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Illinois State Water Survey
at the
University of Illinois
Urbana, Illinois

INVESTIGATIONS OF CROP-HAIL LOSS MEASUREMENT TECHNIQUES

by

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ABSTRACT

An exhaustive study of crop losses from a damaging hailstorm was pursued using a) detailed post-storm field measurements of loss as determined from standard adjusting techniques, b) post-storm aerial photographs taken on different days using infrared color and standard color films, and c) actual yield data from the damaged fields. The measurements of loss from the in-field adjustments at various sampling densities and from the film data were compared with each other and against the final losses reflected in the harvested yields. Film data taken over corn plots where various treatments to simulate hail damages were applied were also studied in a similar fashion. The primary aim of the project was to ascertain whether aerial infrared color photographs could provide objective and quantitative measures of crop-hail loss. The principal results of the 1-year project are listed below.

1. Careful visual stereoscopic inspection of aerial photographs of damaged crops using only standard color film provided estimates of average field loss that were as good in predicting final field losses as those derived from the "best" field adjusting (detailed sampling of 1 point per 5 acres). Badly damaged areas appeared to have unique "signatures" on the photographs consisting of semi-circular areas of loss that suggest a hail-wind related series of vortices.

2. Densitometer measurements of film density determined from the infrared film of both actual and simulated damaged crops showed a) some relationship with the degree of actual corn loss, b) a poor relationship with actual soybean losses, and c) no relationship with the simulated corn losses. This suggests that the simulated hail damage to corn does not

match the actual damage rendered by hail, insofar as the reflectance spectra of the plants are altered due to physiological changes caused by hail.

3. The very dense measurements of loss per field revealed a) amazing variability of loss within most fields; and b) that these measurements predicted the final harvested loss per field better and were generally at lower values than either sampling based on normal adjusting frequencies per field or the actual paid claims. Thus, post-storm field adjusting should incorporate many more sampling points per field than is currently employed as standard practice.

4. However, all forms of field adjusting involving different sampling densities performed during the period 10 to 30 days after the storm did not provide highly accurate assessments of the actual final loss as measured in harvested yields. Although the best loss estimates were from the most detailed field (1 point per 5 acres) sampling, these were generally high by 5% for a given soybean field and low by 8% for any given corn field.

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INTRODUCTION

The primary goal of the 1969 hail research program in Illinois for the Crop-Hail Insurance Actuarial Association was to determine whether the Infrared (IR) camouflage detection color film or Ektachrome Aero color film, when used separately or together to photograph a hail-damaged area, would detect and allow quantification of the crop-hail damage (by film density differences or color gradations). Crop disease studies[1] had suggested this possibility. The resulting photographic data were compared with the adjustor yield-loss values and against actual crop yields to evaluate their potential in this pilot experiment involving one storm.

Necessary ingredients for the 1969 research program or experiment included: 1) a damaging hailstorm relatively close to Champaign, 2) aerial cameras, 3) special film sizes and types, 4) an aircraft modified for aerial photography, 5) a well-equipped film development facility, 6) equipment to analyze quantitatively the photographic data, 7) surface studies and detailed adjustment of loss by a trained adjustor, and 8) a gathering of final yield data in as much detail as possible.

Another phase of the 1969 experiment involved a photographic mission over the hail-test corn plots operated by Western Illinois University at Macomb, Illinois. These plots offered an opportunity to obtain "control" data with respect to checking the proposed photographic approach of detecting and measuring damaged, albeit artificially, crops for accurate comparison with the carefully measured final yields in the test plots. Figure 1 is an example of the Ektachrome Aero and IR color photographs taken of these test plots. The patchwork of the rectangular plots is in the lower center of the normal

EKTACHROME 1:6000 EKTACHROME IR 1:12000

DEFOLIATION AND STAND REDUCTION STATISTICAL STUDY,

WESTERN ILLINOIS UNIVERSITY TEST PLOTS.

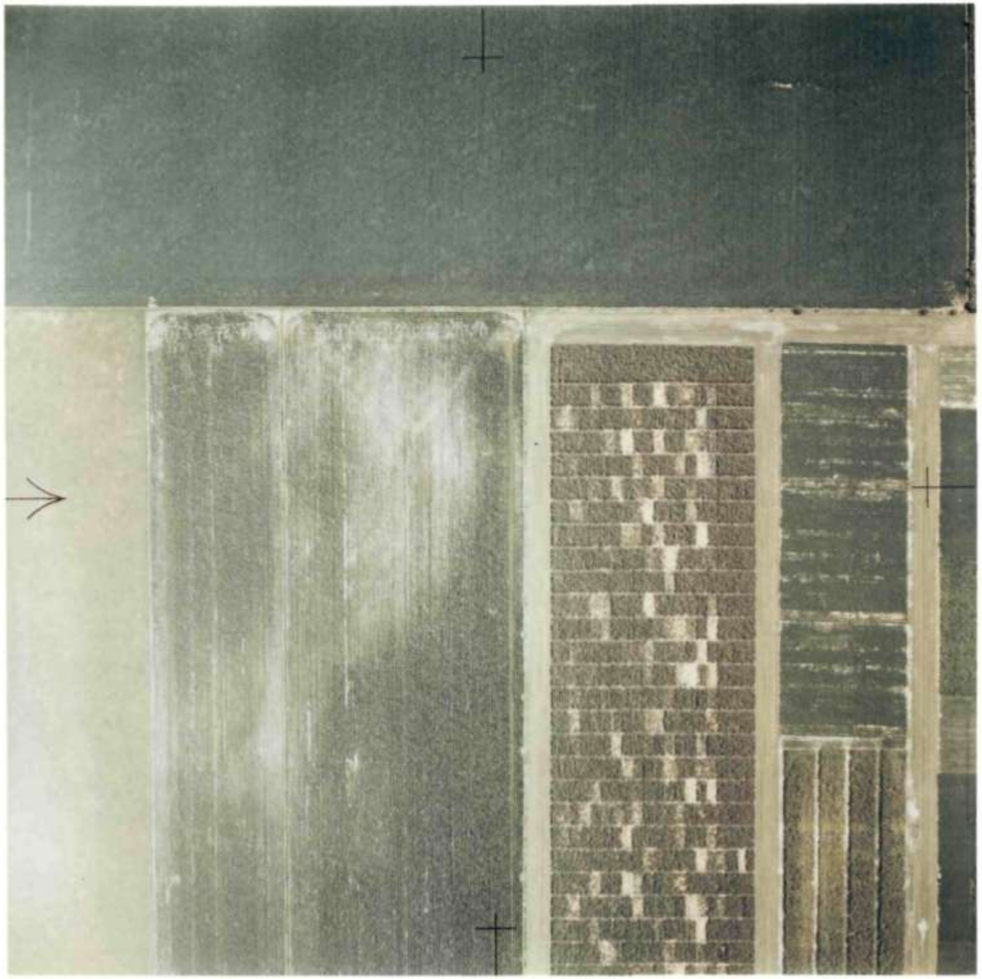

Figure 1

color (Aero) Ektachrome print, whereas it appears on the left edge of the IR print. In the IR print the healthy plants are in vivid red, with the less healthy in darker reds and inert objectives depicted in green.

Inasmuch as the experimental task and its many required techniques were in the exploration phases of remote sensing, and since no one on the Survey staff had any thorough knowledge of these remote sensing techniques, considerable study and acquisition of background information were required to design and properly perform the experiment. Several remote-sensing experts were contacted about the experiment, and one important result of these contacts was to learn that Ektachrome Aero color film photographs should be taken simultaneously with the IR color film to provide the type of control data needed. N. A. Barron, an agriculturalist with minor experience in remote sensing, was added to the staff to perform and direct the experiment.

An experienced crop-hail adjustor,[2] John Hornaday, was employed to perform the detailed adjusting in the storm area studied. He also arranged for and helped secure the final yield values from the farmers in the storm area.

A local aerial surveying firm was employed to build a mount and drive system for the two paired K-24 aerial cameras required. Both cameras were available as Water Survey property items and thus available at no cost. The aerial survey firm also was employed to fly the photographic missions. The experimental plan evolved in early 1969 called for several photographic missions at levels between 1000 and 3500 feet during a 2 to 3 week period beginning 7 to 8 days after the storm occurred. This was to provide measurements at times that would match the normal times of surface adjusting.

The desired damaging hailstorm, as to date and location, occurred east of Rantoul on 11 July. A survey of the storm area on 14-15 July outlined a

6-square-mile study area with quite extensive crop damage. Enusing photographic missions were flown on 21, 25, and 26 July and 4 August. A matched pair of IR and Ektachrome photographs made on 26 July (Fig. 2) encompass severely damaged corn (lower portion) and soybean fields on the IR film. Healthy plants are highly infrared reflective, and are rendered as a bright red color. Unhealthy plants reflect less infrared and appear more blue or green. Detailed adjusting (assessment at 1 point per 5 acres) was accomplished in 48 fields incorporating 1623 acres. Normal loss adjusting is based on 1 point per 10 to 20 acres. This detailed study began on 22 July and was completed in 17 days. Actual yield data for the fields in the storm area were collected in the October-December period. A photographic mission over the Macomb plots (Fig. 1) was made on 29 July.

Secondary goals of the 1969 hail research concerned studies using 1) the adjustor's field data collected during the photographic experiment, and 2) the adjustor work sheet data from various insurance companies for losses next to hailpads in the State Water Survey's Central Illinois rain and hail network. The data from the very detailed survey of loss desired in the photographed fields offered a unique opportunity to study the loss patterns in extreme detail and to make new observations of various adjusting techniques and farming practices that affected loss.

A portion of the Illinois hail research effort in 1968 had concerned the comparison of hailfall parameters as measured on 1-square-foot hailpads with the adjusted losses for adjacent damaged crops.[3] These past data and results were supplemented by those available in 1969, but only a few minor crop losses (22, each less than 25%) occurred next to our 200 hailpads (scattered throughout a 900-square-mile area). Since these 1969 data did not alter the results presented previously,[3] no further information on this effort is presented.

HAIL DAMAGE AREA, DILLSBURG ILLINOIS,

STORM DATE 7/11/69 PHOTOGRAPHY 7/29/69 SCALE 1:12000

EKTACHROME

EKTACHROME IR

Figure 2

In this report, the description of the 11 July 1969 hailstorm and the comparisons of various damage data are presented first. This is followed by three sections describing details of the photographic experiment and the results of the photographic studies for the 11 July hailstorm and the Macomb test plots. Some observations relating to adjusting techniques that were gleaned during these studies are then discussed, and this is followed by the conclusions and recommendations. In addition to references cited in the text, a list of bibliographic materials is provided, and examples of special forms used during the study are shown in the appendix.

DESCRIPTION OF 11 JULY 1969 HAILSTORM

Surface Hail Data

This hailstorm occurred during the afternoon of 11 July, and the outline of the damaged area east of Rantoul, Illinois, is depicted in Figure 3. The first hail began in the northwest corner of the damage area at 1825 CDT, and the hailfall progressed to the southeast with first hail at 1830 CDT in the southeasternmost part of the damage area. Hailfall durations at most locations in the damage area varied from 8 to 12 minutes. Most storm observers reported very high winds associated with the hailfall. Hailstone size reported in the damage area varied from 1/4- to 1-inch in diameter, but stones did not cover the ground at any point. Some minor small hail fell beyond the damage area depicted in Figure 3, but its extent in any direction away from the damage area was less than 1/2 mile.

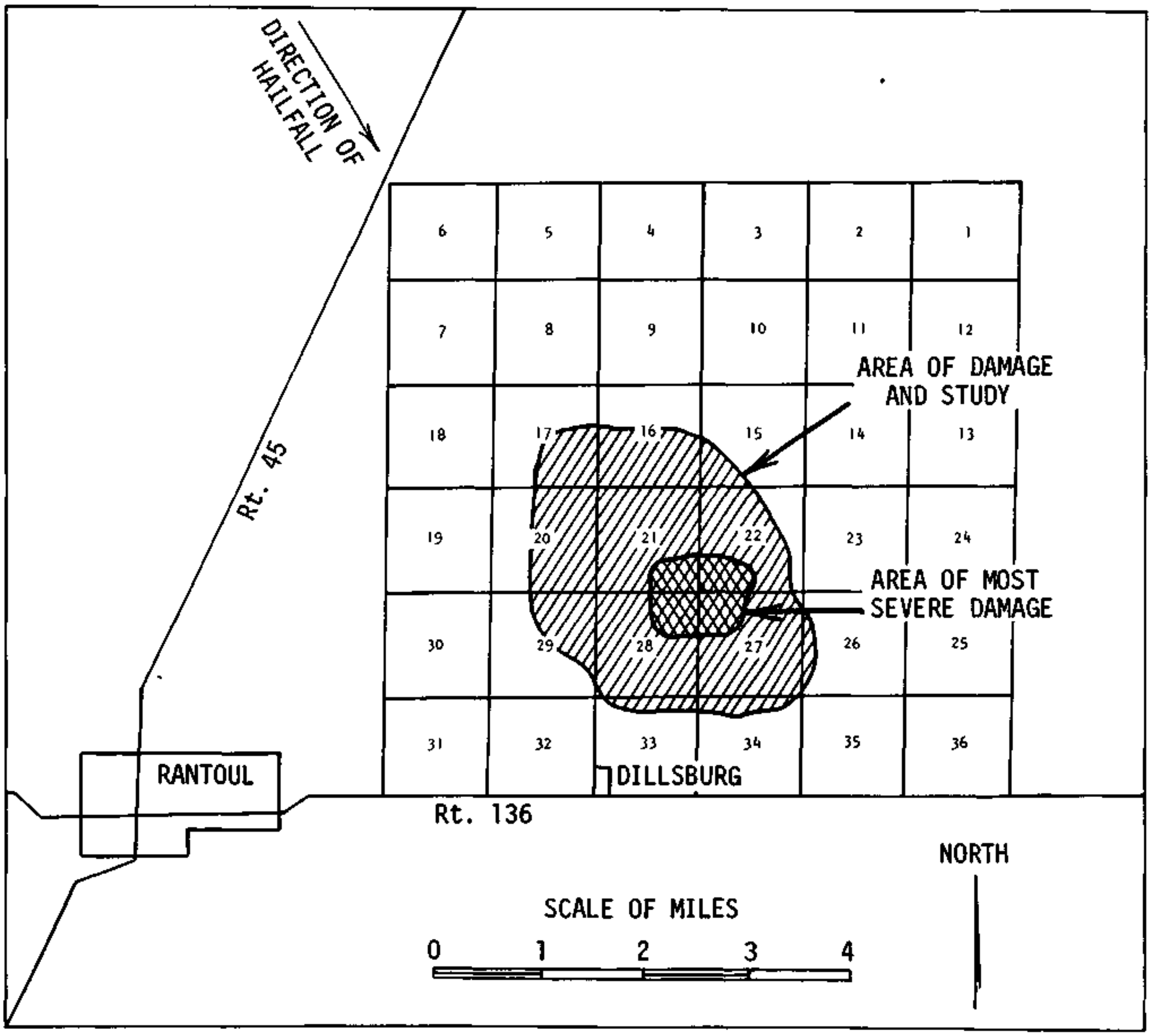

Figure 3. Base map for 11 July 1969 hailstorm

Meteorological Conditions

At storm time an east-west oriented stationary front and attendant small low pressure area were positioned in southern Illinois, 100 miles south of the storm. Surface temperatures in central Illinois had reached 90°F on the afternoon of 11 July, and an unstable air mass existed north of this front. A surge of cold air at the 500-mb level moved across central Illinois during the afternoon and led to positive vorticity advection, an excellent combination for producing quite unstable conditions. These conditions were so capable of producing severe weather that the Weather Bureau issued a Severe Weather Warning at 1800 CDT for an area extending from near Rantoul to Detroit, Michigan.

Operations using the Water Survey's TPS-10 RHI radar provided a series of measurements of the thunderstorms in central Illinois on 11 July. In general, the individual storms were isolated, small (20 square miles in areal extent), and relatively short with tops less than 25,000 feet. However, the echo producing the Rantoul hailstorm that was studied was quite large having an areal dimension of 64 square miles and a top to 31,000 feet at hailstorm time.

Loss Patterns

Corn. Detailed field investigations were made of 22 damaged corn fields, ranging in size from 20 to 60 acres. The total area carefully surveyed consisted of 703 acres in which 163 separate adjustments were made (1 point per 4 acres). The maximum point loss measured was 48%. These 163 point loss values were plotted and used to construct the loss pattern map on Figure 4. Considerable variability is obvious with changes from 5 to 40% losses across 0.2-mile distances in sections 27 and 28. The photographs (Fig. 2) that show damaged corn in their lower sections were taken of portions of sections 22 and 27 with the east-west road being the section line just north of the Special Study Area (Fig. 4).

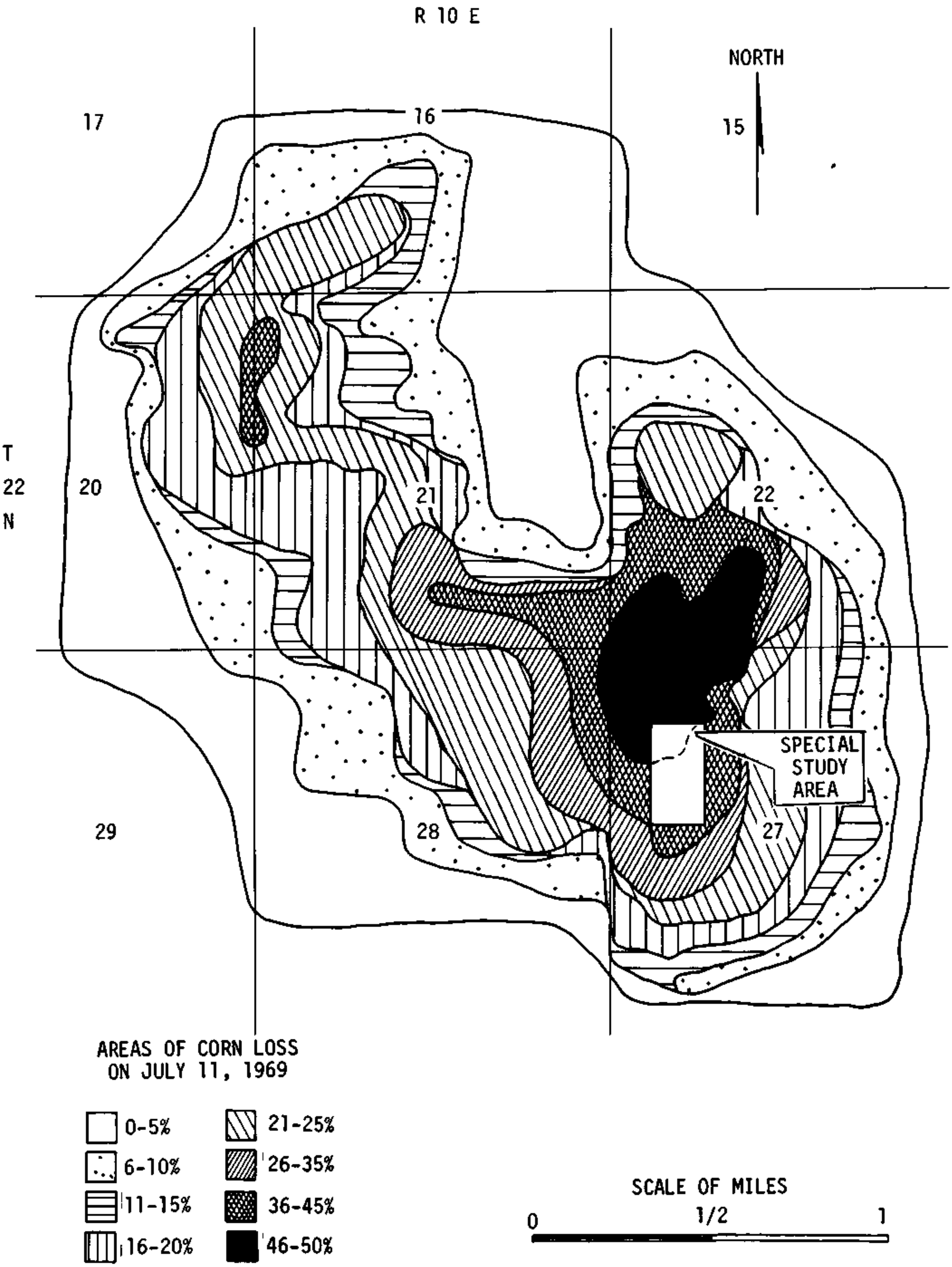

Figure 4. Corn loss pattern for entire storm, 11 July 1969

A 17.5-acre portion of a badly damaged corn field, which is the Special Study Area in Figure 4, was chosen for an intensive study of loss. A total of 40 adjustments, each spaced 150 feet apart to form a uniform grid within a rectangular area, was made within this field (Fig. 5). The loss pattern shown for this field reveals the complexity of loss that existed with a minimum value of 11% at the southeasternmost dot (observation point) and a maximum of 48% 900 feet to the northwest. The adjustor also carefully noted areas within the field where corn had been "downed" by the wind. Certainly, accurate assessment of the average loss for this field would depend greatly upon the number and location of the sites chosen by an adjustor. The average loss based upon the 40 site values was 29.8%. The adjustor chose 6 sites that he believed an actual adjustor might have chosen for assessing the loss in this field, and these 6 values provided a field average loss of 24%. This underestimate represents a 20% error.

Corn in the area suffered much less damage than did soybeans. This was due to differences in the stage of growth of the two crops at the time of the hailstorm. The corn crop generally was in the 9-11 leaf stage when hit by the hail. These 9 to 11 leaves were 10% to 70% defoliated, depending upon their location in the storm. However, a normal corn plant produces 16 leaves, and hence after the storm the plants had a potential of producing 5 to 7 new leaves to feed themselves and to produce the desired ear. This is not to say that corn yields were not decreased, but the losses were not as great as if the plant's full leaf area had been exposed at the time of this particular storm.

There was additional damage observed in the corn fields other than defoliation. The plants in the early-planted corn fields suffered some ear damage due to stones striking the small shoots, and this damage showed up later as the ear emerged. Many plants in the corn field showed evidence of stalk

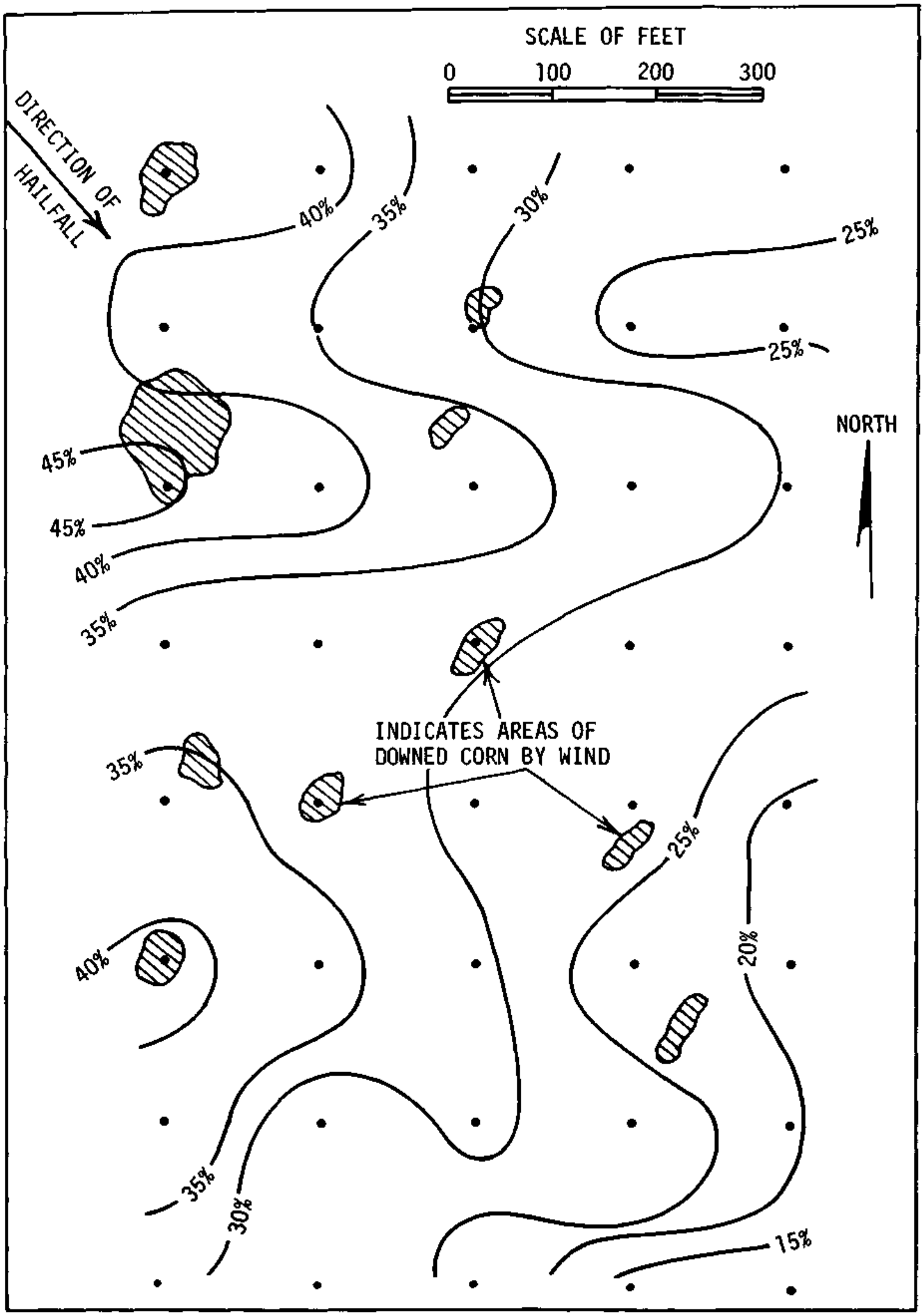

Figure 5. Detailed corn loss pattern in 17-acre field, 11 July 1969

damage due to large stones striking the stalks and either cutting into the stalk or bruising it badly. Also observed in the fields of heavily damaged corn plants was a considerable amount of smut, and some of this is believed to have resulted from hail injuries to the plants.

Soybeans. Detailed investigations were made of 26 damaged soybean fields, ranging in size from 10 to 95 acres. The areal extent of the surveyed area was 960 acres with 198 point adjustments, or 1 for every 5 acres of loss. The bean loss pattern for the entire storm area, as based on the 198 points, is depicted in Figure 6. Its overall shape is not unlike that for the corn losses (Fig. 4), but a major bean loss area occurred in the northwest corner of section 21 where corn losses were not severe. The loss pattern is also more complex than the corn pattern because the bean losses had a greater range, 1 to 97%. The soybeans in the center of the photographs (Fig. 2) are in the southwest corner of section 22 where their damages ranged from 65% (on the right side of the photo) to 87% on the left side.

One badly damaged 20-acre soybean field in section 28 (Fig. 6) was chosen for a special intensive study of loss. Measurements were made at 45 points, each spaced 150 feet apart, and these produced the highly variable loss pattern shown in Figure 7. Losses ranged from a low of 68% in the western edge to a high of 97% at a point 750 feet south, and the field average was 83.1%. The adjustor also picked 6 sites from the 45 to match those thought most likely to be chosen by an adjustor performing a routine adjustment for this field. These produced a field average loss of 98%, an overestimate that represents a 7% error.

Defoliation was not the principal type of damage experienced by soybeans. The principal loss to beans resulted from stem bruising, from cut-off plants

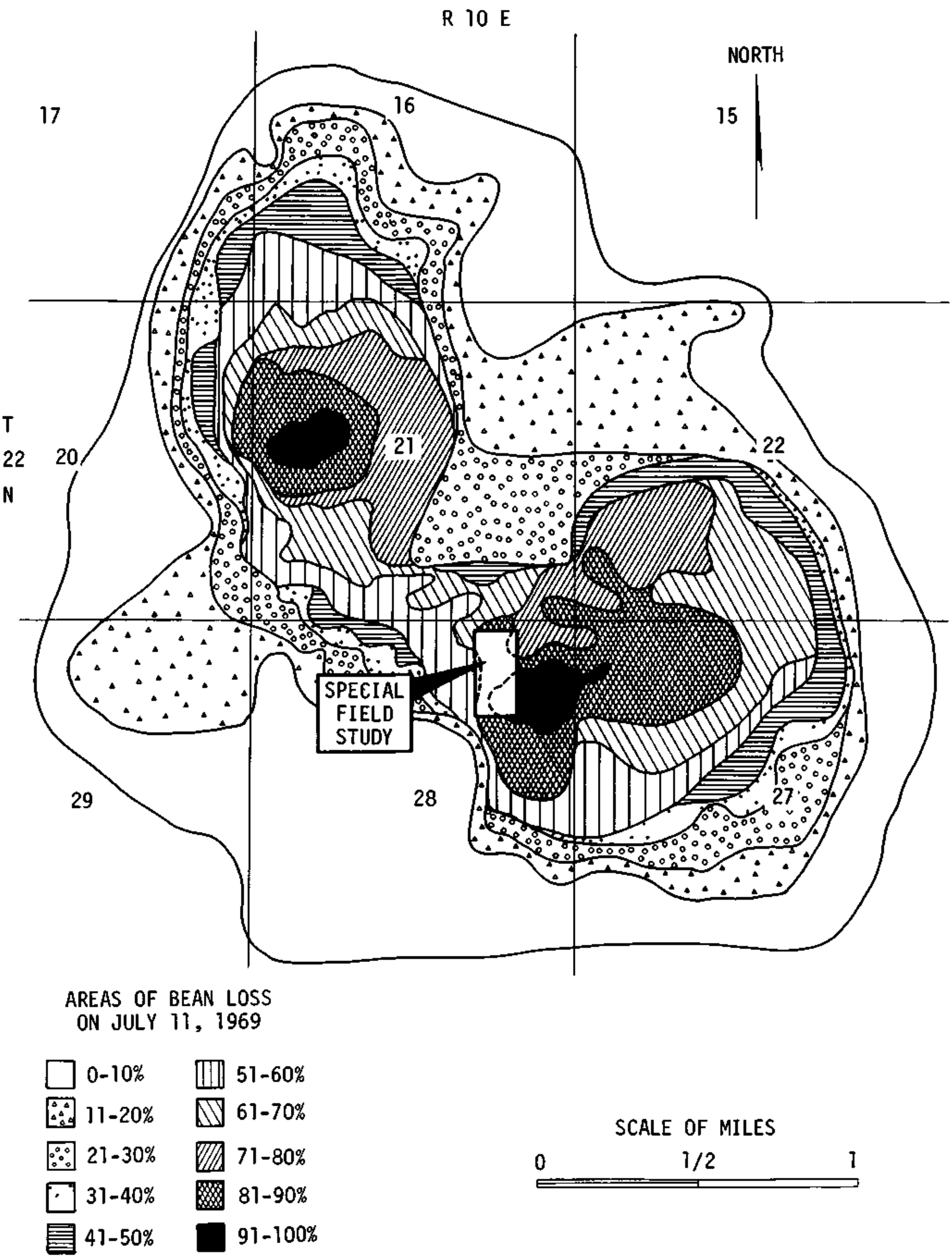

Figure 6. Soybean loss pattern for entire storm, 11 July 1969

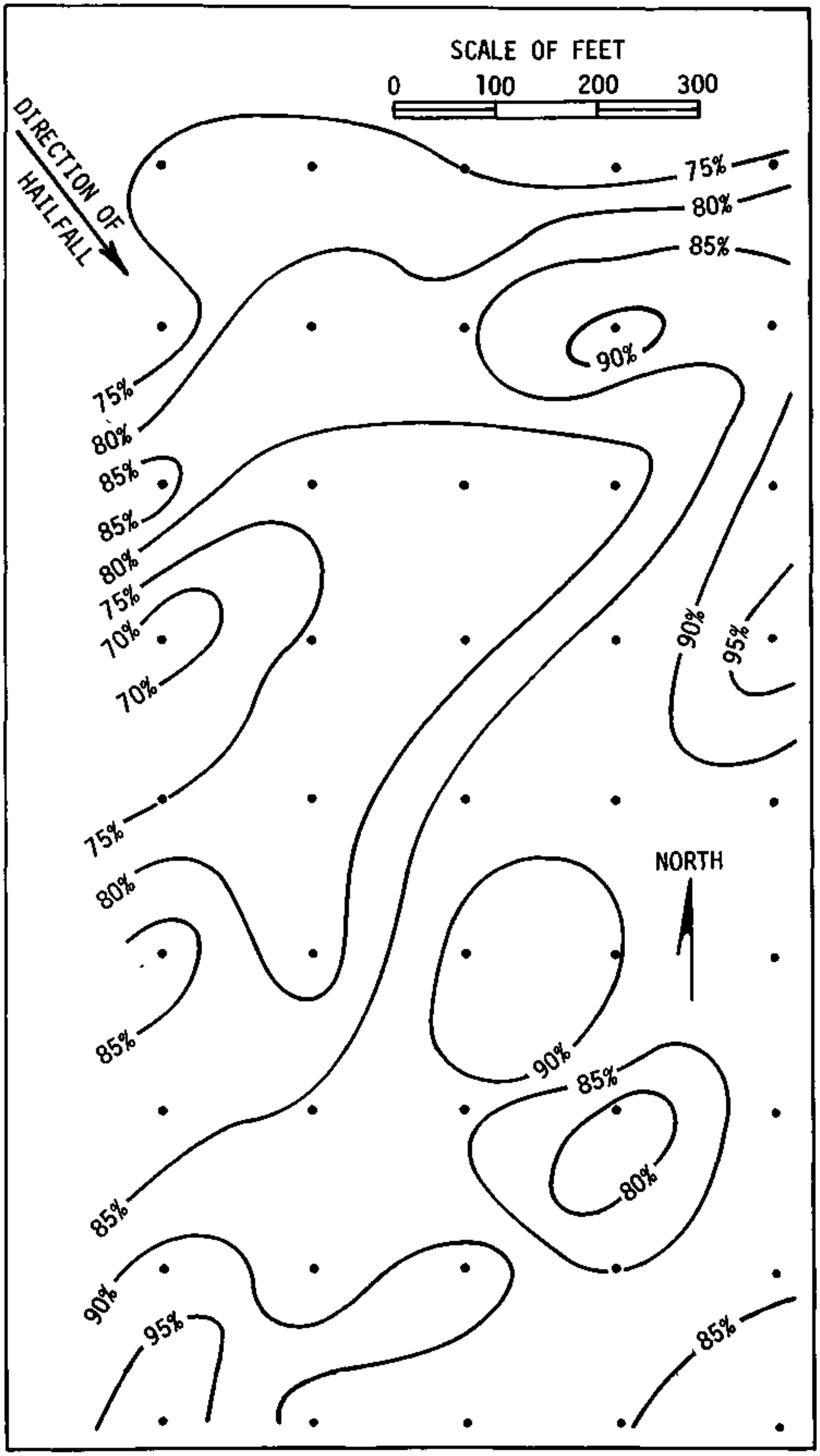

Figure 7. Detailed soybean loss pattern in 20-acre field, 11 July 1969

that partially came back and recovered, and from plants that were completely killed by the hail. The first two types of bean damage identified would likely be the most difficult types to assess by aerial photography.

In observing the bean losses in the areas of the storm, it was quite evident that the rows planted north-south were more severely damaged than those planted east-west. This resulted because during the entire duration of the storm, the high westerly winds with the hail tended to lay the N-S planted stems and stalks over flat on the ground, exposing the entire stem, and making the stems more open targets for the hailstones. However, in the E-W planted fields where the wind direction was parallel to the rows, the plants were blown over in such a way that they tended to pile up and to shield each other. Thus, there was not complete exposure of the stems. This phenomenon was observed in most of the fields in the July 1969 storm area.

Comparison of Field Loss Assessments

The detailed corn and soybean loss assessments made of the 11 July storm offered an opportunity to compare the average loss value per field, as derived from the detailed measurements (1 measurement per 5 acres), with those determined using four other densities of adjusting points per field. The field average losses from the detailed measurements also were compared with 1) those obtained from actual adjustors involved in settling claims, and 2) those derived from use of the final harvested yields.

One density chosen for determining an average loss per field was based on a choice of those sites within the field that were believed to be approximately those that a working insurance adjustor might choose. This density provides results that would emulate actual insurance adjusting. Another density chosen consisted of 5 values including the loss value nearest the center point of the field plus those taken in each of the four corners.' The third field density used for comparison consisted of only the value of the center point in each field and considering it the field "average" loss, and the fourth density used to obtain an average for each field was based upon the highest and lowest values obtained from the detailed field measurements (1 per 5 acres).

Another comparison of field average losses was made using the values obtained from the work sheets of insurance company adjustors who assessed claims in the storm area. A sixth comparison of the detailed measure-loss values was made with the losses derived from the actual yields reported by farmers after harvesting. These actual losses or reductions in yield were referenced against two bases: 1) the final yield compared with that expected by the farmer, and 2) the final yield compared with the average of nondamaged fields at farms in the area immediately surrounding the hailstorm damage area.

The densely measured field averages were assumed to be the best or most correct value for each field. The differences between these best estimates and those determined by any of the other densities and methods were expressed as a percent, either above or below, of this best or most correct average.

Corn. The percentage differences obtained between the 22 pairs of corn field losses derived for each density were then averaged (without regard for the algebraic sign) to produce the average differences or errors (per field) shown in the first line of Table 1. For instance, the average field losses, as assessed by "normal adjusting frequencies" were ± 22.7% of the average of the detailed value. That is, if the correct average loss for a field was 60%, the normal adjusting procedure provided a loss value that could be higher by

Table 1. Comparison of the correct field average percent loss to corn, as determined using one adjustment point per 5 acres, with losses determined from lesser sampling (adjusting) densities[1] and from final yields.

	Differences from field average loss determined from detailed adjustment, 1 per 5 acres				Actual yield reductions[3]	
	Normal adjusting frequencies[2]	Adjusting using center and corners of each field	Adjusting using center point in each field	Adjusting using highest and lowest point values infield	Expected farm yield[4]	Area average yield[5]
Average difference, expressed as percent of correct (detailed) average	±22.7	±3.3	±26.9	±80.0	±83.0	±89.0
Number of overestimates	15	9	9	18	12	8
Maximum overestimates, %	+64.7	+15.3	+155.3	+130.8	+605.0	+773.0
Number of underestimates	7	6	10	3	0	4
Maximum underestimates, %	-44.2	-7.7	-27.0	-73.5	none	-100.0
Number of equal values	0	7	3		1 0	0

[1] Based on data from 22 different fields ranging from 20 to 60 acres in size, and field average losses from 2 to 33%, as based on the detailed sampling.

[2] These varied from 2 to 5 points per field.

[3] Determined from comparisons in 12 fields where actual yields were obtained.

[4] Percent yield reduction based on comparison of actual yield with the yield expected by the farmer.

[5] Percent yield reduction based on comparison of actual yield with the average yield for 8 farms around the storm area (110 bu/acre average).

22.7% (or assessed as a 73.6% loss) or lower by 22.7% (assessed as a 46.4% loss). Comparison of the four average differences derived from the different sampling densities shows that 1) the normal adjusting frequencies provided values that were only slightly better than those obtained using only the center point in each field; 2) the use of the highest and lowest values in a field to get an average loss often provided very large errors with many overestimates of the true field average; and 3) adjusting of a field loss by averaging the center and four corner values provided an average loss very close to the correct field average.

Since actual adjustor data (paid claims) were available for only four of the 22 corn fields studied, these individual values are presented in Table 2 for comparison. All four actual adjustor losses are greater than the "correct" average from the detailed measurements of loss, indicating agreement with the findings in Table 1 for the normal adjusting frequencies. The average difference shown in Table 2 represents an average error of overestimate that is 9.9% greater than the correct field loss. However, the sample is too small to derive many meaningful conclusions. Nevertheless, all four sets of density comparisons in Table 1 and that in Table 2 reveal that adjusting with a few (1 to 3 points) in a field had a distinct tendency to result in higher average field losses than the correct (detailed) loss.

Final harvested corn yields were obtained from storm-area farmers for 12 of the 22 carefully studied corn fields. Also obtained were the yields that each of these farmers "expected" had the 11 July storm not occurred. Yields from eight farms in the immediate area surrounding the hail damaged area also were obtained, averaged (110 bu/acre), and labeled as the "control yield." The final yields from these 12 damaged fields were expressed as a percent of the expected yield and as a percent of the control area yield, and thus two more sets of reductions or losses were derived.

Table 2. Comparison of average field corn loss from detailed field study and actual adjustor values of loss for paid claims.

	Detailed field study			
Field size, acres	Number of point samples	Average loss, %	Actual adjustor's loss value, %	Difference, adjustor-detailed value, %
40	6	23.3	50.0	+26.7
30	5	21.0	22.6	+1.6
20	7	2.6	10.0	+7.4
24	5	1.0	5.0	+4.0
			Average =	+9.9

These losses were compared with the "correct" field average losses (from the detailed measurements), and the results are shown in Table 1. The average differences are quite large, between 80 and 90%, indicating that the so-called correct average loss per field from the detailed studies did not relate well to the losses as measured by the final harvested yields. In fact, for the 12 field comparisons, when the final yield was expressed as a percent of the expected yield, the final losses reflected by the harvested yields were all greater (overestimates) than the loss determined from the detailed adjusting done in July.

The comparison based on actual harvested losses in relation to the control area average yield for 1969 also had a large average error, ± 89.0%, but 4 of the 12 values were underestimates (Table 1). The 12 field reductions determined in this manner and their corresponding field average losses predicted from the detailed adjusting are plotted in Figure 8. If they were perfectly related, they would be aligned along the 1:1 line. The considerable dispersion of points indicates a poor agreement between the predicted and actual losses. The six

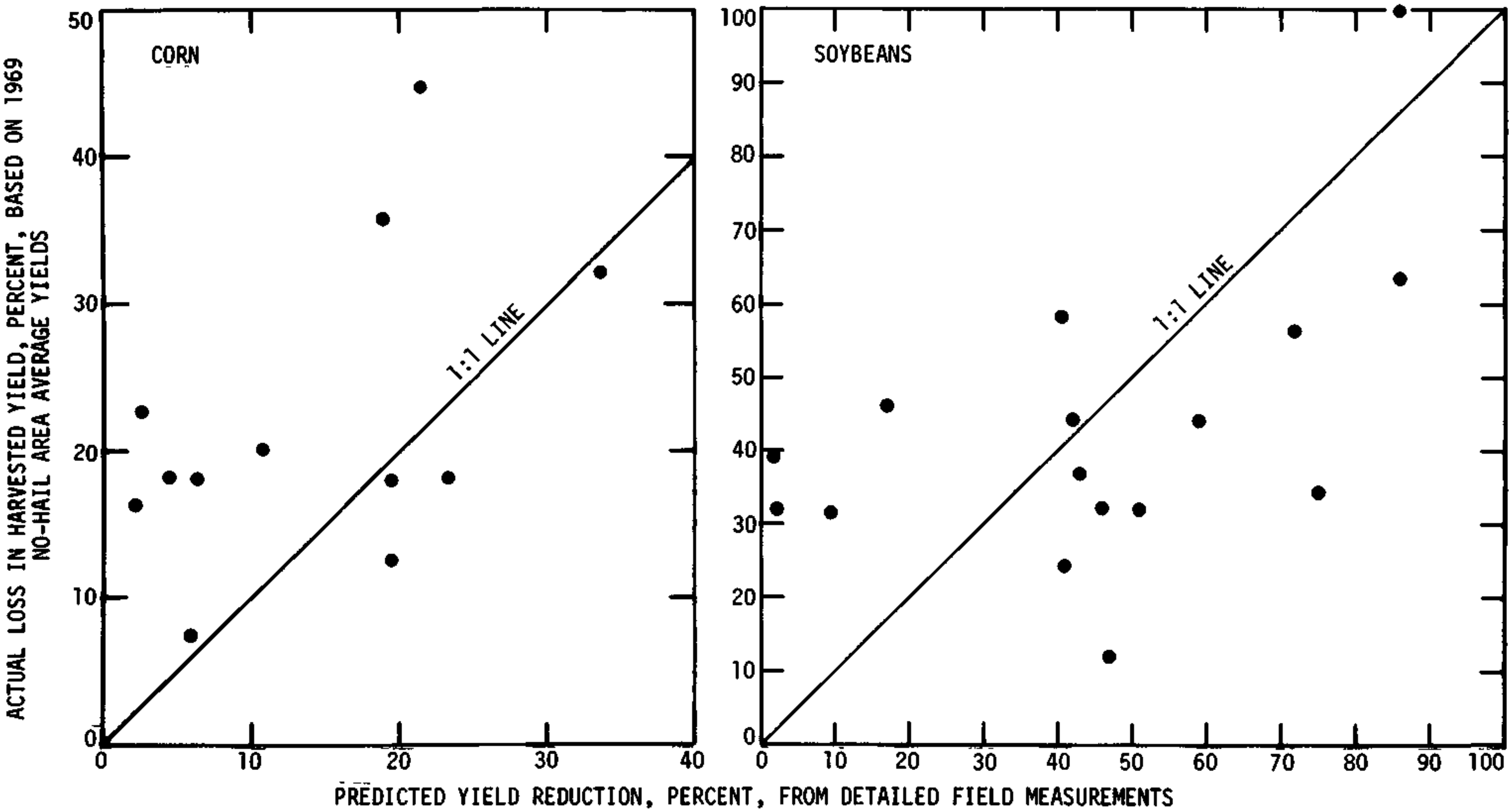

Figure 8. Comparison of predicted yield reductions from detailed field studies (adjustments) with actual yield reductions computed using non-hail area average yields (41 bu/acre = soybeans; 110 bu/acre = corn)

predictions of losses that were under 15% were all considerable underestimates of the loss shown in the harvested corn.

Soybeans. A similar comparative analysis was made of the average field losses for the 26 fields when soybean losses were measured in detail. The results in Table 3 are generally similar to those obtained for corn (Table 1). If the field average loss is determined using loss measurements taken from the middle of each field and its four corners, the average error of estimating the "correct" field average loss is very small, ± 3.8%. The "normal adjusting frequencies" chosen produced an average error (difference) that is ± 18.3% of the correct field loss, and the use of only the loss at the center point of each field is only a slightly poorer approach. As with corn, determining the field average loss using the highest and lowest values provided large errors, and this indicates that a rather skewed distribution of losses apparently exists in many hail damaged fields.

Adjustor worksheets were obtained for seven settled claims in the storm area that related to the soybean losses in fields that had been studied in great detail. The results for these fields appear in Table 4, and these reveal that the adjustor's values exceeded the detailed, or "correct," loss in six of the seven fields. As with the same comparisons for the corn fields, it appears that values from the working adjustors were generally too high. This may be due to an inadequate number of measurements, poor adjusting, or to a tendency for an upward readjustment of loss to satisfy the insurees.

Final harvested soybean yields were obtained from storm area farmers for 16 of the soybean fields that had been studied in great detail. Also obtained for these 16 fields were the bean yields "expected" by the farmers if the 11 July hailstorm had not occurred, and a control bean yield was calculated

Table 3. Comparison of field average percent loss to soybeans, as determined using one adjustment point per 5 acres, with field losses determined from lesser sampling densities[1] and from actual yields.

	Differences between stated measurement techniques and field average loss determined from detailed adjustment, 1 point per 5 acres				Actual yield reductions[3]	
	Normal adjusting frequencies[2]	Adjusting using center and corners of each field	Adjusting using center point in each field	Adjusting using highest and lowest point values infield	Expected farm yield[4]	Area average yield[5]
Average difference, expressed as percent of correct (detailed) field average	±18.3	±3.8	±21.2	±70.2	±21.0	±15.0
Number of overestimates	14	11	14	13	6	7
Maximum overestimate, %	+81.0	+34.8	+87.5	+298.0	+1095.0	+2337.5
Number of underestimates	11	7	11	12	10	9
Maximum underestimate, %	-63.9	-3.4	-53.5	-100.0	-89.0	-74.4
Number of equal values	1	8	1	1	0	0

[1] Based on data from 26 fields ranging from 10 to 95 acres in size, and field average losses ranging from 1 to 86% as based on the detailed sampling.

[2] These varied from 2 to 5 points per field.

[3] Determined from comparisons in 16 fields where actual yields were obtained.

[4] Percent yield reduction based on comparison of actual yield with the yield expected by the farmer.

[5] Percent yield reduction based on comparison of actual yield with the average yield for 8 farms around the storm area (41 bu/acre average).

from the yields reported by eight farmers with farms not affected by the storm but in the area immediately adjoining the storm area. The harvested yields in the 16 fields were expressed as a percent of the expected yields and of the control yield which was 41 bu/acre. These two sets of reductions in yields, or losses, were compared with the loss determined from the detailed field measurements, and their average and extreme differences are listed in Table 3. The average difference of ± 21 and ± 15% reveal the degree of general error in the loss values predicted by the detailed measurements, and the greater frequencies of underestimates shown in Table 3 indicate that the predicted values of loss considered correct were too high with respect to the losses shown by the actual harvested yield. This is borne out in Figure 8 which shows that 9 of the 12 predicted soybean losses of 40% or higher were below the 1:1 line, or were associated with actual harvested losses that were much less than the predicted values. However, as with corn, the lower predicted losses (less than 20%) were all underestimates of the actual losses.

Table 4. Comparison of average field soybean losses from detailed field studies and from actual adjustor values of loss for paid claims.

	Detailed field study			
Field size, acres	Number of loss measurements	Average loss, %	Actual adjustor's loss value, %	Difference, adjustor-detailed value, %
20	5	43.0	80.0	+37.0
20	6	9.5	22.0	+12.5
80	9	75.3	80.0	+4.7
74	7	9.3	4.0	-5.3
30	6	1.3	7.8	+6.5
18	4	0.5	3.0	+2.5
20	5	2.5	18.9	+16.4
			Average =	+10.6

DESCRIPTION OF PHOTOGRAPHIC STUDY

Introduction and Objectives

The aerial study of crop diseases[4] and investigations of crop damage due to hail had been the subject of extensive research. However, the physiological effects of hail on crops has not been studied in detail. The possibility exists that these effects could be sensed and used as an indicator of hail damage. One technique that might be employed to do this would be to detect changes in reflected radiation[5] that occur from hail damage by using special aerial photographic techniques.

It was thought that an optimum time for hail damage photography existed. After hail, damaged tissues would die and significantly affect the spectral reflectance properties of the plant. Any such effect was expected to be most apparent several days after hail damage and before new growth effectively covered over damaged tissues.

The optimum photographic scale for damage detection was unknown at the start of the experiment. Scale should be as small as possible, compatible with the degree of detail and resolution required. This would keep the cost of photography and the time required for analysis to a minimum.

A photographic method to detect damage using emulsions sensitive in the near Infrared was developed. To assess the influence of scale and time of photography, a representative crop-hail damage area was photographed at intervals of several days after the causative storm and with different scales and exposure levels.

The objectives of the research experiment were:

1) To develop a photographic method for aerial identification of actual hail damage.

2) To evaluate the relative advantages of Ektachrome Aero and Ektachrome Infrared color film for damage detection.
3) To assess damage from inspection of the film.
4) To compare the results with those from field studies of the loss.
5) To investigate ways of reducing photographic data for machine analysis.
6) To examine photographic data from simulated-hail-damage test plots.

Development of the Method

The detection and quantitative assessment of crop damage due to hail is dependent on many factors. The pre-storm plant environment, storm factors, and the post-storm plant environment all combine with the type of farming system and the management capacity of the farmer to influence yield. Major influencing factors were thought to include.

Weather Factors	Crop Factors
1) Hail intensity	1) Crop species
2) Hail duration	2) Plant population
3) Areal distribution of hail	3) Row width
4) Winds associated with hail	4) Stage of growth
5) Subsequent high winds and precipitation	5) Fertilization
	6) Post storm cultivations

Any attempt to measure damage must take these variables into account, either individually or by some process of integration.

The possible physiological effects of hail on plants appeared to be a basis for a method of damage detection. Studies of the spectral reflectance characteristics of plant leaves[5,6] (Fig. 9) indicated that the reflectance signature changed when plants were subjected to stress. Published data on spectral reflectance for single leaves and several thicknesses of leaves, showed that a much greater amount of energy is available in the infrared region of the spectrum, 700-900 millimicron (mμ), than in any other 200-mμ region in the visible spectrum. Thus, an attempt was made to find a method capable of detecting changes in this spectral region.

New photographic materials have provided improved tools for scientific studies and offered the possibility of their use in this crop-hail study. A study of emulsion types of various films showed that the sensitivity of Kodak Infrared Ektachrome film included the 700-900 mμ region. However, only one of the three emulsion layers, the cyan-forming layer, is sensitive to this region. While the cyan-forming layer is also sensitive to light in the remainder of the sensitivity range, its sensitivity declines rapidly below 700 mμ. Thus, it appeared that crop-hail damage to plants affecting the spectral signature of the plant in the 700-900 mμ region would be recorded by the cyan-forming layer, and this formed the basis of the method used.

The next consideration in this method of detection of damage by infrared film was to measure the density of the red image on the film and relate this to the crop damage as measured on the ground. The density of the red image was measured by a densitometer using a red filter.[7] The assumption was made that background effects were small if only a low percentage of bare soil between the rows was visible from the air.

Some technique to reduce the effect of natural variation in incident radiation was needed. A test target consisting of a grey scale was photographed

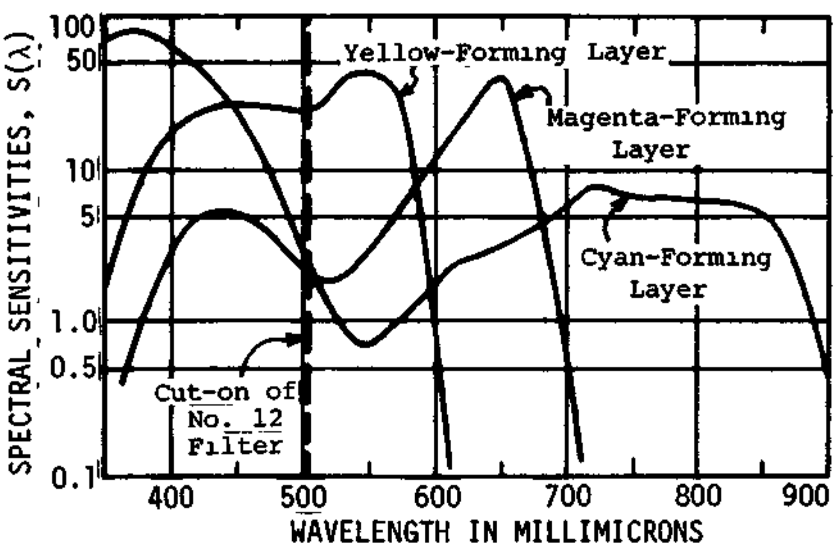

Figure 9. Spectral sensitivity curves for ektachrome infrared film, Type 8443, taken from Kodak Technical Publication M-28

at the same exposure before and after a photographic mission as a control. A particular grey in the panel could then be selected in the image and used as a densitometer standard density. Any differences in density between identical panels on each end of the film roll would be an indication of faulty processing, or a variation in the incoming radiation. The spectral reflectance curves for the various panels were not determined, and no attempt was made to determine any particular reflectance scale.

Project Plan

Collection of photographic and ground data were planned on the basis of an expected storm size and areal damage distribution. The average storm covers an area about 5.9 miles long and 1.1 miles wide, with most intense damage near the center.[8] On each flight mission the aircraft taking the aerial photographs flew a series of east-west parallel tracks across the major axis of the storm damage pattern (Fig. 3), obtaining photographs of all the damaged crop area as well as the no-damage areas surrounding the storm.

Ground measurements of crop damage were planned and handled in three stages. First, it was necessary after, the storm to define the general storm boundaries and the approximate percent damage inside the storm area. This defined the storm area to be studied with surface and photographic data, and until this was done, the photographic missions could not be made.

Second, the adjustor adjusted the area for damage using normal adjusting techniques but getting many more point measurements than usually obtained. These data provided an overall, rather detailed picture of the damage distribution and intensity. During this stage, the farmers in the area were contacted for permission to take measurements on their fields, and they were also asked to provide final yield data and other agronomic data (see Appendix 1).

Third, the adjustor made a very detailed study of a badly damaged field of beans and a badly damaged field of corn. These results were used to assess errors that might occur by inadequate field sampling or by analytical procedures.

The photographic study also had three phases. As soon as the hail damage area had been defined, a test to examine the requirements for resolving detail was made. Weather bad for photography delayed the test until July 21, ten days after the storm.

After the optimum film scale of 500 feet to an inch (photographed at 3500 feet altitude) was determined, flight lines were drawn across the storm area. In this second phase, the storm area was overflown on several different dates using the same flight paths to collect data to determine the optimum times for photography after the storm (see Appendix 2).

Finally, a flight to Western Illinois University's corn test plots for hail damage studies at Macomb was made to obtain photographs of the simulated-hail-damage plants. Table 5 lists information on the flight times and dates.

Description of Photographic Equipment

Two K-24 aerial cameras were used throughout the project. The aerial camera mounting in a Cessna 180 aircraft was adapted to enable the two cameras to be mounted together. This involved making a special mounting plate which held the cameras rigidly in position, back to back, and enabled adjustments to be made so that their fields of view coincided. The mounting base contained rubber damping blocks which prevented excessive vibration. The mounting plate could be swiveled to adjust for drift.

Several refinements were necessary to obtain photographic coverage. First, the rate of photography was too high for manual cranking of the cameras. Therefore,

Table 5. Photographic flight dates and associated photographic data.

			Ektachrome*		Ektachrome IR**		
Date	Time	Scale (ft/in)	Number of frames	f Stop	Number of frames	f Stop	Comments
			11 July 1969 hailstorm flight data				
7/21/69	1000	50	33	3	41	5.6	Scattered clouds at 1200" 60% cover
7/25/69	0945	500	55	8	55	11	No haze
		500	43	11	43	16	No haze
7/26/69	1005	250	48	8	48	11	Moderate haze
8/ 4/69	1204	500	46	11	46	11	
			Macomb corn test plots at Western Illinois University				
7/29/69	1200	500	9	8	9	11	10% cloud cover in area
		500	4	11	4	16	
		250	4	5.6	4	8	
		250	13	8	13	11	

Note: Shutter speed 1/150th second throughout

* Used with factory supplied color correction filter

** Used with Wratten #12 filter, and factory supplied color correction filter.

the cameras were driven from the aircraft's 24-volt power supply, and the photographs were taken simultaneously at a rate controlled by an intervalometer. Secondly, the aircraft positioning had to be reasonably accurate, and the start and end points of the required photo coverage clearly seen. A drift sight with cross hairs was used to position the aircraft and to control picture taking.

The same film type and the same magazine **were** used on a particular camera throughout the entire experiment. The same shutter speed, 150th/sec, was used throughout. Blur was not apparent at the height (3500 feet) and ground speed (120 mph) used, and with this shutter speed the cameras could be used stopped down to f8 or f11 for better definition.

Scale Selection

The scale of photography (determined by total length of lens and the aircraft altitude) was selected according to the expected information content of the image and the size of the densitometer light spot used to take readings of the film density.

The information requirement was to detect the essential features of hail damage. It was not required to resolve individual plants, but the scale had to be sufficiently large so that small localized changes of damage intensity could be seen. It was also essential to have adequate information about the positions of the field adjustment points and the areas adjacent to them.

The selection of scale also depended on the densitometer spot size. The densitometer output is a function of the intensity of light passing through the image and the area of the image spot. Initial tests indicated that a spot size of about 0.15 inch would be satisfactory. Apart from the absolute spot size, the error due to incorrect positioning of the film relative to the spot has to be considered. The smaller the scale, the more significant a positioning error becomes.

Examination of the early flight data taken from several heights, and consideration of the analytical requirements, led to the choice of a scale of 500 feet per inch as optimum. This scale was used for the major part of the subsequent photography.

Film Storage, Handling, and Processing

Kodak Ektachrome Aero and Ektachrome Infrared 6.5-inch wide film on rolls were used throughout the project. Manufacturers' recommendations were followed closely and each roll was handled in the same manner to minimize any variability. The above film types were not in stock for K-24 cameras, and required special orders. Hence, each emulsion type was made at the same time, and was as nearly homogeneous as possible. Film was stored in an insulated cabinet at -18°C, and 24 hours before usage, the rolls were removed from storage and allowed to reach ambient temperature. Table 6 lists camera, filter, and development data.

After photography, the film rolls were unloaded, replaced in the original cans, and processed locally. Periods of exposure to heat and humidity during transit in hot weather were kept as short as possible. Processing was done in a Morse automatic rewinding tank using the Kodak E-3 process. Processing times were kept consistent, and temperatures were controlled to within 0.5°F of the mean of the particular range specified. Film was hung overnight to dry. Since both films required 1.5 fallons of processing solution, three 1-gallon packs were made up at one time for the processing of two rolls. Fresh solutions were used for each roll of film.

In the type of tank used, streaking of the film was a problem. This occurred at the ends of the rolls , and was thought to be the result of chemicals seeping down the film coils at the rewind spool centers. However, the bulk of the film was not affected. Initial "once-through" winding by hand was tried, together with gentle tensioning of the film on the spools, and this reduced the problem. Even after doing this, about 5 feet of leader was required.

Table 6. Photographic equipment data sheet.

Camera data

K-24 cameras

Lens focal length - 7.0"

Film width - 6.5"

Frame size - 5 x 5"

Filter data

Camera

Ektachrome Infrared -
Color correction* + Wratten #12

Ektachrome Aero -
Color correction"

Densitometer

Kodak Wratten #92 (Red)

Kodak Wratten #5 8 (Green)

"Color correction filters
supplied by manufacturers

Development data

Morse rewind tank. Rewind time 43 secs.

Kodak E-3 process, fresh chemicals each roll.

Densitometer spot size

Hailstorm of 7/11/69 —— 0.15-inch diameter

Macomb Corn Test Plots —— 0.05-inch diameter

Analytical Equipment

The desired facility for analyzing the film data had to be capable of measuring film density changes at several different wavelengths with reasonable accuracy and reliability. A densitometer appeared to be the desired type of equipment for this job. An investigation was made with a view to using a commercial machine. Several densitometers were located on the University of Illinois campus, but because of heavy work loads it was not possible to allocate one for our use. Therefore, a partially developed densitometer available at the Survey had to be employed.

The basic system (Fig. 10) consisted of a microscope adapted to hold a light source and a duodiode. A film table carried the transparency between two plates of glass. The table could be moved horizontally in both directions to locate the densitometer spot over a given point. The duodiode could be adjusted in the vertical direction, and the lens could be moved relative to the duodiode. Filters could be placed in position over the lens.

The light source was a single filament tungsten 6-volt bulb. The bulb was mounted in an aluminum tube containing frosted glass plates to diffuse the source. A microscope objective was used to provide a light beam. This assembly could be moved in a vertical direction by a rack and pinion gear, changing the objective position relative to the film plane.

Several combinations of equipment were tried before the required level of accuracy and repeatability of performance were obtained. The major problems encountered were dc drift and fluctuating light output. In the final system developed, the light source was supplied by a power pack, and the duodiode was biased by a square wave from a function generator. The output was picked off as a voltage across the duodiode, and displayed on a calibrated oscilloscope.

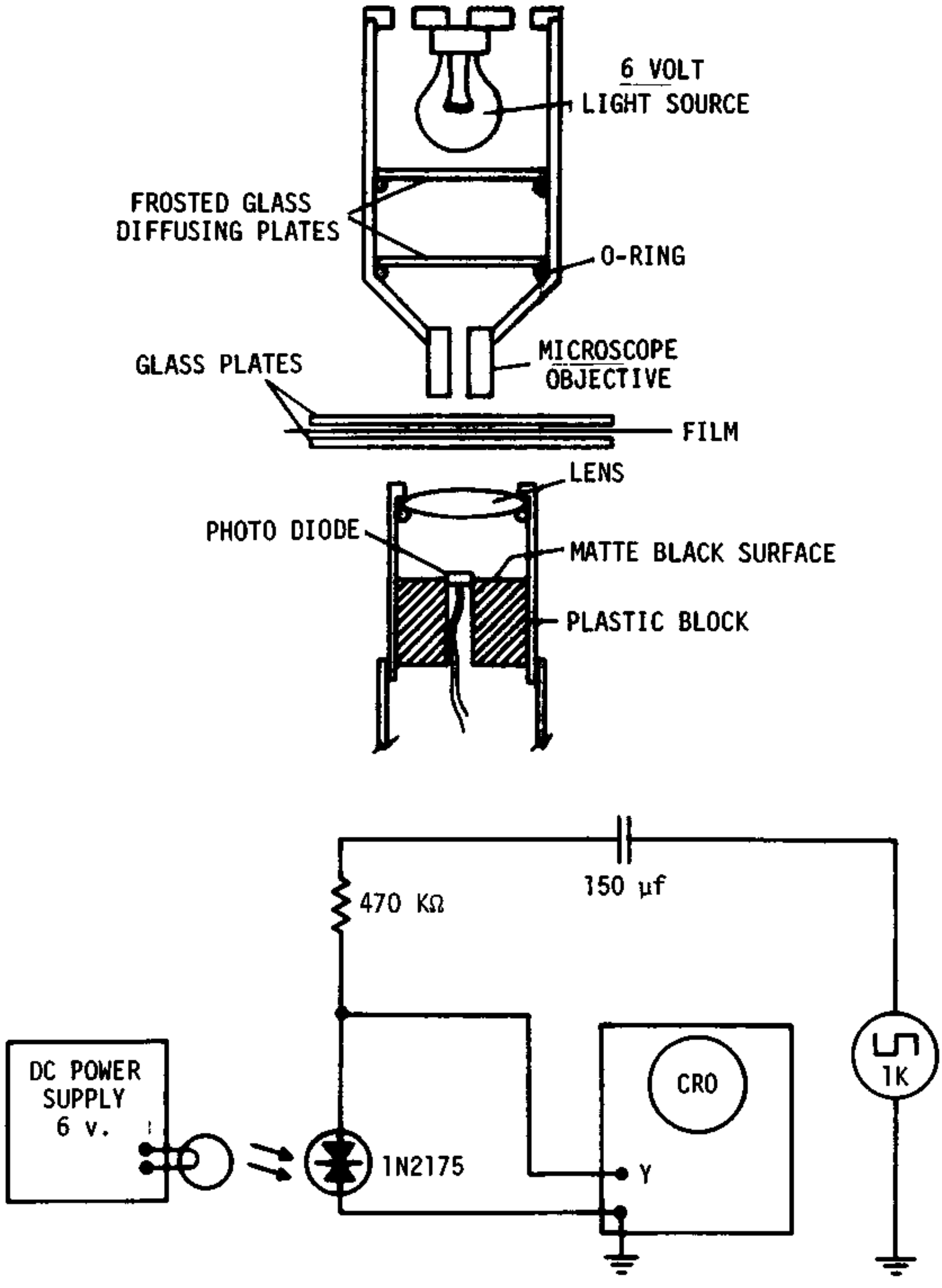

Figure 10. Diagram of the final densitometer system and circuitry

Adjustments to the optical system were made by trial and error to obtain maximum output. With each spot size tested, there was an optimum set of adjustments which gave maximum output. After these adjustments had been made, density step wedges were used to calibrate the output. A calibration curve for the 0.15-inch spot size is shown in Figure 11.

Another major problem was maintaining optical alignment. Thermal expansion of the supporting mount due to the light source became significant over periods of hours. Therefore, tests were not run over one hour duration. Accidental jolts were avoided, and when they did occur they were partially compensated for by repositioning the spot over the calibration density and resetting the oscilloscope. Figure 12 is an example of work done in the initial stages of development. An electrometer and an X-Y plotter were used at this time, together with a synchronous motor, to drive the film table. Such work did not give repeatable results and was finally abandoned in favor of the system described above.

RESULTS OF PHOTOGRAPHIC STUDY OF 11 JULY HAILSTORM

Preflight Photographic Tests

Preparation for aerial photography was carried out several weeks before the studied storm occurred. This preparation included tests of the camera drives, and test runs to determine 1) the approximate exposure level and 2) the best means of using the test chart.

Exposure levels were determined by photographing agricultural test plots containing corn and soybeans from a height of 50 feet. Exposures were made in full sun with occasional scattered clouds at 1000 CDT, the expected optimum

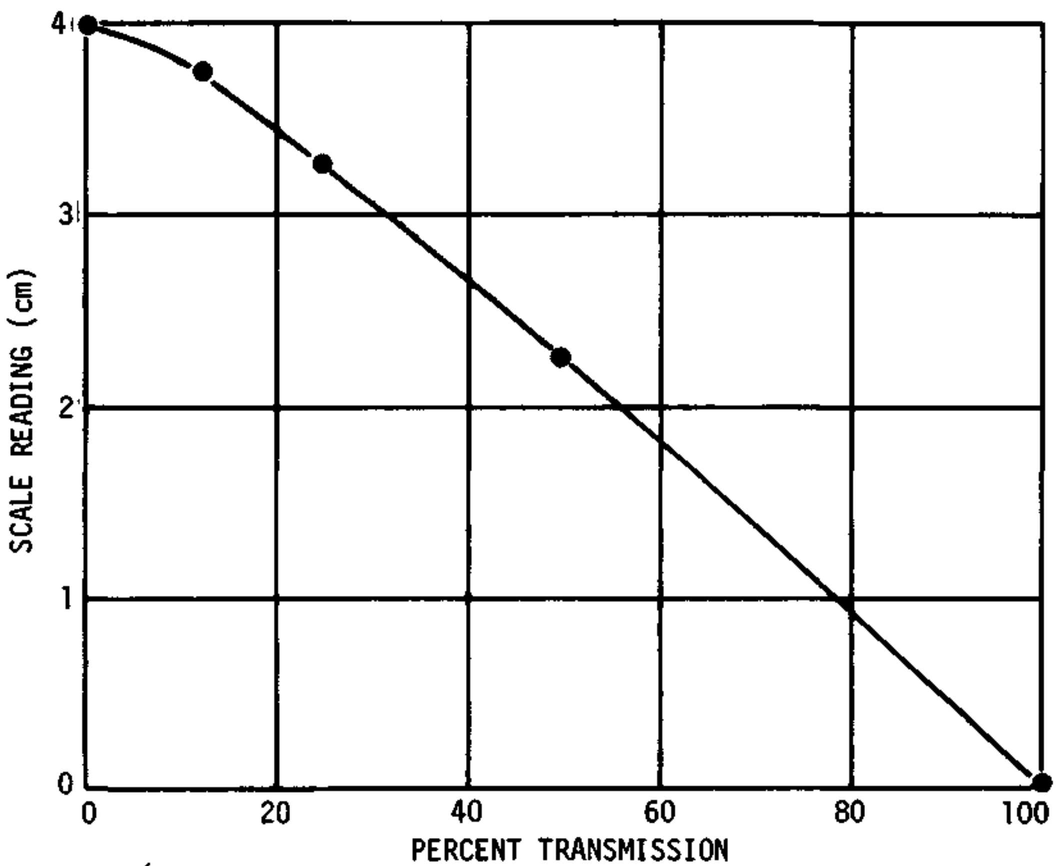

Figure 11. Calibration curve of percent transmission against scale reading, without filters, for 0.15-inch spot size

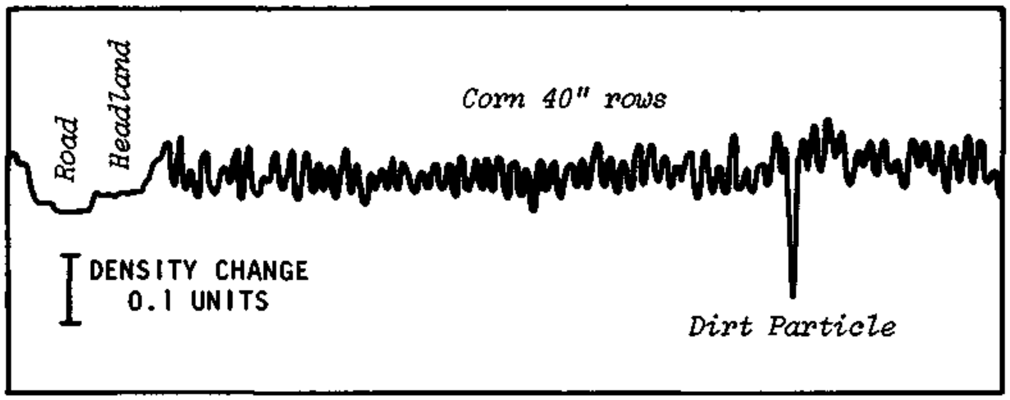

Figure 12. Densitometer trace from ektachrome infrared film at right angles to corn rows

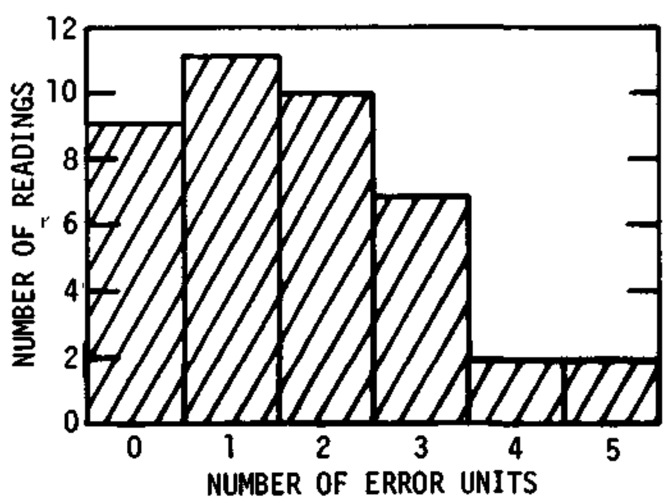

Figure 13. Histogram of the number of readings with a given number of error units from the stereoscopic study of Macomb Test Plots

time for photography over a storm area. Very little detail could be seen in cloud shadow areas on the infrared film. Because of the high image density, no information could be extracted from these areas. Thus, an appreciable amount of cloud cover would prevent successful photography.

Initial Studies of Storm Area

After the hailstorm on 11 July (Fig. 3) was chosen for study, the area was examined on the ground in the following week to define the storm boundaries, but photographic scale tests were delayed until 21 July by bad weather. Photographic missions and data collection were then done periodically on three subsequent days (Table 5). The detailed field studies of the damaged crops were begun on 21 July to match the common practice of starting adjustments at least 10 days after a storm. The film transparencies were examined visually over a light table. Several rolls of film taken on the different dates were mounted side by side for detailed comparisons. The Infrared Ektachrome and Ektachrome Aero film data were compared for the same flight and between the different flights.

Areas of damage were visible as areas of different hue and saturation. The damage areas were generally somewhat circular in shape, and varied in diameter up to a maximum of about 300 feet. Several of these appear in the center of Figure 2. All the photographic data were examined for changes in tone texture and pattern. Regions of special interest were inspected with a stereoscope, and some areas were traced with a pantograph for further study.

Examinations of these areas were made using tracings of the transparencies and these showed that damage areas were quite visible in aerial photographs. Damage was not evenly distributed from field to field, or even within individual fields (Figs. 1, 2, 5, and 7). Much of the variation was thought to be due to associated wind vortices which affected localized areas. In addition, crops on slightly higher ground, especially those on a small hill crest, showed more damage than those in surrounding lower areas. Damage caused the amount of plant cover to be reduced, and a larger area of soil was visible between the rows. This caused a color change in the Ektachrome Aero photographs in the damaged patches.

Densitometer Studies

Some tests were run using a synchronous motor to drive the film table. Figure 12 shows an example of densitometer output displayed on an X-Y plotter. Corn rows were readily visible. Some of the literature reviewed shows that useful information could be obtained from the shape and height of the trace. However, work in this potentially interesting area had to be discontinued as instrumentation was not available. The alternative approach of sampling density at various points was adapted.

Two fields, one of badly damaged corn (Fig. 5) and the other of soybeans (Fig. 7), were selected for a detailed study of losses. The losses at the many measurement points in each field were plotted against the film density values obtained using the densitometer with various filters. Figures 14 and 15 show examples of the results obtained. For corn, the three scattergrams for the Infrared film show a better relationship between crop damage and film data than those based on the Aero film. This was a consistent trend throughout the analysis of the data. Correlation coefficients for the infrared data were generally 0.6, and do not seem to be greatly affected by any particular filter. There also seems to be little relationship in the data below 30% loss, indicating no change in image density with increasing damage in the 10-30% range.

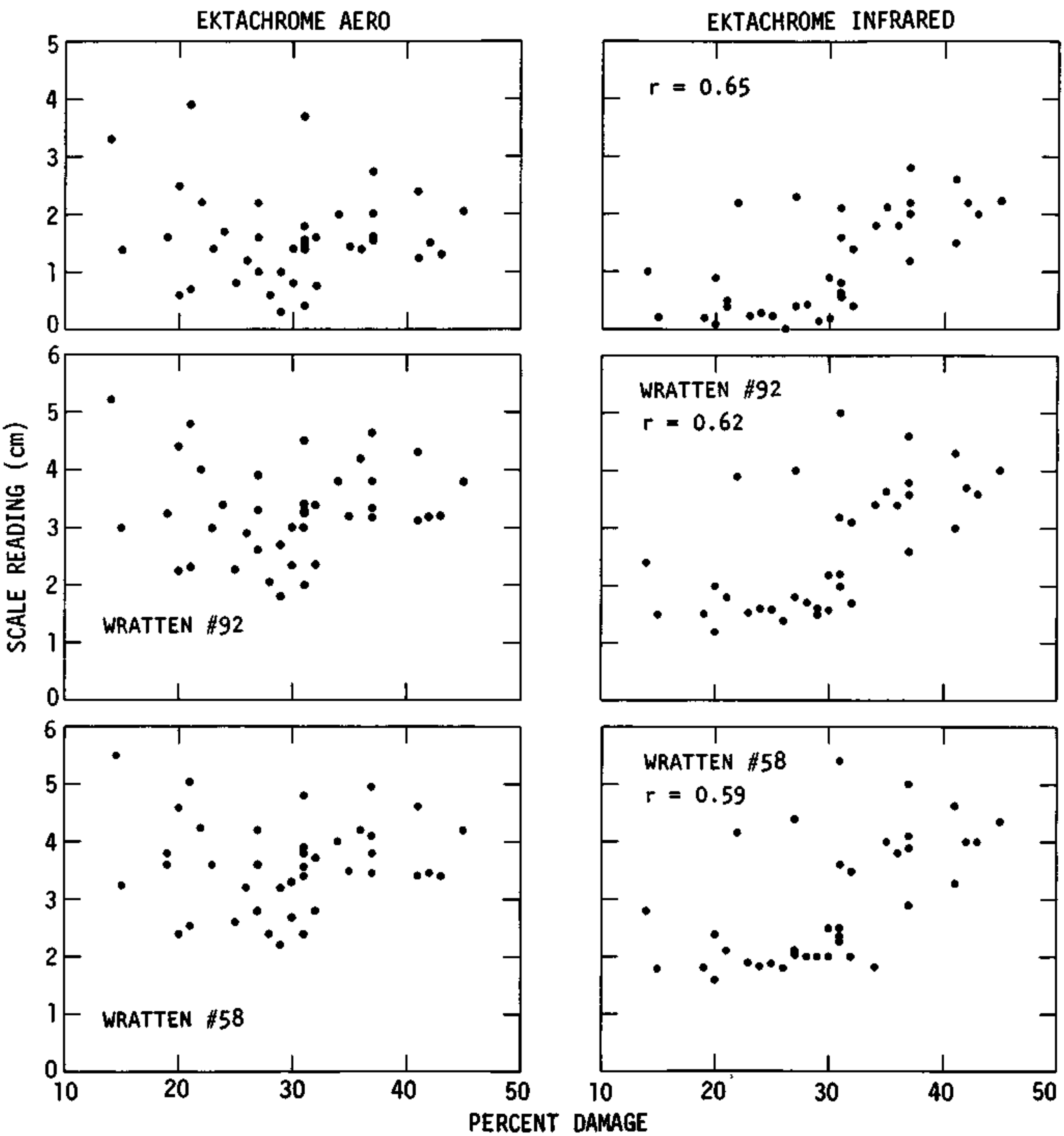

Figure 14. Corn special study area, percent damage plotted against scale reading (density) in centimeters

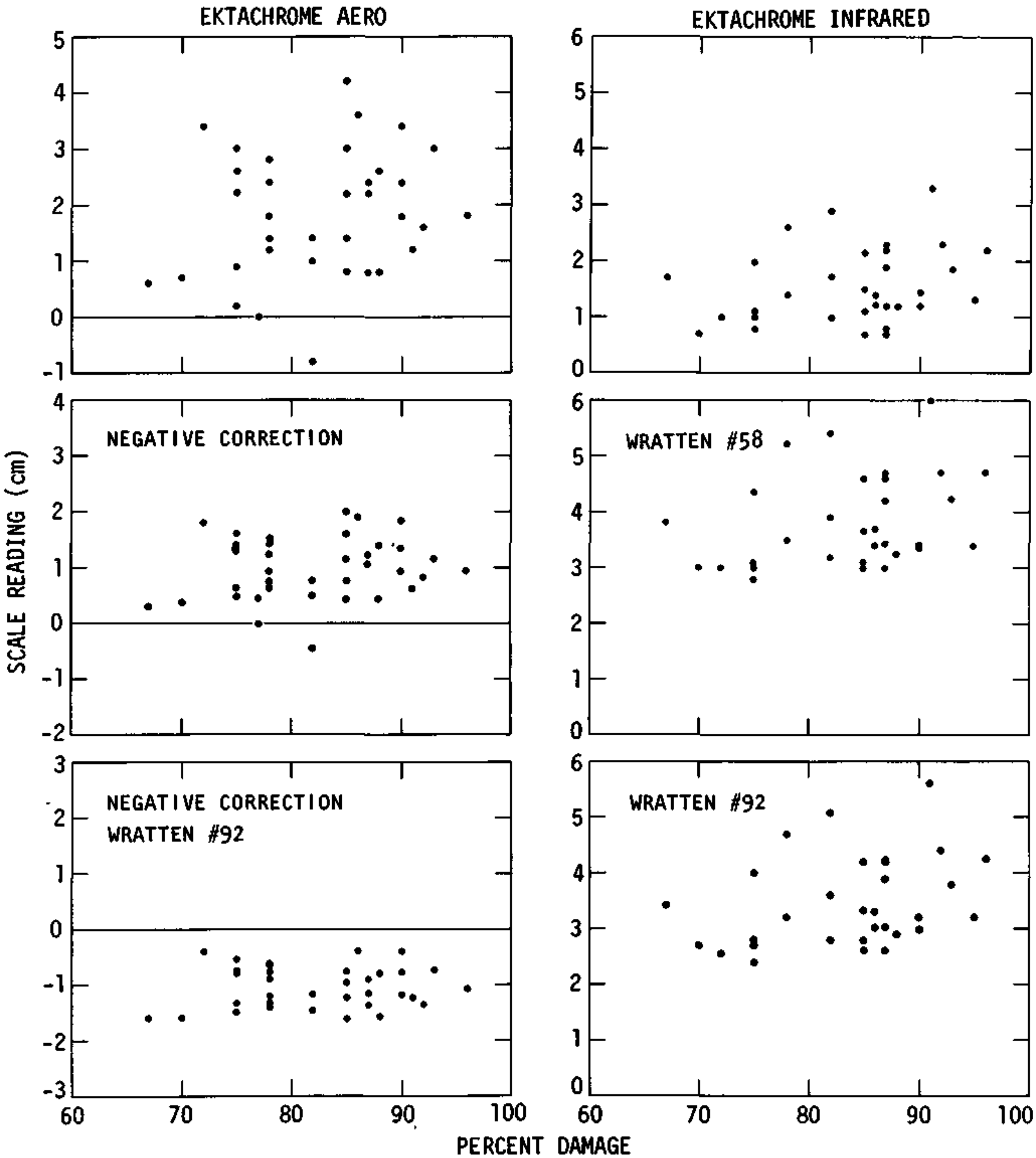

Figure 15. Bean special study area, percent damage plotted against scale reading (density) in centimeters

Soybean damages in the storm (Fig. 6) were higher than those to corn (Fig. 4). In the bean studies the percentage of soil visible between the rows was greater than expected. Densitometer spot readings showed the infrared reflectance from the soil was also higher than expected, and interferred with the density measurement of plant reflectance. In an attempt to remove the effect of this factor, a correction factor was developed. First, areas of bare soil in a damaged field were located on film and their density measured. Secondly, the density in undamaged bean fields was measured. A straight line relation was assumed to exist between these two points, one at 0% cover and the other at 100% cover. For each density reading, the contribution due to soil was subtracted from the total reading. This technique did not produce much improvement, and this was partly due to difficulty in estimating percentage crop cover from the image. The soybean loss and film density values (Fig. 15) for infrared showed a slight relationship, but the results were not as good as those for corn.

Previous Aerial Photography

In addition to hail damage, factors such as soil fertility and soil moisture influence crop cover. Black and white aerial photographs of the storm area taken in October 1966 were examined. Tonal variations were small in most areas. However, there were localized areas, particularly on slopes where tonal variation was noticeable, probably due to changes in soil type. On the basis of this study it was concluded that such tonal variations were not great enough to mask the effect of hail damage.

Discussion of Results

Visual examination of the photographs, together with the ground checks, yielded several important results. First, it was found that crop areas with severe hail damage could be ascertained by scanning aerial photographs. Damaged areas showed a definite mottled pattern apparently as a result of interactions between hail and wind during the hailstorm.

Secondly, results from visual analyses indicated that there was no particular advantage in the use of Ektachrome Infrared film for visual damage detection. However, any possible physiological changes caused by hail were largely obscured by plant recovery during the ten days that elapsed before photography began. In addition, infrared imagery is not commonly available, and presents some difficulties in interpretation.

The damage in several fields was assessed further in a subjective manner using visual inspection of the aero film data. The plot of field average losses from the final yields and those from this subjective method (Fig. 16) revealed that film inspection was at least comparable with the adjustor's predicted yield reduction (Fig. 8). However, the Y axes of these two figures are calculated on slightly different bases. While one of these measures may be marginally preferable, they are not significantly different. Because of good plant recovery, the soybean damage estimates, Figure 16, were generally greater than the actual damage. From inspection of Figure 16, it appears that if film data were to be used to assess damage, an adjustment could be applied which would take into account the recovery occurring in any particular season.

The densitometer studies showed that for machine interpretation of film data, the Ektachrome Infrared was preferable to Ektachrome Aero. Plots of film density against percent corn damage for Ektachrome Infrared showed correlations of about 0.6 for various filters. However, these plots indicated that for the lower damage range, density did not change with varying damage.

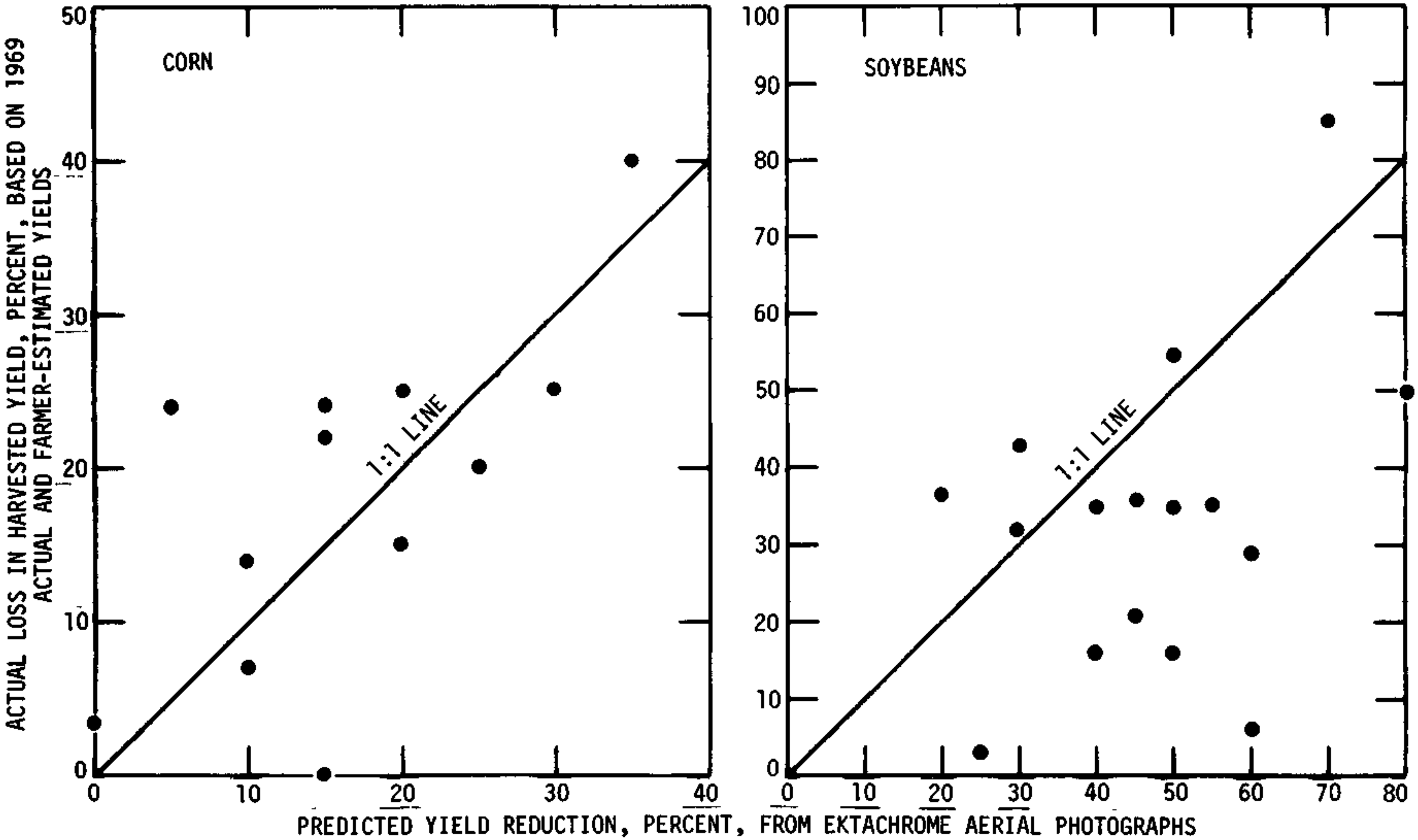

Figure 16. Comparison of predicted yield reductions from aerial photographs with actual yield reductions computed using farmer's yield estimates and actual yields on an individual field basis

Conclusions

Areas with relatively severe crop-hail damages could be delineated by visual inspection of the Ektachrome film. It appears likely that an experienced photo interpreter, with perhaps a short ground inspection of the area, could assess quantitatively the losses in hail damaged areas with an accuracy comparable to that derived from field adjustments. A photographic record of a damaged area has the important advantage that small areal variations in damage can be taken into account, and it is available for further inspection at later dates. Stereo viewing would enable ridges where damages tend to be most severe to be identified.

Densitometer studies indicate that a relationship between corn damage and image density exists in the infrared film. Further work would be required before this method could be assessed as a practical technique. Other causes of variation present in the damage area may be confused with hail damage, particularly in the low damage areas.

Unfortunately, no matter how accurately a particular damage adjustment method is at the time hail occurs, it cannot predict the degree of plant recovery. Some adjustment for post-storm recovery could be made at harvest time to allow for this. It is believed that this attempt to control variables may not be justified in view of the many biological variables involved in the total process. However, it is concluded that visual damage assessment from film taken at storm time is a practical proposition.

PHOTOGRAPHIC STUDY OF MACOMB CORN TEST PLOTS

Introduction

Simulated hail damage plots at Macomb, Illinois, were photographed on 29 July 1969 to compare the film density and visual observations with the data from controlled ground conditions. These simulated damage plots, managed by Western Illinois University, were subjected to systematic defoliation and stand reduction occurring at the various growth stages indicated in Table 7. A given percent defoliation was accomplished by snipping off that percentage of the leaf area from each leaf on the plant. Stand reduction was carried out by removing whole plants and thus reducing the population. These two treatments were applied at different growth stages, as shown in Table 7. Treatments were applied to 760 plots arranged in 40 rows and 19 columns.

Table 7. Treatments applied to corn test plots at various stages.

Class	Treatments applied	Class	Defoliation	Leaf stage
1	0% stand reduction	1	0% defoliation	6 leaf stage
2	10% stand reduction	2	50% defoliation	10 leaf stage
3	25% stand reduction	3	75% defoliation	14 leaf stage
4	50% stand reduction	4	100% defoliation	85% tassel
5	75% stand reduction			B blister
				M milk
				S soft dough

Results

Aerial photography was obtained at several scales and exposure levels; details of the flight are shown in Table 5. Both Ektachrome Aero and Ektrachrome Infrared were used (Fig. 1). Photography was performed in a manner identical to that for the 11 July hailstorm project.

Several pictures were selected for analysis on the densitometer and visually by use of a stereoscope. The infrared film was selected for the density measurements using a spot size of 0.05 inch. This choice of film was made after an examination of the 11 July results which indicated that the infrared film and a Wratten #58 green filter in the densitometer optical system might be a good combination. The optical density of each plot was measured without filters and with the Wratten #58. The study was limited to a single plant population, 20,000 plants per acre.

The results were used to examine the relationship between film density and stand reduction, defoliation, yield, and stand reduction combined with defoliation. Scattergrams were plotted to investigate the above relationships using different colors for each growth stage. A comparison of the results for all stages, and those for between stages, showed that no clear relationships existed between density and any of the other parameters, except possibly defoliation. Theoretically, treatments applied to later growth stages, such as the 85% tassel and the 14 leaf stage, should show the strongest relationships. However, Figure 17 shows there was no relationship between defoliation and image density for these two growth stages. Unfortunately, data were insufficient to allow another variable to be held constant. If this had been the case, both stage and stand reduction levels could have been held constant, and defoliation plotted against film density.

The Ektachrome Aero film data at a scale of 250 ft/inch were selected for a stereoscopic study. Five classes of stand reduction and four classes of defoliation for the various plots were defined and labeled in Table 7. Stand reduction and defoliation for each plot were then visually (film) rated in percent and converted to the nearest class. These classes were compared with the actual stand reduction and defoliation classes. Table 8 shows that the comparison of the two classes was made by summing the number of errors made. "For example, if the actual defoliation was class 2, and it was visually assessed

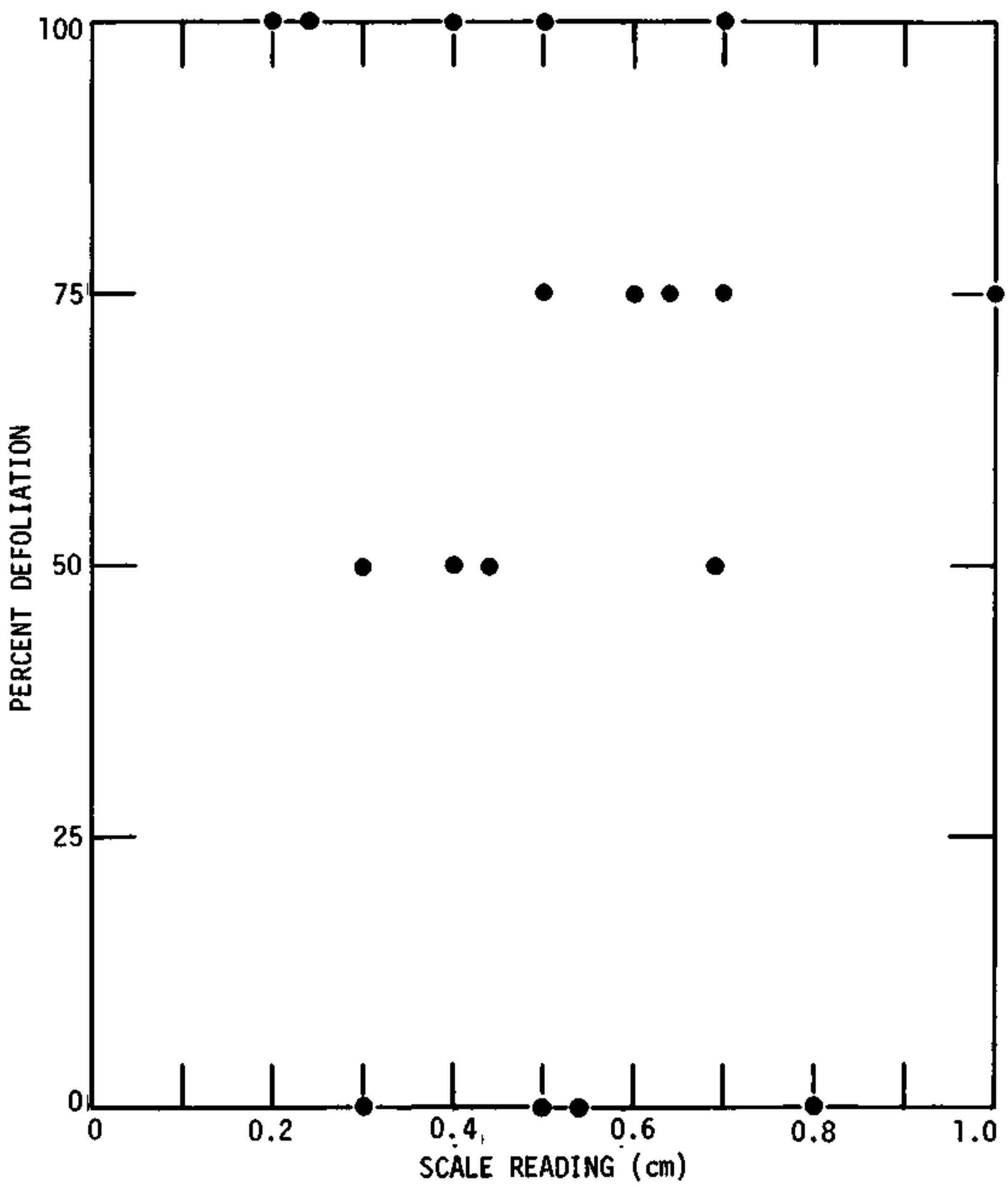

Figure 17. Comparison of scale reading (film density) and defoliation for the 14-leaf and 85%-tassel growth stages. Data from simulated hail damage corn test plots at Macomb.

Table 8. Comparison of the actual classes of stand reduction and defoliation at Macomb with those estimated from stereoscopic interpretation of the Ektachrome Aero photographs.

Test plot number	Plot location Row	Plot location Column	Class of stand reduction Estimate	Class of stand reduction Actual	Class of defoliation Estimate	Class of defoliation Actual	Error per plot SR	Error per plot D	Error per plot SUM	Comments
1	37	15	3	4	3	3	1	0	1	
2	37	13	2	2	1	0	0	-1	1	
3	38	8	4	4	3	0	0	-3	3	
4	38	10	3	3	2	2	0	0	0	
5	35	9	4	4	1	1	0	0	0	
6	34	14	4	4	3	3	0	0	0	
7	33	10	3	4	0	1	1	1	2	
8	32	5	0	0	1	0	0	-1	1	Control
9	31	15	3	2	0	3	-1	3	4	
10	30	12	3	3	2	2	0	0	0	
11	30	13	3	3	1	1	0	0	0	
12	30	5	4	4	0	0	0	0	0	
13	29	14	2	1	3	3	-1	0	1	
14	29	15	1	1	0	2	0	2	2	
15	29	16	1	0	0	0	1	0	1	Control
16	28	13	4	4	3	3	0	0	0	
17	28	14	3	2	1	3	-1	2	3	
18	27	3	2	1	0	0	-1	0	1	
19	23	13	4	3	2	3	-1	1	2	
20	23	15	4	4	1	2	0	1	1	
21	21	12	3	3	1	3	0	2	2	
22	21	7	3	4	2	1	1	-1	2	
23	21	2	2	3	1	0	1	-1	2	
24	22	4	1	4	2	0	3	-2	5	6 leaf stage
25	22	8	3	2	1	2	-1	1	2	
26	20	9	3	4	2	0	1	-2	3	
27	20	14	4	2	3	3	2	0	2	85% tassel
28	19	4	4	4	1	0	0	-1	1	
29	19	5	1	2	0	0	1	0	1	
30	19	6	0	0	0	0	0	0	0	
31	19	7	4	0	2	3	-4	1	5	85% tassel
32	19	8	3	4	2	3	1	1	2	
33	19	9	0	1	0	3	1	3	4	
34	19	11	3	2	3	1	-1	-2	3	
35	18	4	3	3	3	0	0	-3	3	
36	18	8	3	3	2	2	0	0	0	
37	18	12	0	0	0	3	0	3	3	
38	17	14	4	3	2	3	-1	1	2	
39	17	15	1	1	1	0	0	1	1	
40	17	4	3	4	2	0	1	-2	3	
41	32	11	3	4	1	1	1	0	1	

at 3, the error would be +1. Stand reduction was treated similarly. Table 8 shows the error involved in making each estimate. The standard deviation of the error distributions for stand reduction was 1.1 and that for defoliation was 1.17. The frequency distribution of the error sums is shown in Figure 13. The maximum possible error sum for any plot would be 9, but 30 of the 42 error sums were 2 or less and the largest was 5 for 2 plots.

Discussion of Results

The results did not show clear relationships between film density and yield, stand reduction, or stand reduction plus defoliation. However, there was some indication that defoliation varied with film density when treatments were applied in the later stages of plant growth. This seemed to be logical as the effect of defoliation (applied to every leaf of every plant) would be to diminish the leaf area. The effect of stand reduction was thought to be small, due to the leaves from surrounding plants spreading in to fill the vacant volume. Both effects would diminish with plant recovery and the generation of new leaves.

Visual rating of stand reduction plus defoliation was more successful than expected. Estimates of the error involved in determining from aerial photographs percentages of stand reduction and defoliation made at all growth stages showed that stand reduction could be estimated with reasonable accuracy, ± 15%. The error involved in estimating defoliation was greater with 50% of the observations having an error less than ± 25%. It was thought that defoliation estimates could be improved if observations were limited to measurements at the later growth stages.

While the experimental techniques may simulate hail damage adequately for yield studies, it is questionable whether they represent a true field situation for photography. Any relationships derived for these experimental conditions would have to be applied with care to real hail damage situations.

Conclusions

The densitometer study of the film data of the corn-test plots at Macomb showed that no strong relationship existed between optical density of the infrared emulsion and corn crop parameters. The densitometer study of actual damaged corn showed a much better relationship. Thus, a recommendation for any future studies would be to investigate the effects of simulated damage on plant physiology.

The visual study of the Macomb test plot photographs showed some promise for the aerial identification of stand reduction and defoliation by photo interpretation. These results suggest that the degree of damage on simulated hail damage plots could be identified with reasonable accuracy for corn in its later growth stages. It is possible that the same accuracy could be achieved for earlier growth stages if the elapsed time between treatment and photography was reduced.

EVALUATION OF ADJUSTING TECHNIQUES AND FARM PRACTICES

The detailed study of losses in 48 fields damaged by the 11 July hailstorm brought forth certain interesting observations relating to various factors that affected loss assessment. These factors were grouped according to those involving adjusting techniques and those involving farm practices.

Adjusting Techniques

Effect of number of adjustment sites in the fields. This storm, as in all hailstorms, tended to distribute the hail in such a manner that the point-to-point variance in resulting crop damage was considerable. Not only was the difference in distribution of damage in the total hail area considerable, but the variance of damage in individual fields was remarkably greater in some areas of a field than in others (Figs. 5 and 7). This suggests that adjustors need to make systematic samplings of various areas of damaged fields to avoid making serious errors in adjustments. For example, an 80-acre bean field had a loss of 18% in its northwest corner and one of 82% in its southeast corner. It is not difficult to visualize what would happen if an adjustor, in haste, would have examined only a certain section of the field and based his percentage of payment on that area for the entire field.

It appears, after this detailed study of all the fields in the 6-square-mile study area, that almost all 48 fields required a systematic sampling of loss. At least a count in each corner and one in the center of each field was essential if a final loss average, fair both to a farmer and an insurance company, was to be determined. However, in some fields of extreme damage, more than the above number of samplings would have been necessary to guarantee an accurate adjustment.

Changes in loss estimation due to adjusting at different times after the storm. An original impression gained after first viewing and adjusting the damaged corn 10 to 15 days after the storm was that the damage to the plants (and yield loss) would result from loss of leaf area and damage to the stalk. Since the ears had not yet appeared on the plants, it seemed impossible that they would be affected when they emerged. However, some of the early-planted corn, that was just beginning to tassel at the time of the storm, did show some minor ear damage by 22 to 24 days after the storm.

Apparently the small shoot of the ear contained in the area between the stalk and the junction of the leaf had been struck by a hailstone. This resulted in the rupturing and breaking of the leaf surface that surrounds the young ear shoot. The breaking of the leaf in this area permitted the ear, when it emerged, to come through the leaf sheaf instead of emerging in the normal manner. The emerging ear had a half-moon shape because it was tied in the leaves and actually emerged through the stone-struck area of the leaf sheaf that surrounded the stalk. Furthermore, these "banana" shaped ears were producing no kernels on the underneath side of the curl. The above-mentioned problem would produce a reduction in yield due to the ears' inability to produce the normal number of kernels. This kind of phenomenon was not widely evident, but the amount was sufficient to affect the degree of loss, and this change with time is something for adjustors to be aware of. Such later undesirable conditions were largely responsible for losses in the harvested yields being greater than the predicted losses from the detailed study.

Another observation made during the later period of study (20 to 25 days after the storm) was the alarming amount of smut which had infested the early-planted corn plants. This smut was not evident in the fields 10 to 15 days after the hailstorm. Close examination of the plants indicated that the cancerous-like smut growths appeared where the plants had been struck by a large hailstone. This smut has to be attributed to the injury that the plant had suffered at the time of the hail. Several corn fields outside the hailstorm area were examined and other farmers in the area were contacted concerning the smut, and no evidence was found of any infestation of smut in these non-damaged fields.

<u>Effects of unknown factors and future events on adjustment</u>. One of the most serious types of damage sustained by both the soybeans and corn throughout the storm area was bruising on the stem of the beans and on the stalk of the corn. At the time of the detailed field study, practically all of the corn and

the vast majority of the beans affected were still standing. The unknown factor and question was, "How many of these seriously bruised plants would break over before harvest time?" The principal factor that might cause such breakage would be the weather between the time of adjustment and harvest. If the plants stood, they would produce some beans and about average ears of corn. However, if another thunderstorm with heavy rain and high winds had occurred in this area there would have been considerable breakage at the bruise points.

Certainly no one was able to predict the weather conditions from adjustment to harvest. The adjustor and farmer can arrange for a deferred adjustment until the extent of damage can be determined. In this study the badly bruised plants were counted as being non-producers at harvest time. However, there was no severe weather after the storm to bring further losses, and this explains the tendency of the predicted losses from the detailed study to be greater than the losses actually found in the harvested beans (Fig. 8).

Technology Factors

Effect of row direction on the amount of damage and adjustment in soybeans. An observation derived from this storm study was the difference in the amount of damage sustained by the soybeans that were planted in north-south rows as opposed to those planted in east-west rows. The 11 July hailfall and associated winds came from the WNW resulting in more measurable loss to the rows planted north-south. The wind which accompanied the storm was more perpendicular to the north-south rows and laid these plants flat to expose the stems. This allowed very serious bruising. The bean plants planted in east-west rows tended to pile up on each other, offering protection to the other plants, and in particular the damage to the bean stems was less than in the north-south rows. An adjustor should be aware of this and a simple explanation to the farmer will generally be readily understood.

Effect of variety of beans on difference of ultimate loss. Another interesting observation derived from this storm study was the ability of certain soybean varieties to withstand more hail and to recover better from hail. This storm offered an excellent opportunity to observe and compare the ability of two major bean varieties to withstand damaging hail. These two varieties, which are new and rather comparable, were found planted in two adjacent 40-acre fields that were in the very center of the storm and were the most damaged of the fields in the storm area (see Fig. 6, section 28).

Quick observation of both fields indicated a considerable difference between them. The first type was not as badly defoliated nor as cut down as the other. There were far fewer dead plants in the first type than in the second. The bruising in the first type was not as severe as in the second, and the first-type plants were scabbing over and healing while the second ones seemed to be rotting and breaking. The damage to the second variety was 25 to 30% greater than the damage to the first.

This points up the necessity of the adjustor being familiar with major plant varieties and their differences. Knowledge of how hail damage affects different varieties and how varieties withstand and recover from the effects of hail appears essential.

CONCLUSIONS AND RECOMMENDATIONS

Visual assessment of hail damage by inspection of Ektachrome Aero photographs over a light table showed that both damage in the field and simulated hail damage could be estimated with reasonable accuracy. The use of a stereoscope is recommended as it enables a more rapid and accurate assessment of crop and topographic conditions. The photographic and in-field studies of the 11 July hailstorm both consisted of a high density of samplings of point loss in the storm damage area. Both data sources revealed that damage was unevenly distributed, and the photographic data indicated that badly damaged areas generally took the form of patches somewhat circular in shape and about 200 to 300 feet across. This was thought to be due to the variability of hail and associated wind vortices. Damage was particularly severe in exposed areas and on ridges.

The quantitative assessment of damage by visual inspection of the film data required some knowledge of the damage occurring in the area so that some particular level of loss could be used as a reference value when evaluating the other damage levels. In any future applications of the visual film approach, there would be a slight advantage in using normal color film, as opposed to infrared color film which gives a false color rendition (Fig. 2), because photogrammetrists are generally more familiar with normal color type of image. Some zero damage areas would have to be included so that the general variability of soil type and patchy crop growth due to causes other than hail can be allowed for.

Densitometer measurements using different filters in the system were used to compare film density at various field points with the actual in-field loss adjustments made at these points. The results of these studies showed that while some relationship may exist, especially for corn, more research needs to be done before this method of machine analysis of film data becomes a practical proposition. However, the loss values determined from the film density values predicted the actual harvested losses (Fig. 16) as well as did the best (detailed) adjustor values (Fig. 8). Obviously, plant recovery after hail damage was a very important influence on the amount of loss as reflected in final crop yield. No method other than deferred adjustment is presently available to make allowance for it, and the best that a field adjustor or a photogrammetrist can do with field data taken shortly after the storm is to make value judgments on conditions as they exist at the time of the field inspection or aerial photography.

This very detailed crop-loss study of a 6-square-mile area that experienced a typical crop-damaging hailstorm has provided various interesting results in addition to those regarding the detection and quantification of loss with aerial surveying techniques. Detailed measurement of the crop loss, based on an adjustment for every five acres in 48 fields, provided several interesting results concerning the proper density of loss adjustments per field, problems in adjusting techniques, the variability of loss, and the problems in adjusting related to farm practices.

Comparisons of field average losses, as determined from the very detailed measurements versus those from normal adjusting frequencies per field and against those from actual adjustments (paid claims), revealed that the latter two provided averages that differed by ± 18%, on the average, from the detailed loss value and were frequently larger than the detailed loss. Thus, it would appear that normal adjusting techniques of sampling may not be adequate for obtaining a good measure of loss for a field. Field average losses as derived using loss measurements in the center and four corners of a field gave quite good estimates of the average losses determined from the detailed (1 point per 5 acres) measurements. The excessive variability of loss across most fields apparently leads to considerable error of estimating the average field loss if too few points of measurement are employed.

The comparisons of the detailed (predicted) field average losses with those derived from the final harvested yields indicated a rather poor prediction of final loss, particularly for the hail-reduced corn yields. The predicted corn losses were generally underestimates of the final losses. The predicted yield losses (from the detailed field assessments) for soybeans more closely approximated the final harvested losses than did those for corn, but the predicted bean losses of 40% or more were largely overestimates of the final loss. These results clearly illustrate that even when detailed, skilled adjustments of crop-hail losses were made for each field, they did not relate well to the final losses in harvested corn or soybeans.

Farming practices noted to have a significant effect on the amount of damage, and thus loss assessment, included the orientation of the rows of soybeans with respect to the wind direction during hail and the soybean variety. Certain varieties appeared to withstand hail damage better than others, and beans planted in rows perpendicular to the wind-hail suffered much more damage than those in rows parallel to the wind.

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Appendix 1. Data sheet for detailed field adjusting studies.

Use this sheet for each separate UNIT, e.g., 40-acre field.

UNIT #______________Farm____________

Variety: __________________ Purpose: feed or seed ⧄ ⧄

Seed:

Rate: ________________ lbs/acre ____________ ⧄ ⧄ ⧄

Density (1000 plants/acre): ________________ ⧄ ⧄ ⧄

Row spacing: ___________ ft. _______________ ⧄ ⧄ ⧄

Row direction: ______________________________ ⧄ ⧄ ⧄

Dates (month, day):

Planting: ___________________________________ ⧄ ⧄ ⧄

Heading: ____________________________________ ⧄ ⧄ ⧄

Maturation: _________________________________ ⧄ ⧄ ⧄

Harvest (approx.): __________________________ ⧄ ⧄ ⧄

Present stage: ______________________________ ⧄ ⧄ ⧄

Yield (approx.):

lbs/acre: ___________________________________ ⧄ ⧄ ⧄ ⧄

Field treatments:

Fertilizer, amount/dates (approx.): __________

Spraying, amount/dates (approx.): ____________

Average crop height: ft. _______ inches _________ ⧄ ⧄ ⧄

Greater than 1-ft height variation: ⧄no, ⧄yes ⧄

Probable cause: Soil: _______________________ ⧄

Fertilizer: too much/too little ⧄

Spraying: too much/too little ⧄

Planting: too late/stand too thin ⧄

Weeds: ⧄no, ⧄yes: ___________________________ ⧄

Percent of ground area: ______________________ ⧄

Species: ____________________________________ ⧄

Significant effect on yield: ⧄no, ⧄yes ⧄

Appendix 2. Flight record data sheet.

HAIL FLIGHT RECORD

Date ______________________ Location ______________________

1. Cloud coverage:

   ▱ Clear ▱ Misty ▱ Ground haze

   ▱ Heavy haze ▱ Partly cloudy ▱ Overcast

2. Cloud shadows in survey area:

   ▱ No ▱ Yes (Approx. % ground covered, ____%)

3. Wind:

   ▱ Direction ▱ Velocity ▱ Gusty

4. Air turbulence:

   ▱ None ▱ Light ▱ Medium ▱ Heavy

5. Ground temperature, approximately: ____°F.

6. Hail damage visible:

   ▱ No ▱ Not easily ▱ Readily (patches, streaks)

7.

Run #	Altitude ____ft	Cloud base ____ft
Camera data	Color IR	Aerial Ektachrome
Stop		
Speed		
Filter		
Starting frame	No. Time	
End of run frame	No. Time	

8. Is leaf movement in the wind visible?

   ▱ No ▱ Yes

9. Comments: