Quantification of Crop-Hail Losses by Aerial Photography

STANLEY A. CHANGNON, JR., AND N. A. BARRON

Illinois State Water Survey, Urbana

(Manuscript received 30 June 1970, in revised form 29 September 1970)

ABSTRACT

Experiments designed to evaluate the potential of infrared (IR) color and standard color aerial photographs to measure crop-hail losses were performed. Detailed post-storm field measurements of loss (by standard adjusting techniques) and actual harvested yields (control data) were used for comparisons. Studies were made from a damaging hailstorm and from simulated hail damage on corn test plots.

Stereoscopic analysis of standard color film provided estimates of average field loss for corn and soybeans that were better than those derived from the "best" field adjusting that involved detailed sampling of 1 point per 5 acres. Badly damaged areas had unique "signatures" on the photographs consisting of semi-circular areas of loss that suggest a hail-wind related series of vortices of 100–500 ft in diameter.

Measurements of IR film density for the simulated hail-damaged corn at the 14-leaf and later growth stages also showed a good relationship with the amount of harvested corn loss, but a weaker relationship existed at the 10-leaf stage (at hailstorm time and in the simulated fields), and none was apparent at the 6-leaf stage. The IR film density values for storm-damaged soybeans did not relate well to actual harvested losses. Corn-hail losses $\leqslant 30\%$ per field at the 9- to 11-leaf stage were poorly ascertained by standard point assessment, stereoscopic analysis, and the IR film density technique. In this loss range, the IR photographs may have been taken too late after the storm or the physiological damage insufficient to be sensed in the infrared range. On standard color film, the stand reduction was too slight to be detected stereoscopically. Since the standard assessment method provided poor estimates of corn and bean losses when they were in the 1–30% range, either the causes for such low loss are not understood or succeeding weather conditions greatly alter the apparent loss at assessment time. If the latter is true, early season hail losses should be assessed at harvest. The very dense measurements of loss revealed amazing spatial variability in loss per field. Also, these dense measurements predicted final harvested field losses better and provided generally lower estimated losses than those obtained by insurance adjustors with their sampling methods.

1. Introduction

One of the major weather-related industries in the United States is the crop-hail insurance business. For the past 10 years, the average annual crop value insured has been $2,889.1 million (15% of the total annual national crop production), the annual average premium income was $111.1 million, and the annual paid losses were $68.2 million (Jones, 1969).

A very important phase of the crop-hail insurance business system is the field measurement of hail loss, and its cost and accuracy are of continuing concern both to those insured and to the insurance companies (Brown, 1967). Traditionally, these assessments are performed by an adjustor who has been trained to assess loss to various crops. Studies involving artificial simulation of hail damage to various crops at different growth stages have provided detailed guidelines that the adjustor refers to as he physically examines a damaged crop (Camery and Weber, 1953; Hella and Stoa, 1964), 2–4 weeks after the loss. A field assessment usually consists of the adjustor walking through a potentially damaged field and choosing 2–5 locations, depending on the field size and severity of loss, where he measures the loss. Normally, for a grain crop, 100 plants are carefully examined at each "location" or point to ascertain how many plants are a total loss, the degree of defoliation, and the amount of stem bruising. For other crops, such as fruit, the loss of quality is important and bruising is measured. These values are then interpreted and shown as a percent loss with respect to the expected value or yield (normally the farm average of the past 5 years), and the quantification of loss for a given insured field is the average of these point measurements. Such an assessment of loss in all but the mature growth stage of a crop is a prediction of the reduction in the final yield. As such, this field loss value can be accepted as final at the time of adjustment, or it can be deferred by the adjustor (company) or by the farmer until harvest time to allow for any major uncertainties of either party.

Obviously, the cost of performing this phase of the crop-hail insurance business is high, and non-random inaccuracies could result in large financial losses to the companies or the insured. The use of crop-damage data as a measure for evaluating hail suppression experiments also depends on accurate loss assessment (Schickedanz and Changnon, 1970). The need for accuracy in any economic or scientific data makes other means of assessing accuracy worth consideration, and remote sensing techniques offer possible alternative means of assessing crop-hail damage. These techniques also would permit study of crop-hail losses in uninsured areas.

Remote sensing of hail-damaged crops was initially investigated with standard black-and-white film. This technique was found unsatisfactory unless the photographs were taken at such a low level as to make the total photography of a singe hailstorm loss area economically prohibitive (Changnon, 1969). However, recent usage of infrared (IR) camouflage detection color film to measure the amount of crop damage due to diseases in potatoes (Manzer and Cooper, 1967) and in beans (Philpott and Wallen, 1969) suggested the possibility that color film, and particularly IR color film, would record information that could be used to measure the amount of crop damages from hail. IR color film measures the reflected radiation which has been shown to change with physiological changes in a crop. When a crop is diseased, its reflectance properties are registered as different film densities and different colors. Thus, healthy plants are depicted on IR color film in a bright red, whereas totally dead plants and inert materials are depicted as green.

Experiments to evaluate the potential of IR color film and standard Ektachrome Aero color film to measure crop-hail losses were performed in Illinois during 1969. The possible use of IR color film to detect and quantify the variations in crop-hail damage separately or in conjunction with Aero color film was based on the assumptions that hail damage produces varying physiological changes or stress in plants, and that these induced changes are related to final yield reductions and appear in reflected radiation registered on the film.

A Cessna-180 aircraft was outfitted with two vertically pointing K-24 aerial cameras, one for the IR film and the other for the Aero film. Photographs with both films were taken simultaneously to provide more easily interpreted information.

One experiment was based on photographic data collected for a severely damaged crop area in central Illinois and another was made on test plots in western Illinois where hail damage to corn had been simulated. Aerial photographs were taken at different heights to determine the best height for measurement. They were made also on different days after the hailstorm to match the usual period when adjustors assess losses. The Aero color film was analyzed primarily by standard stereoscopic techniques, and the IR color film by densitometer measurements of film density. The resulting film values for each field and plot were evaluated against the yield reduction measured in the harvested yields. Further, the film values for the actual damaged fields were compared with values of loss obtained by very detailed (1 sampling point per 5 acres) measurements collected by a skilled adjustor.

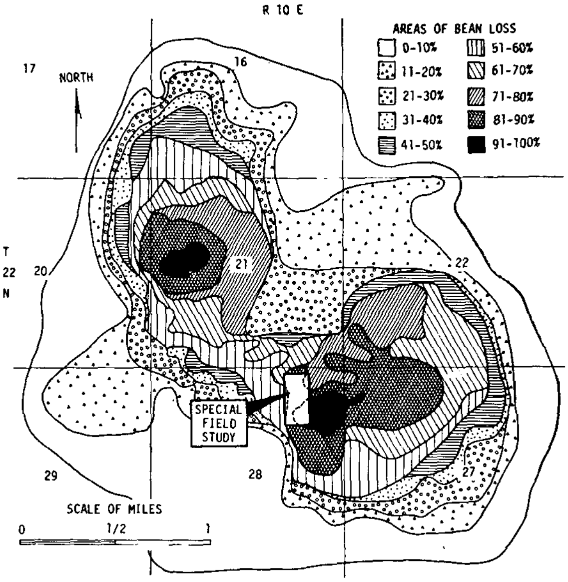


Fig. 1. Soybean loss pattern for 11 July 1969 hailstorm, with loss defined by 198 surface assessments.

This paper describes the types and methods of data collection, the analytical techniques employed with special reference to the film equipment and theoretical considerations, and the results of the experiment as shown by comparative analyses of the hailstorm data and those from the corn test plots.

2. Types of data and methods of collection

a. Surface hailstorm data

The hail-damage area chosen for study resulted from a hailstorm in central Illinois on 11 July 1969. A 2-day field survey outlined a 6-mi^2 study area with crop damage. Hailfall durations at most locations in the damage area varied from 3–12 min, and most observers reported high winds with the hailfall, but maximum winds measured 5 mi away were 28 mph. Hailstone sizes varied from $\frac{1}{4}$ to 1 inch in diameter, but stones did not cover the ground at any point.

Detailed field investigations were made of 22 damaged corn fields, ranging in size from 20–60 acres. The total corn area consisted of 703 acres in which 163 separate adjustments were made (1 point per 4 acres). The maximum point loss assessed was 48%. Similar investigations were made of 26 damaged soybean fields, ranging from 10–95 acres. The extent of the surveyed area was 960 acres with 198 point adjustments, or 1 for every 5 acres of loss. Normal loss adjusting is based on 1 point per 10–20 acres. Thus, the detailed surface adjusting was accomplished in 48 fields incorporating 1663 acres. This work began on 22 July and was completed in 17 days.

The percent loss pattern of beans for the entire studied storm area, as based on the 198 data points, is depicted in Fig. 1. Its overall shape was not unlike

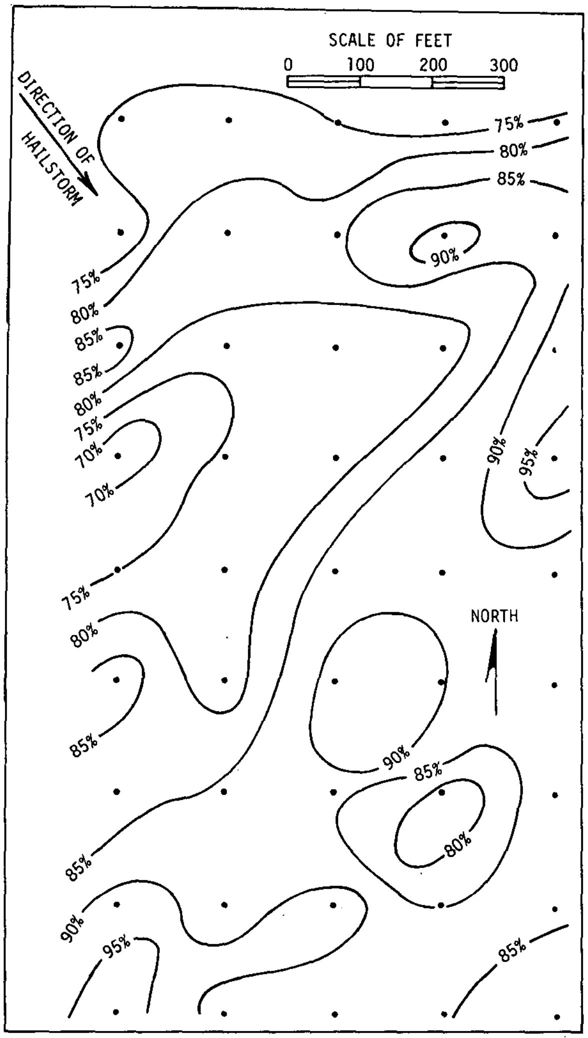


FIG. 2. Detailed loss pattern in 20-acre soybean field from hail on 11 July 1969, as based on surface assessments of loss at 45 locations.

that obtained for corn, but corn 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 damaged. These 9–11 leaves were 10%–70% defoliated, depending on their location in the storm. However, since a normal corn plant produces 16 leaves, the plants had a potential after the storm of producing 5–7 new leaves to feed themselves and to produce the desired ear. Defoliation was not the principal type of damage to soybeans. The principal damage resulted from stem bruising, from cut-off plants (that partially recovered within 30 days after the storm), and from plants that were completely killed by the hail.

The soybean point losses ranged from 1–97%. One badly damaged 20-acre soybean field in section 28 (Fig. 1) was chosen for a special intensive loss study. Measurements were made at 45 points, each spaced 150 ft apart; these produced the highly variable loss pattern shown in Fig. 2. Losses ranged from a low of 68% in the western edge to a high of 97% at a point 750 ft south; the field average was 83.1%.

In observing the bean losses, it was quite evident that the rows planted north-south were more severely damaged than those planted east-west. During the entire duration of the storm, high westerly winds associated with the hail tended to lay the north-south planted stems and stalks over flat on the ground, exposing the entire stem, and making them more open targets for the hailstones. However, in the east-west planted fields, where the wind direction was parallel to the rows, the plants were blown over in such a way that they tended to shield each other. Also, notable differences in degree of soybean losses were noted between varieties.

b. Simulated hail damage plot data

Simulated hail damage to corn plants was performed in 1969 by agronomists on experimental plots located at Western Illinois University at Macomb. These simulated damage plots had been subjected to systematic defoliation in four classes (0, 50, 75 and 100%) and stand reductions in five classes (0, 10, 25, 50 and 75%) at each of seven major growth stages (6 leaf, 10 leaf, 14 leaf, 85% tassel, blister, milk, and soft dough). A given percent defoliation was accomplished by cutting off that percentage of the leaf area from each leaf on the plant, and stand reduction was carried out by removing whole plants to reduce the population. Treatments were applied to most of 760 plots arranged in 40 rows and 19 columns covering 6 acres. The plots were harvested in November 1969, and the yield of each was expressed as a percent of those from untreated control plots within the array of 760.

c. Aerial photographic data

The optimum time for crop-hail damage photography was unknown at the start of the experiment. After a hailfall, damaged plant tissues should die and significantly affect the spectral reflectance properties of the plant. In planning the experiment it was decided that such an effect would be most apparent 7–10 days after hail damage and before new growth effectively covered over damaged tissues. This period also matched the general times of loss assessment used by insurance adjustors. Because of adverse weather conditions (rain, low clouds, and/or excessive haze), photographic missions of the hailstorm area could not be accomplished until 21 July, 10 days after the storm. Other missions were flown on 25 and 26 July and on 4 August.

On each mission over the hailstorm area the aircraft flew a series of east-west parallel tracks across the major axis of the damage pattern (Fig. 1). All of the damaged crop areas as well as the no-damage areas surrounding the storm were photographed, the photographs being taken simultaneously at a rate controlled by an intervalometer. The same film type, magazine and shutter speed (150th of a second) were used on each camera throughout the experiment. Blur was not apparent at test heights of 1000–3500 ft and at a ground speed of 120 mph.

The optimum photographic scale for damage detection was also unknown at the start of the experiment. The scale should be as small as possible, compatible with the degree of detail and resolution required, to keep the cost of photography and analysis to a minimum. The scale of photography (determined by total length of lens and the aircraft altitude) was selected according to the information content of the image and the size of the densitometer light spot used to take readings of the film density. Photographs collected on the first data flight on 21 July at the 1000- and 3500-ft levels revealed the 3500-ft data to be preferable. This provided a scale of 500 ft inch^{-1}, and all subsequent film data were collected at this scale.

Exposure levels were determined prior to the storm by photographing agricultural test plots containing corn and soybeans from a height of 50 ft. This and all project photography was done during full-sun conditions.

Storage, handling and processing of IR color film is very critical. Manufacturers' recommendations were followed closely and each roll was handled in the same manner to minimize any variability. Film was stored in an insulated cabinet at −18C, and 24 hours before usage the rolls were removed and allowed to reach ambient temperature. After photography, the film rolls were unloaded and immediately processed in a special local laboratory.

A photographic mission over the corn test plots at Macomb was made on 29 July. Photographic techniques, scales and exposures were identical to those used to collect the hailstorm data.

d. Crop-yield data

The photographic data and the detailed field data for the hailstorm on 11 July were compared with the losses calculated from actual yields reported by storm-area farmers after harvesting in October–November 1969. These actual losses or reductions in yield were determined by comparing the harvest yield with the average of the non-damaged fields at farms in the area immediately surrounding the hailstorm damage area.

Final harvested corn yields were obtained for 12 of the 22 carefully studied corn fields and compared with the average yield (110 bushels per acre) from eight farms in the surrounding area. Final harvested soybean yields were obtained for 16 of the soybean fields that had been studied in great detail. These reduced yields were expressed as a percent of the area average (41 bushels per acre) calculated from the yields of eight nearby farms not affected by the storm.

3. Analytical techniques and instrumentation

The surface loss assessments for each location in a given field were averaged. These were compared with the field losses as determined from the actual harvested yields. These percentages of loss in actual yields also were compared with field values obtained from stereoscopic interpretations of the film data.

Initially, the film transparencies were viewed over a light table to search for changes in tone texture and pattern. Regions of special interest on both film types were inspected with a stereoscope, and possible damage areas were outlined for further field study. Areas visible as having different hues and saturations on the film were found to have moderate to severe damage, as identified in the field. These regions of different hues and saturations resulted from totally destroyed plants and from major defoliation by hail. Therefore, all these regions in each field were mapped and then planimetered. The combined areal extent of these regions was expressed as a percent of the total field size and this percentage was used as an expression of yield reduction.

The use of IR film to detect hail-damaged crops hinged on the possible physiological effects of hail on plants. Studies of the spectral reflectance characteristics of plant leaves (Myers and Allen, 1968; Purdue Laboratory, 1968) indicated that the reflectance signature changed when plants were subjected to stress. Details concerning the considerations developed for the spectral reflectances of hail-damaged plants and their relationship to IR film characteristics, the resulting choice of densitometer system and filters, and the techniques used to evaluate natural variations in incident radiation on each flight mission are presented elsewhere (Barron *et al.*, 1970).

The densitometer analysis consisted of measuring the density of both the IR and the Aero color films at points in fields where an assessment of loss had been made. Much of this analysis was performed using the detailed loss data collected in an intensively studied corn field and soybean field (Fig. 2).

Infrared films taken on the different dates were compared to study temporal changes. The IR and Aero film data for the same flights were compared using their density values and stereoscopic interpretational results.

4. Results for the 11 July hailstorm

a. Surface measurements

The detailed field measurements of loss by the adjustor in 22 corn fields and 26 soybean fields indicated great variability of assessed crop loss across short distances. The maximum loss in each of the 48 fields was at least 100% greater than the lowest loss value in the fields, and in 29 fields the maximum was more than 300% greater than the lowest value. Figs. 1 and 2 also reveal this excessive degree of spatial variability in loss, as determined from normal adjusting tech-

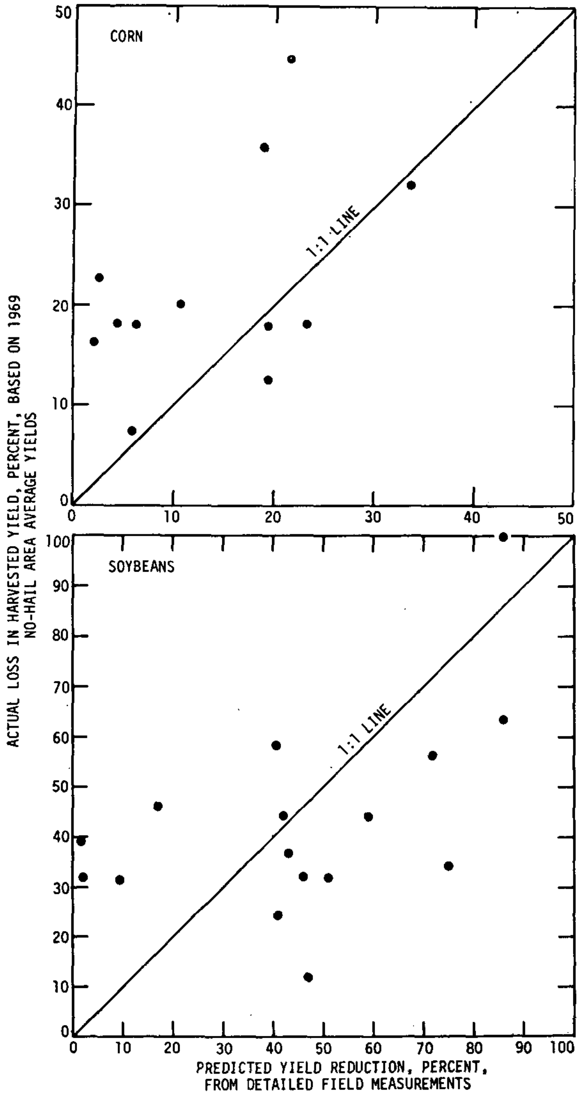


FIG. 3. Comparison of predicted yield reductions from detailed field assessments with actual yield reductions computed using no-hail area average yields.

niques except for a much greater density of point measurements.

Assessments of loss to settle actual insurance company claims were performed by insurance adjustors in 7 of the 26 soybean fields studied in detail. The field average loss values from both sources are presented in Table 1, and these reveal that the company values exceeded the detailed, and presumably more correct, loss values in 6 of the 7 fields. Results for similar corn field comparisons (Barron *et al.*, 1970) also indicated higher loss values in the claims settled by the insurance company adjustors. Such differences may result because the typical company adjustor samples too few locations per field; has a tendency to use too many sampling locations in the higher loss portions of the field; or makes an upward readjustment of loss to satisfy the insured.

The scattergrams of Fig. 3 are based on a comparison of the predicted yield reduction or loss from the detailed field studies with the actual loss as measured in the harvested yields. These were based on data from 12 corn fields and 16 soybean fields where harvested yield data were secured. The considerable dispersion of the points around the 1:1 line indicates the poor agreement between the best surface predictions and the actual loss. The six predictions of corn loss that were under 15% were all underestimates of loss and only four predicted losses were greater than the actual loss. Conversely, the soybean predicted losses from the detailed field measurements largely overestimated the actual losses. Nine of the 12 predicted losses $\geqslant 40\%$ were associated with actual losses lower than predicted. However, as with corn, the lower predicted losses ($\leqslant 20\%$) were all underestimates of actual loss. Correlation coefficients obtained for the data in Fig. 3 were 0.48 for the corn values and 0.51 for the soybean values.

b. Stereoscopic analysis

Detailed stereoscopic analysis of the Aero color photographs of the damaged fields showed that many damaged areas were visible. Damage caused the amount of plant cover to be reduced, and the larger area of soil visible between the rows caused changes in the hue and saturation of the photographs. Since other factors such as soil fertility and soil moisture influence crop cover, black and white aerial photographs of the storm area taken when no crops existed (October 1966) were compared with the color photographs. The soil-related tonal variations were not sufficiently great to be confused with the crop-soil tonal variations due to hail damage. Field checks of several film-determined damage areas also substantiated their reality.

Damage areas shown on the film were not evenly distributed from field to field, or even within individual fields. Tracings were made outlining the apparent damage areas in each field, and examples are shown

TABLE 1. Comparison of average field soybean losses from detailed field studies and from insurance company adjustor values of loss for paid claims.

Field size (acres)	Number of loss measurements from field study	Average loss from field study (%)	Insurance company loss value (%)	Difference, company minus detailed value (%)
20	5	43.0	80.0	+37.0
20	6	9.5	22.0	+12.5
80	18	75.3	80.0	+4.7
74	12	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

in Fig. 4. These tracings indicated that most damage areas were semi-circular with diameters ⩽500 ft. This suggests that the damaging hailfalls were closely associated with small-scale wind vortices 100 to 500 ft in diameter which tended to concentrate the hailstones in a series of swirls not unlike the shapes and sizes of the cycloidal suction marks noted to occur with tornadoes (Fujita and Bradbury, 1970). Aerial photographs of hail deposited on the ground by a South Dakota hailstorm also indicated maximum deposition in a series of swirls (Schleusener, 1966).

The sum of the damage areas in each field was expressed as a percent of the total field. For example, the total extent of the damage areas in the fields shown in Fig. 4 represented 41% of an 80-acre soybean field and 35% of a 40-acre corn field. The actual losses in the harvested yields for these two fields were 34 and 31%, respectively.

The predicted losses, as determined from this type of analysis of the 12 corn fields and 16 soybean fields where actual yield data were available, were compared with actual losses. The scattergram based on these comparisons (Fig. 5) reveals a reasonably good relationship for corn losses and a somewhat poorer one for soybeans. The correlation coefficient for the actual and predicted corn losses (Fig. 5) was 0.81, whereas that for the actual vs predicted losses, as obtained from the detailed measurements (Fig. 3), was 0.48, indicating corn losses predicted from the photographic data were better related to actual loss than were the losses predicted by detailed field measurements. The soybean loss predictions from film data had a correlation coefficient with actual losses of 0.65, whereas that for actual and predicted losses by detailed field measurements (Fig. 3) was 0.51. Thus, Aero film analysis was superior to the best, most detailed form of surface assessment for both corn and soybeans at their stages of growth. The stereoscopic analysis of the IR color photographs was more difficult and gave generally poorer results than those derived from the Aero color photographs.

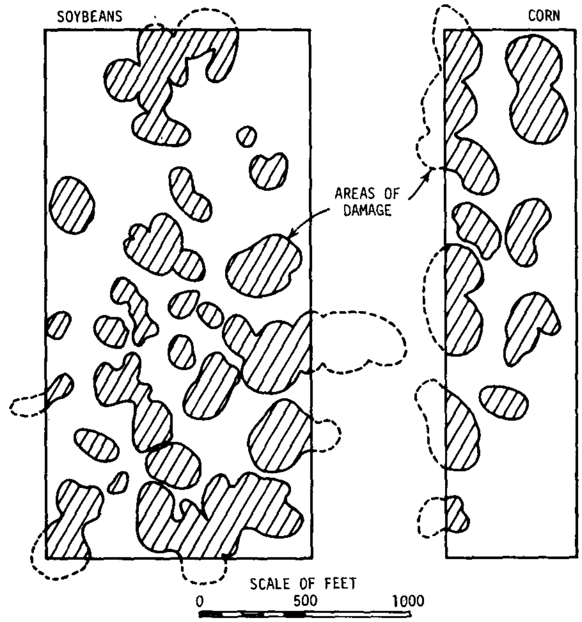


FIG. 4. Areas of crop-hail damage delineated for an 80-acre soybean field and a 40-acre corn field using stereoscopic analysis.

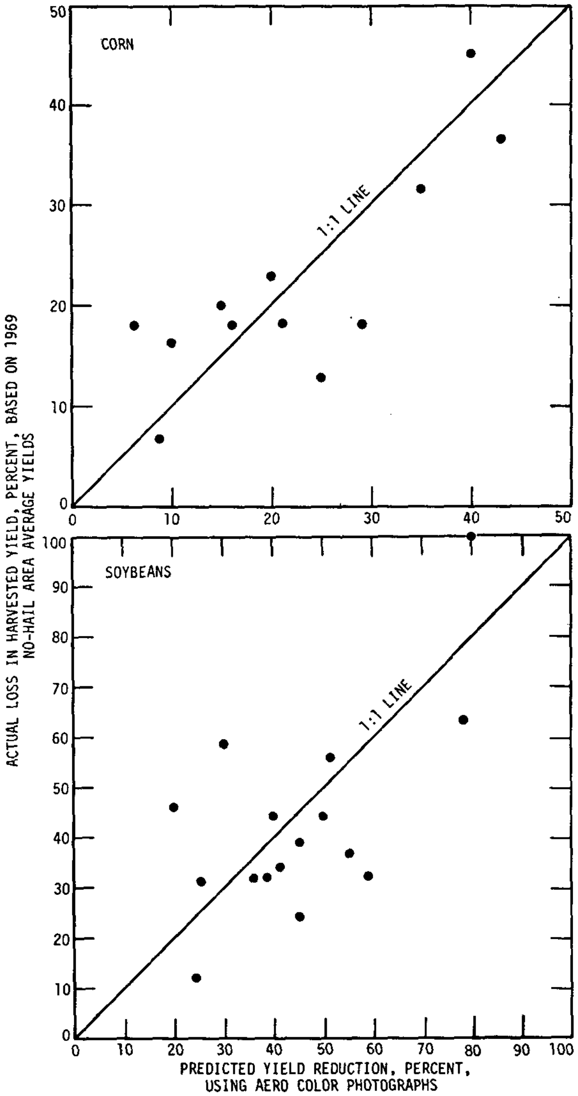


FIG. 5. Comparison of predicted yield reductions from stereoscopic analysis of Aero color photographs with actual yield reductions computed using no-hail area average yields.

c. Film density-loss analyses

The assessed losses at many measurement locations in corn and soybean fields were compared with the IR and Aero film density values for these locations. Densities were obtained using the densitometer without a filter as well as in conjunction with various filters.

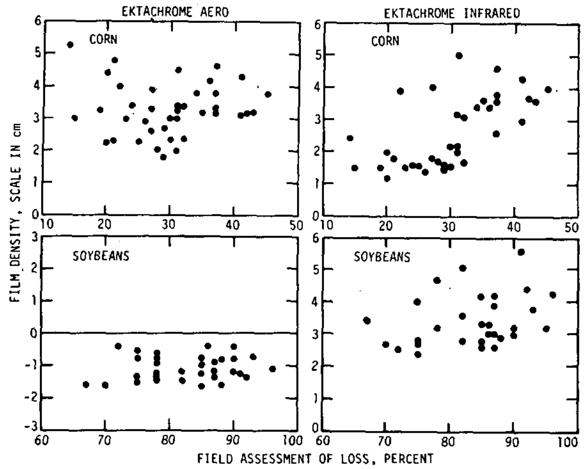


FIG. 6. Comparison of percent corn and soybean losses as assessed at field locations with IR film density values using red filter.

Infrared color film values showed a better relationship with corn loss values than did those based on the Aero color film. Furthermore, photographic data taken 10 days after the storm furnished better results than those obtained on the flights 14, 15 and 24 days after the storm. Correlation coefficients for the degrees of loss and IR values (from photographs 10 days after the storm) for different filters were generally 0.60–0.65, and were not markedly better for any particular filter. Scattergrams based on use of a red filter to analyze both film types at 40 locations of corn loss (Fig. 6) indicate that little relationship existed in the values below 30% loss with no change in image density with different losses in the 10–30% range. This was a consistent trend with all the filters used. This could be considered a failure in the film density method, although it might be a result of inaccuracies in the procedure of loss assessment for lower levels of damage, as revealed in Fig. 3.

Soybean damages in the storm were higher than those to corn, and the amount of soil visible between the soybean rows was greater than expected. The densitometer spot readings showed the infrared reflectance from the soil was also higher than expected and interfered with the density measurement of plant reflectance.

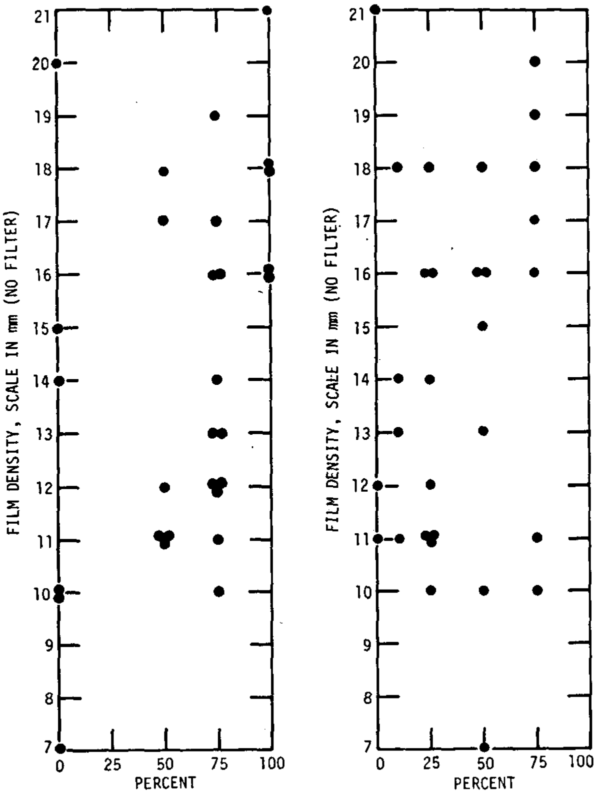
In an attempt to remove the effect of this factor, a correlation factor was developed. First, areas of bare soil in a damaged field were located on film and their density measured. Secondly, the density in undamaged bean fields was measured. A straight line relation was assumed to exist between these 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, and the soybean values shown on Fig. 6 have been so corrected. This technique did not produce much improvement, due partly to the difficulty in estimating percentage crop cover from the image. The soybean losses and density values from the IR film for 32 locations (Fig. 6) showed a slight relationship, but the results were not as good as those for corn. The Aero color density values exhibited no relationship with the field loss assessments.

Since the average field losses from the detailed measurements were not good estimates of the actual loss determined from harvested yields, the weak relationship between assessed losses at discrete field locations and the IR film density values is not necessarily indicative of a failure of the IR density method. Unfortunately, the crops at these discrete locations in each field could not be harvested separately so a completely valid test of the IR film density approach for assessing crop-hail damage could not be realized for the 11 July hailstorm. However, the analytical problems and poor results for the soybean data indicate that the film density analytical approach may not be any better than the approach involving stereoscopic analysis of Aero color film.

5. Results for simulated corn-hail damage plots

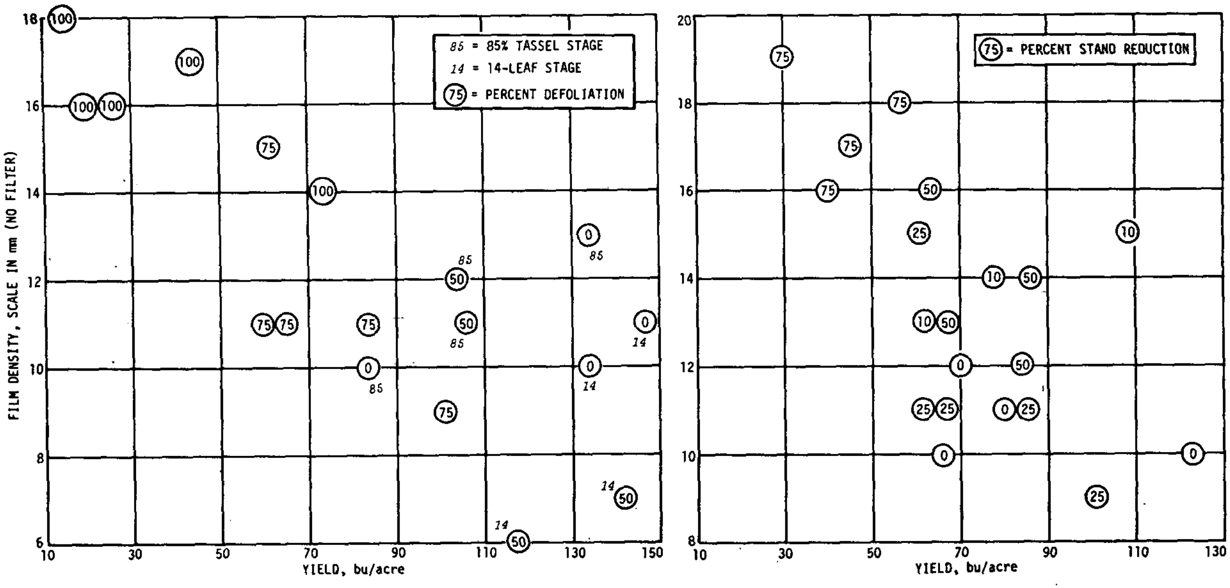
a. Stereoscopic analyses

The Aero and IR color photographs of the simulated corn-hail damage plots were analyzed stereoscopically.



a. Defoliation b. Stand reduction

FIG. 7. Scattergrams of IR color film density values (no filter) associated with different defoliation and stand reduction levels, as applied during the 85% tassel stage to 20,000 plants acre^{-1} population at simulated hail damage plots.



a. Varying defoliation (percent) with 25% stand reduction

b. Varying stand reduction (percent) with 75% defoliation

FIG. 8. Relationship of plot yields and IR color film density values (no filter) for varying defoliation levels (at constant stand), a., and for varying stand reduction levels (at constant defoliation), b., as based on treatments at the 14-leaf and 85% stages to 20,000 plants acre^{-1} populations.

As with the 11 July hailstorm, the results from the IR film data were not as good as those from the Aero color film; the Aero color film data taken at a scale of 250 ft inch^{-1} were found to furnish the best results. The stereoscopic analyses of the plot data consisted of estimating the stand reduction as one of the five possible classes and defoliation as one of the four possible classes employed. Such estimates were accomplished for 40 plots chosen at random from the 760. The estimated values were then correlated with actual stand reduction and defoliation values supplied later by the Macomb research group.

The correlation coefficient between actual stand reduction values and those estimated from Aero film at a scale of 250 ft inch^{-1} was 0.68, and that for defoliation values was 0.27. No attempt was made to estimate yield values stereoscopically because the plots were too small to adequately employ the technique found useful in analyzing the actual hailstorm film data.

b. Film density-loss analyses

The study of film density for the corn test plots revealed that the best results were derived from the IR color photographs. The optical density of each plot with an initial planted population of 20,000 plants per acre was measured using the densitometer with and without filters. The relationships between film density and stand reduction, defoliation, stand reduction plus defoliation, and yield were investigated for the 6-leaf, 10-leaf, 14-leaf, and 85% tassel growth stages. These were the only stages that had been "treated" at the time of photography.

Results for each growth stage showed that no clear relationships existed between the IR film density and stand reduction or defoliation. Samples of the poor relationships found appear in both graphs of Fig. 7 which is based on plots with treatments made at the 85% tassel stage.

However, relationships were indicated when the available density data for plots of different defoliation levels but with a constant level of stand reduction were compared with yield (Fig. 8a), and when densities for varying stand reductions with a constant defoliation level were compared with their yields (Fig. 8b). An inverse relationship appears in the film density-defoliation graph with a correlation coefficient of 0.80; this relationship supports the hypothesis that defoliation affects plant physiology and its spectral reflectance. The scatter is greater for defoliations $\leqslant 50\%$, but this was partially due to differences in results between the 14-leaf and 85% tassel stages. These are labeled for the plots with 0 and 50% defoliation levels to show their differences, and their effect on the relationship. The graph of stand reduction (Fig. 8b) also shows a comparable inverse linear relationship with a correlation of 0.62. Results of both graphs on Fig. 8 indicate that the IR film density values obtained without a filter were measuring defoliation as hypothesized, but also were measuring stand reduction equally well.

When the density data from sets of three plots, with each set representing a different defoliation-stand reduction combination, were compared with yield, improved density-yield relationships were found. Fig. 9 shows the variability in plot yields from five types of treatments, each applied to three replication plots of

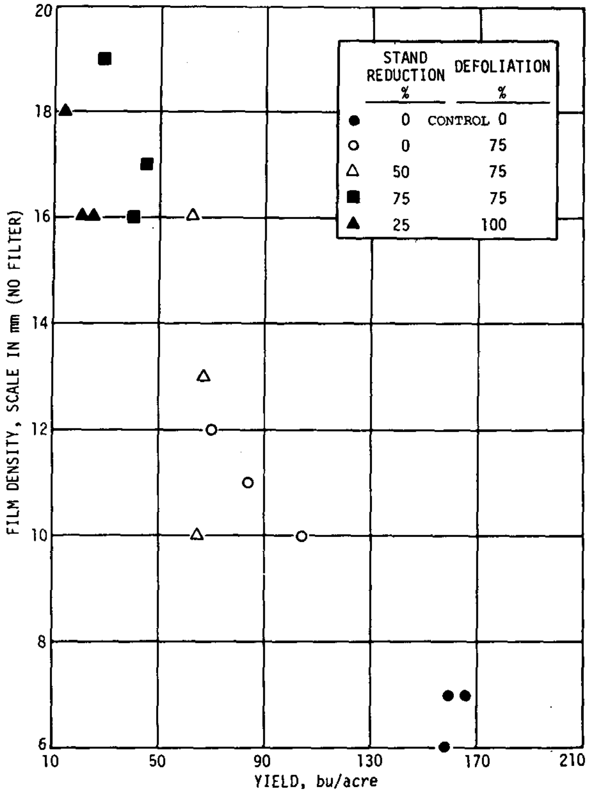


FIG. 9. Comparison of plot corn yields and IR color film densities (no filter) for five sets of treatments at 85% tassel with each treatment replicated at three test plots, as based on an original 20,000 plants acre^{-1} population.

corn in the 85% tassel stage. This allows inspection of the inter-plot variability in yields and densities, as well as variability between treatments. In general, film density increased as yields decreased, and the correlation coefficient was 0.88. The two most excessive treatments, stand reduction and defoliation percentage combinations of 75-75 and 25-100, had generally low yields and comparable densities (16-19), but their yields varied considerably. For example, the yields for the three plots with 75-75 treatment were in the 29–45 bushels per acre range, whereas those for the plots with 25-100 treatment were only 14–23 bushels acre^{-1}. The relatively large density differences with comparable yields shown for some treatments, such as by the three plot values for the 50-75 treatment, suggested the possibility of sampling error related either to the plot data or to the densitometer spot size. The maximum spot size employed might have been too small to measure properly the crop as opposed to the soil, or it might have been partially sampling the foilage from adjacent plots that had only minor treatments.

Because of the occasional large density-yield differences found between the values of three plots of identical treatment, the values of density and yield for each set of three plots with identical treatment were averaged. This was repeated for each of the four plant stages. Fig. 10 presents scattergrams of the resulting data points.

The scattergram for the 6-leaf stage data indicates no relationship between film density and loss, but it should be noted that all but one loss value was 30% or less. The 10-leaf stage scattergram suggests a linear relationship between density and loss, especially for those losses >30%. The correlation coefficient was 0.75. The 10-leaf type and degree of relationship are not unlike that obtained for the 11 July hailstorm which occurred when corn was in the 9–11 leaf stage (Fig. 6). The scattergrams for the 14-leaf and 85% tassel stages (Fig. 10) show even better linear relationships having correlation coefficients of 0.91 and 0.95, respectively.

6. Conclusions

Stereoscopic analysis of Aero color photographs of hail-damaged corn fields in the July storm provided good estimates of the loss, estimates better than those from the IR-film density analysis. Results from the steroscopic analysis of Aero color photographs of the simulated corn-hail plots proved that detection and quantification of corn loss by this method is highly dependent on stand reduction, and that defoliation is poorly ascertained. The success of the stereoscopic analyses of the Aero color photographs for the July storm obviously was related to the fact that there was a considerable reduction in stands and that the amount of reduction at this stage of growth was reasonably well related to eventual loss in yield.

The stereoscopic analysis of the Aero color photographs revealed that in both corn and soybean fields there were semi-circular swirls or areas of loss that ranged from 100–500 ft in diameter. These suggest the repeated occurrence of small-scale downdraft vortices in which hailstones are concentrated.

Infrared film density analyses of corn losses provided good estimates of plot yield reductions from simulated crop-hail damages at the 14-leaf and 85% tassel stages. Density values of corn at the 10-leaf stage for actual hailstorm loss and for simulated damage were not well related when field losses were less than 30%, but were satisfactory for heavier losses. Infrared film density values at the 6-leaf stage did not relate well to any degree of loss.

Several interesting facts were revealed by field assessment of hail loss in 48 fields through use of standard adjusting techniques but employing 2–4 times more point assessments per field than normally obtained in settling insurance claims. First, there was great spatial variability in loss with 100% or greater differences in all 48 fields which ranged from 20–90 acres in size. Second, the detailed field assessments tended to overestimate actual soybean losses, underestimate actual corn losses, and were generally less than the field losses

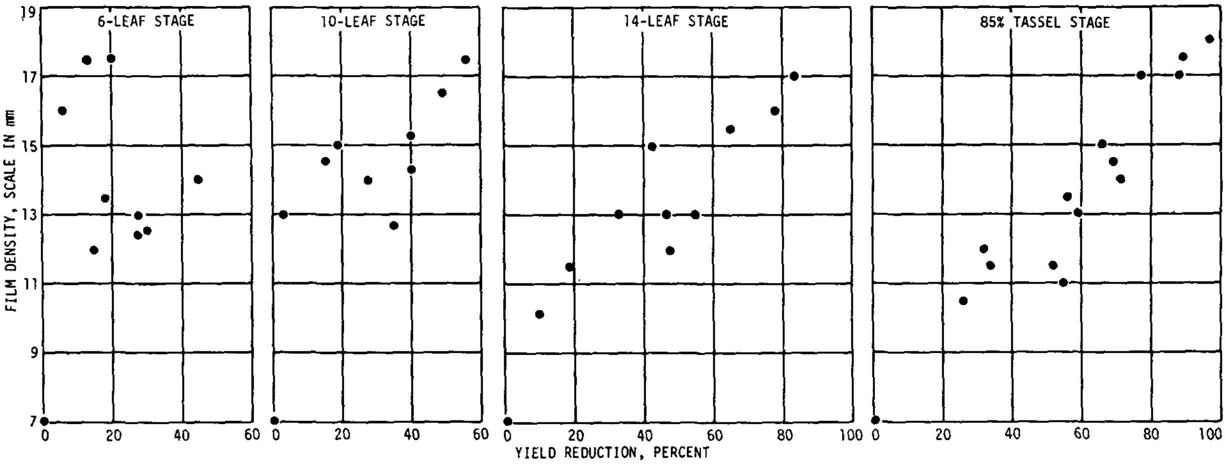


FIG. 10. Comparison of corn yield reductions and IR film density (no filter) for four growth stages, with each data point the average of values for three replication plots with all plots started at a 20,000 plants acre^{-1} population.

(corn and soybeans) determined by insurance company adjustors. Third, the lack of agreement between the field loss values from the detailed assessments and those determined at harvest (control) was particularly poor for field losses $\leqslant 20\%$.

A review of the results from the Aero film-stereoscopic and the IR film-density analyses, and the detailed field assessments of early (10-leaf) growth stages of corn indicates 1) that when losses are 20–30% or less, the damage is related to defoliation and stem bruising, and 2) that this form of early damage or its degree of loss is not well measured by any of the three techniques evaluated. Since many of the annual paid losses in Illinois are in the 1–30% range and from storms prior to mid-July, they represent an economically significant portion of the paid hail losses. Thus, it appears that study of the light damage-producing factors in the 10-leaf and earlier stages is needed to properly understand these factors, and to learn how to measure these factors better. The ambiguity in the loss measurements of early season damages is also a result of the type of weather conditions that occur in the remaining portion of the growing season; thus, the ambiguity may not be highly resolvable. In this case, one might recommend that assessment of corn loss from storms during the 10-leaf or earlier stages should be deferred to harvest. However, the success of the IR film density techniques for the 14-leaf and 85% tassel stages suggests that the technique might work for damages during the earlier growth stages if the photography were done earlier, 3–7 days after the hailstorm, and before subsequent new leaves cover the damaged leaves. The comparable film density results at the 10-leaf stage for the simulated damage plots and actual storm damages to corn indicate that the simulation techniques are valid.

Predictions of field and point soybean losses in a major July hailstorm were not particularly good with any method employed. The best estimates of final loss came from stereoscopic analysis of Aero color photographs. The IR film density values did not provide measures of soybean loss; apparently, the plant damage was not being detected because it was not physiological and thereby not affecting the spectral reflectance, or the photographic scheme (scale) was not adequate to detect the reflectance from the small remaining portions of leaves. As opposed to corn, aerial photographs of soybean fields, including those without much hail damage, exhibit considerable soil, and in damaged fields the high ratio of soil area to plant area is believed to be the major reason for the inability to use IR film density to distinguish damage. The leaf size of a bean plant is also much smaller than that for corn. Stereoscopic techniques of standard color film discern the barren areas of damaged soybean plants more readily than do analyses of IR film densities. A rapid decrease in density-loss relationships with time was found, suggesting that the IR technique for beans might provide better results if done within 3–7 days after a hailstorm.

Certainly the use of IR color film appears to be an emerging and extremely useful technology in agricultural studies. Such film is better than Aero color film in analyzing crop-hail damages using film density measurements, although Aero film is superior for use in the stereoscopic analytical approach. Testing of various filters on the densitometer used to measure IR film density revealed that results with no filter were superior to those with any red or green filter.

Results for both films and analytical approaches were sufficiently good to recommend further study, particularly the IR film density approach for soybeans and corn at early growth stages with photographs taken 3–7 days after the storm. However, the detailed investigation of a single severe July hailstorm and simulated corn-hail damage plots in this study provides only limited results to evaluate the capability of aerial color photographs to quantify crop-hail losses. Therefore, certain conclusions herein must be viewed with regard to this limited sample.

Acknowledgments. This research was performed largely using funds from the Crop-Hail Insurance Actuarial Association. Mr. E. Ray Fosse of that Association and Richard G. Semonin of the Water Survey staff kindly gave useful advice on the planning of the project. Dr. John Adam, Mr. Floyd Huff, Mr. Edward Silha, and Mr. Don Staggs of the Survey staff helped with instrumentation and analytical problems. Mr. John Hornaday performed the detailed field assessments and ensuing analysis.

Dr. Dean Wesley of Western Illinois University is acknowledged for his cooperation in supplying detailed data for the Macomb corn test plots. Finally, the considerable help of many farmers in giving permission to study their fields and in supplying detailed yield data is gratefully acknowledged. Without their assistance, this program could not have been successfully performed.

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