49.2*	49.0**	1.8	43.6	54.8	1.6
3/3 bent below head				58.7**	40.0**	1.3**	51.2**	46.9**	1.9	43.2	54.5	2.3
1/3 hit center head				40.0	58.0	2.0						
2/3 hit center head				43.2	54.9	1.9						
3/3 hit center head	40.5	57.6	1.9	38.6	59.6	1.8						

P- Dunnett (.05)= 6.5 (.01)= 7.5 I-Dunnett (.05)= 6.1 (.01)= 7.1 T- Dunnett (.05)= 0.7 (.01)= 0.8

*, ** Significant at 5 and 1% level, respectively.

Appendix 10. Percentage of Grain in Various Kernel Sizes as Affected by Simulated Hail Treatments on Chief and Froker Oats at Watertown in 1974.

	Time of Treatment											
	Early Boot			Late Boot			Heading			Soft Dough		
	P	I	T	P	I	T	P	I	T	P	I	T
Chief												
Check	24.0	73.5	2.5	24.0	73.5	2.5	24.0	73.5	2.5	24.0	73.5	2.5
1/3 bent below flag leaf							29.3	68.4	2.3	26.0	72.2	1.8
2/3 bent below flag leaf							33.1*	65.0*	1.9	20.7	76.5	2.8
3/3 bent below flag leaf	29.3	69.0	1.7				36.0**	61.4**	2.6	23.3	73.9	2.8
1/3 bent below head				28.2	69.7	2.1	24.5	72.6	2.9	21.0	76.5	2.5
2/3 bent below head				35.5**	62.9**	1.6	35.2**	61.7**	3.1	17.9	79.0	3.1
3/3 bent below head				29.0	69.5	1.5	32.6*	63.3**	4.1*	24.3	73.1	2.6
1/3 hit center head				25.4	72.4	2.2						
2/3 hit center head				21.1	77.2	1.7						
3/3 hit center head	30.2	68.2	1.6	30.5	68.0	1.5						

P- Dunnett (.05)= 8.1 (.01)= 9.4 I- Dunnett (.05)= 7.5 (.01)= 8.7 T- Dunnett (.05)= 1.2 (.01)= 1.4

	Early Boot			Late Boot			Heading			Soft Dough		
	P	I	T	P	I	T	P	I	T	P	I	T
Froker												
Check	72.0	27.3	0.7	72.0	27.3	0.7	72.0	27.3	0.7	72.0	27.3	0.7
1/3 bent below flag leaf							65.8	33.4	0.8	63.8**	35.6*	0.6
2/3 bent below flag leaf							68.4	30.8	0.8	63.8**	35.6*	0.6
3/3 bent below flag leaf	66.0	33.5	0.5				60.6**	38.4**	1.0	68.6	30.6	0.8
1/3 bent below head				65.0*	34.3	0.7	63.6**	35.7*	0.7	66.9	32.7	0.4
2/3 bent below head				66.3	33.2	0.5	58.4**	40.5**	1.1*	62.6**	36.7**	0.7
3/3 bent below head				69.0	30.4	0.6	59.6**	39.3**	1.1*	65.0*	34.5	0.5
1/3 hit center head				64.4**	35.1	0.5						
2/3 hit center head				69.4	29.9	0.7						
3/3 hit center head	71.5	28.1	0.4	70.6	28.8	0.6						

P- Dunnett (.05)= 8.0 (.01)= 9.2 I- Dunnett (.05)= 8.1 (.01)= 9.4 T- Dunnett (.05)= 0.4 (.01)= 0.5

*, ** Significant at 5 and 1% level, respectively.

Appendix 11. Percent Blast in Chief and Froker Oats as Affected by Simulated Hail Treatments at Brookings and Watertown in 1973.

	Chief				Froker			
	Early Boot		Late Boot		Early Boot		Late Boot	
	Blast %	Increase %	Blast %	Increase %	Blast %	Increase %	Blast %	Increase %
Brookings								
Check	15.3	0	15.3	0	13.6	0	13.6	0
1/3 hit center head			16.0	4.6			13.7	0.7
2/3 hit center head			16.5	7.8			15.5	14.0
3/3 hit center head	25.3*	65.4	30.9*	102.0	17.8	30.9	17.0	25.0
	Dunnett (.05)= 9.8				Dunnett (.05)= 5.5			
	(.01)= 12.9				(.01)= 7.2			
Watertown								
Check	--	--	8.9	0	11.1	0	11.1	0
1/3 hit center head			9.9	11.2			11.4	2.7
2/3 hit center head			13.8*	55.1			13.4	20.7
3/3 hit center head	--	--	19.3**	116.9	14.7	32.4	15.4	38.7
	Dunnett (.05)= 3.7				Dunnett (.05)= 5.2			
	(.01)= 5.0				(.01)= 6.9			

*, ** Significant at 5 and 1% level, respectively.

Appendix 12. Percent Blast in Chief and Froker Oats as Affected by Simulated Hail Treatments at Brookings and Watertown in 1974.

	Chief				Froker			
	Early Boot		Late Boot		Early Boot		Late Boot	
	Blast %	Increase %	Blast %	Increase %	Blast %	Increase %	Blast %	Increase %
Brookings								
Check	11.4	0	11.4	0	17.4	0	17.4	0
1/3 hit center head			14.6	28.1			18.1	4.0
2/3 hit center head			16.5	44.7			19.1	9.8
3/3 hit center head	20.9**	83.3	18.0	57.9	21.4	23.0	19.6	12.6
	Dunnett (.05)= 7.0				Dunnett (.05)= 5.9			
	(.01)= 9.2				(.01)= 7.8			
Watertown								
Check	15.1	0	15.1	0	14.9	0	14.9	0
1/3 hit center head			15.9	5.3			15.7	5.4
2/3 hit center head			13.1	-13.2			14.3	-4.0
3/3 hit center head	13.6	-9.9	14.1	-6.6	14.9	0	14.4	-3.4
	Dunnett (.05)= 6.8				Dunnett (.05)= 5.6			
	(.01)= 9.0				(.01)= 7.4			

*, ** Significant at 5 and 1% level, respectively.

Appendix 13. Percent Head Droppage for Chief and Froker Oats as Affected by Simulated Hail Treatments at Brookings and Watertown in 1973.

	Chief		Froker		
	Time of Treatment				
	Heading % Drop[1]	Soft Dough % Drop	Late Boot[2] % Drop	Heading % Drop	Soft Dough % Drop
Brookings					
Check	0	0		0	0
1/3 below flag leaf	0	0		0	0
2/3 below flag leaf	0	0		1.7	0
3/3 below flag leaf	0	0.8		0	0
1/3 below head	3.3	0.8	11.7	10.7**	0.8
2/3 below head	1.7	0.9	43.3	10.9**	3.4
3/3 below head	4.2*	0	56.0	10.0*	0.8
	Dunnett (.05)= 3.8			Dunnett (.05)= 8.7 (.01)= 10.7	
Watertown					
Check	0	0		0	0
1/3 below flag leaf	1.7	0		0.8	0
2/3 below flag leaf	0	0		0	0
3/3 below flag leaf	0.8	0		0.8	0
1/3 below head	1.7	0		0	0
2/3 below head	0	0.9		1.7	0
3/3 below head	3.3*	0.8		0	0
	Dunnett (.05)= 2.9			Dunnett (.05)= 1.8	

1 Values represent whole plots, each has been corrected for the various intensities.
2 Values represent actual droppage count because this treatment wasn't tagged.
*, ** Significant at 5 and 1% level, respectively.

Appendix 14. Percent Head Droppage for Chief and Froker Oats as Affected by Simulated Hail Treatments at Brookings and Watertown in 1974.

	Chief				Froker			
	Time of Treatment							
	Early Boot	Late Boot	Heading	Soft Dough	Early Boot	Late Boot	Heading	Soft Dough
	% Drop	% Drop	% Drop	% Drop	% Drop	% Drop	% Drop	% Drop
Brookings								
Check	0	0	0	0	0	0	0	0
1/3 below flag leaf			9.4	0			0	0
2/3 below flag leaf			0.8	3.4			0.8	0
3/3 below flag leaf			9.2	0.8			0.8	0.8
1/3 below head		9.2	13.3	5.0		2.5	8.3*	5.8
2/3 below head		12.5	25.0**	14.2		8.3*	6.7	7.5
3/3 below head	2.5	15.0*	21.7**	13.4	0	5.0	4.2	7.5
		Dunnett (.05)= 14.7				Dunnett (.05)= 8.2		
		(.01)= 17.7				(.01)= 9.9		
Watertown								
Check	0	0	0	0	0	0	0	0
1/3 below flag leaf			0.8	0			0	0
2/3 below flag leaf			0	0			1.7	0
3/3 below flag leaf			0	0			0	0
1/3 below head		4.2	8.3	0		0	0.8	0
2/3 below head		24.2**	14.2*	0		10.9**	5.0	0
3/3 below head	0	17.5**	7.5	0	0	5.9	4.2	0.8
		Dunnett (.05)= 14.2				Dunnett (.05)= 6.2		
		(.01)= 17.2				(.01)= 7.5		

*, ** Significant at 5 and 1% level, respectively.

Appendix 15. Blast and Spikelet Numbers of Oats in 1974 Standard Variety Oats at Two Locations.

	Brookings[1]		Watertown[2]	
Variety	Spikelet No./Panicle	Blast %	Spikelet No./Panicle	Blast %
Trio	25.3	4.7	25.6	10.5
Dupree	31.7	5.7	28.1	7.1
Nodaway 70	24.9	10.4	24.0	9.2
Portal	34.0	11.2	22.5	18.2
Purdue (61353)	30.5	12.1	26.0	14.2
Diana	28.8	12.2	24.7	9.3
Random	45.7	13.1	38.4	26.0
SD 711035	17.4	13.2	17.1	10.5
MN 71101	32.3	13.6	27.1	13.7
Froker	29.5	14.2	28.3	13.8
Noble	36.0	14.4	29.7	13.8
Stout	27.6	14.5	28.0	16.4
Astro	30.9	14.6	23.1	12.1
Burnett	30.8	14.9	30.9	12.3
SD 711045	19.1	15.7	17.8	9.6
1641-2 (Wisc)	37.8	16.4	33.1	15.4
Dal	32.2	16.8	30.7	25.1
Kelsey	38.6	16.8	28.6	24.1
Otee	29.5	17.3	28.9	13.5
Cayuse	31.1	19.3	28.8	12.5
Chief	39.1	19.4	36.4	12.4
Grundy	28.8	19.8	30.2	12.9
M-73	36.4	19.8	34.9	13.5
SD 955	33.6	20.2	26.2	23.4
Lodi	38.8	21.6	35.0	20.6
Holden	28.7	22.3	26.0	16.5
Ot 186 (Hudson)	35.0	22.6	40.6	21.9
Otter	40.6	26.4	39.4	21.8
Goodland	31.0	26.8	27.9	27.2
Garland	37.3	27.9	28.5	14.7
Average	32.1	16.6	28.9	15.7

1 Average of 4 replications with 10 heads per replication.
2 Average of 2 replications with 10 heads per replication.