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Some Applications of Remote Sensing of Crop-Hail Damage in the Insurance Industry

by Neil G. Towery

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ABSTRACT

A 4-year research project was conducted on the feasibility of using aerial photography for the adjustment of crop-hail damage. The results indicate that loss assessments could not be made with sufficient accuracy (±10%) in individual fields. However, the photography could be used for qualitative assessment of damage. Aerial photographs are now being used by adjusters as an additional tool in the normal adjustment procedures.

Infrared photography taken from 12,000 feet above ground is used to make mosaics of entire damage areas. Photographs from 6000 feet are being used by adjusters settling individual farmer claims.

Other research led to the development of mapping losses in an entire storm or field with a computer. These techniques are also being used by insurance companies as aids in their procedures.

INTRODUCTION

In May 1974, the Illinois State Water Survey began a project related to the study and application of remote sensing to measure hail damage to crops in Illinois. The two objectives of the project were: 1) to investigate the application and accuracy of aerial photography in the quantitative assessment of damage to Illinois' primary crops, and 2) to investigate the use of aerial photography as a means to delineate severe crop damage areas as an aid in the field operational aspects of storm surveying. The Water Survey had done pioneering research in 1969-1970 about the potential of aerial photography for measuring crop-hail damage (Changnon and Barron, 1971). The goal of this later project was to study the issue intensively and to develop, if possible, technologies that would be transferable to the insurance industry and to the research sponsor, the Country Companies. The findings that relate to the measurement and characteristics of hail also have scientific pertinence to that area of meteorology that includes severe storms and weather modification.

This report presents the highlights from the results of the four years of research that extended from 15 May 1974 to 14 May 1978. Project reports (Towery et al., 1975, 1976, 1977) present more details than are included here.

A brief discussion of general data collection procedures appears in the next section, followed by the results of the crop loss quantification. Then the operational use of the photographs is presented. Computer mapping of losses and sampling methods is discussed next, followed by a brief discussion of other research application of the projects, and finally a summary.

Acknowledgments

The research was performed under the direct supervision and guidance of Stanley A. Changnon, Jr., then Head of the Atmospheric Sciences Section and now Chief of the Illinois State Water Survey. The assistance of Christine L. Dailey, John R. Eyton, Donald E. Luman, Randi Olson, and Timothy Welch, who all participated in various phases of analyses, is gratefully appreciated.

Roy Whiteman, Louis Rediger, and Donald Bradshaw of the Country Companies gave encouraging support to the project. John R. Williams, Carroll Kries, and Robert Weiser obtained the many important loss assessments necessary to the research. The ground truth information was a necessity in all phases of the project. We are especially grateful to Mr. Williams, Head of the Aerial Survey Department of the Country Companies. He worked effortlessly and cooperatively with the Survey staff on various phases of the project and continually offered new ideas and information.

DATA COLLECTION PROCEDURE

The project required two data sets, aerial photographs and suface measured assessments of storm damaged crops. The commonly used data collection procedure was to obtain natural color (1974, 1975) and false color infrared (1975) aerial photographs taken 6 to 14 days after a hailstorm occurrence. The photography was taken from 3000 and 5000 feet above ground. Guidelines for selecting a storm for study were that loss of yield had to be greater than 60% and concentrated in a relatively small area (usually less than 6 square miles).

Aerial photographic missions require more than normal flying expertise for quality photographs. The pilot must be able to fly the aircraft along a straight line, and this can be difficult on days with high or gusty winds. Hence the photography was done by a commercial aerial photography firm. The film was processed by a photographic laboratory in such a manner that film transparencies could be received within 2 days.

The crop-hail adjuster working on the project then selected fields for crop loss assessments, and afterward obtained owner's (or tenant's) permission to enter and measure losses in the field of interest. Time and resources did not permit assessments of all fields in a storm area. An attempt was made to select fields representative of all crop stages existing at that time as well as ranges of damage. The adjuster made assessments of the crop yield loss with standard crop loss adjusting (estimating) procedures.

There was one important exception from normal crop adjusting procedures: loss assessments were made for many (10 or more) specific, point locations in the fields, as opposed to the few points (5 or less) in a field normally used to derive an average loss for that field. Many point locations were necessary because the overall analytical procedure was to compare the crop loss at a particular location (spot) with the same location on the film. The assessment location on the ground covered an area of approximately 200 to 300 square feet. A similar spot covered 300 square feet on a 3000 foot photograph and 800 square feet on a 5000 foot photograph. To accomplish this, distance measurements to each assessed location were made from objects such as fences, houses, roads, etc., which were detectable in the aerial photograph. The adjuster used a rolatape, a wheel that measures distances as it is rolled along a hard surface, to measure the distances.

In general, the adjuster walked along the crop rows and made loss assessments at points when the crop loss changed by 10 to 15% from his preceding assessment. This method was used in a field until a fairly complete sample of the range of damage had been obtained.

RESULTS

Crop Loss Quantification

The first research objective focused on developing a method to quantify crop-hail losses within a particular field or area based on remote sensing. The research was based on a comparative statistical analysis of data from natural color and false color infrared aerial photographs, calibrated against selected field assessments as ground truth. It was hoped that an accurate, as well as an inexpensive, technique for assessing losses could be devised. This objective was partially based on a belief that hail damage would affect the reflectance of crops, which would in turn be detectable in infrared film (Changnon and Barson, 1971), and then could be measured in a precise manner.

Photographic data and field loss data were needed to satisfy this objective, as well as the second, which dealt with developing methods by which crop-hail adjusters could use the aerial photographs for improving crop adjusting procedures performed shortly after a storm.

Excellent aerial photographic data and ground calibration information were collected on 10 storms during the summers of 1974 and 1975. A variety of analyses were performed on all of the storm data (Towery et al., 1976a). The final net result was that quantification of field losses, at an accuracy deemed sufficient to determine losses for loss payments by the insurance industry, was not possible using images on aerial photographs. Accuracy sought by Survey scientists for remote sensing estimates was ±10% of the field estimated values. Ground truth (assessor) field estimates are believed to vary by ±5% based on human error, crop staging problems, "after storm" weather, etc.

Understanding the reasons for the poor accuracy might help similar future research. There were three primary reasons for the inability to achieve desired loss quantification (±10%): 1) the inescapable errors associated with the measurements of film dye densities; 2) inability to establish a good relationship between the field (calibration) assessments (loss-of-yield measurements) and the measurements of reflected radiation on the film (in the film dyes); 3) large variations in the reflected radiation measurements due to the influence of varying soil color, soil moisture differences, crop variety differences, and differing farm practices.

An example of the large variations between radiation measurements and the field loss-of-yield values is given in figure 1 based on one storm. The scattergram (figure la) presents a plot of the densitometer measurements (the ratio of infrared to natural red densities) against loss of yield for a group of 12 corn fields. Most of the damaged corn was in the 9 to 12 leaf crop stage. There is a general trend which suggests that a relationship exists; however, the percent loss of yield for any given densitometer measurement varied as much as 45 to 50 percent, and a few variations were as high as 90 percent. However, at the extremes of loss, some useful information is suggested. Most (36 of 38) densitometer readings of ≤1.2 were ≥75% losses, and 13 of 16 values of >2.6 were losses of <10%.

The scattergram presented for nine soybean fields with the beans in two adjacent stages (R-6 and R-7) shows even more variation of damage for a given densitometer measurement. Losses of yield shown for most of the densitometer reading commonly varied by 50% (10 to 60%, 18 to 68%, etc.).

The second and third reasons for failure to obtain desired accuracy in loss estimates were the most critical. The crux of the second reason was the inability to discriminate between the two types of crop-hail damage (direct and indirect) detected on the photographs. Direct damage is defined as destruction of plants (or yield-producing structure), and indirect damage is removal of leaf area which ultimately leads to reduced yields. This is compounded by the fact that there is not necessarily a correspondence between the amount of physical damage (both direct and indirect) and estimates of losses to crop yields. There is a large number of combinations of direct and indirect damage and both types usually occur together to produce the total loss of crop yield in a given

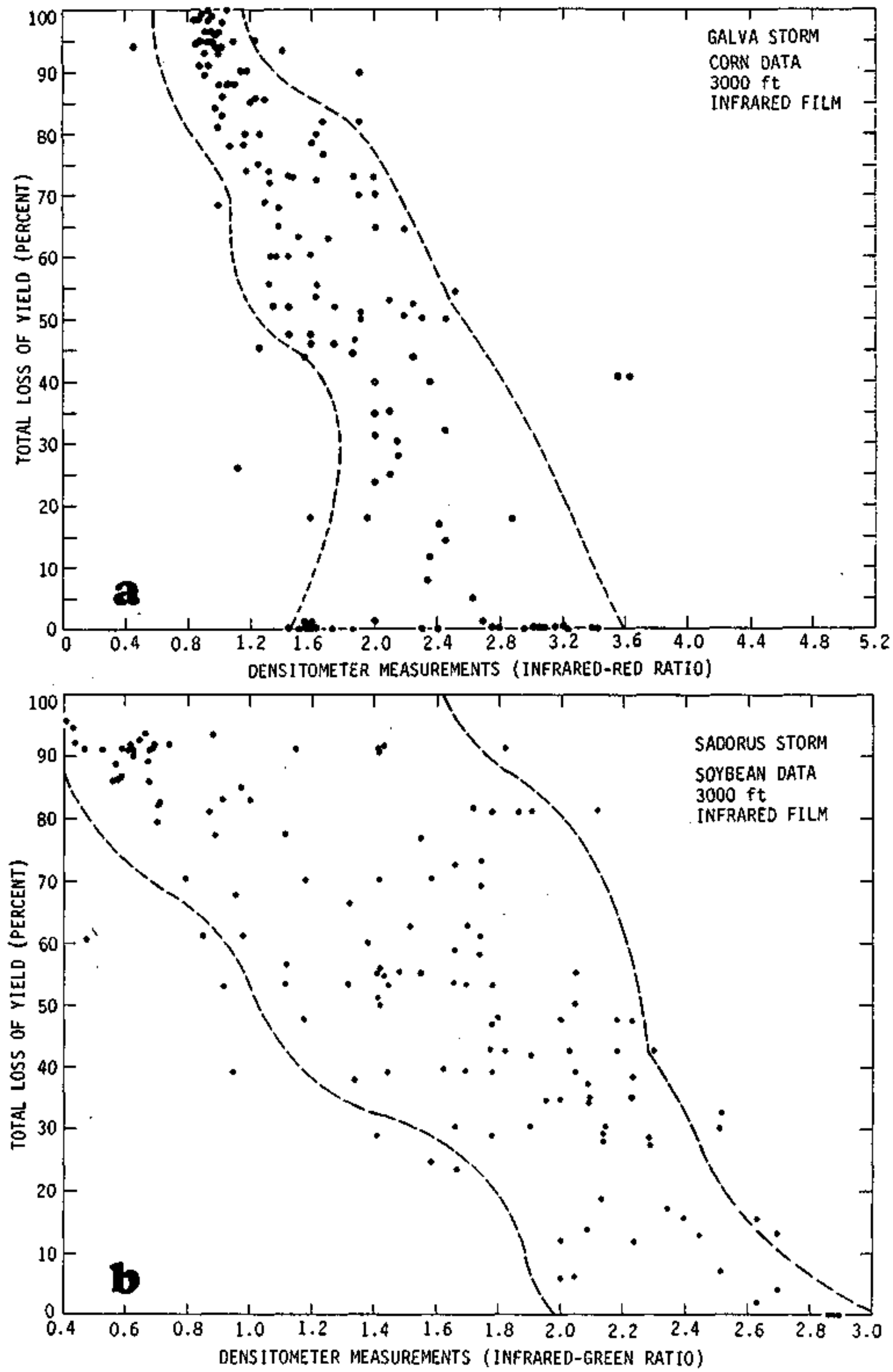


Figure 1. Scattergram of densitometer measurements and percent loss of yield for 12 corn fields (la) in the Galva strom, and 9 soybean fields (lb) in the Sadorus storm. Ninety percent of the values lie between the dashed lines. Flights at the 3000 ft (915 m) level.

damaged field. Furthermore, after a certain amount of physical damage (foliage removal) has occurred, variations in soil moisture and color can be seen from above (in the film), which results in the third problem. These two reasons are somewhat interrelated and when both were present, the quantification of loss capability was poorest.

The range of errors encountered in almost all analyses is described in the following example. One of the analysis methods employed "discriminant analysis" (Towery et al., 1976a). Using this method of analysis, data points from nine soybean fields were identified as ground truth, or calibration information, to establish a model to predict loss values in another "test" field. The 32 loss values to be estimated in the test field were, in fact, known. Stratification of damage and classes was used. The 32 values of this test are listed in table 1 where the test (predicted) class values are listed alongside their actual class values, arrayed in order of increasing value. Basically, if prediction was good with the discriminant model, the two columns would closely match; however, they do not match. For instance, there were 12 actual (known) values between 0 and 20%. The model estimates placed only 4 values in the proper class or range. It even placed 4 values from the 45 to 65% class in the 0 to 20% class. The next group (20 to 45%) did better, with 7 of 13 values properly classified. The last class (45 to 65%) had only 1 of 7 values correct. In summary, only 12 of the 32 predicted values were in their proper class.

The results of the discriminant analysis for many other tests led to similar conclusions — the model was not useful for purposes of predicting percent loss. The examples of very wide scatter in percent loss for a given densitometer measurement (figure 1) and the poor predictive capability of a discriminant analysis model (table 1) demonstrate that the desired accuracy (±10%) of loss assessment for individual fields was not achieved. However, potential future research projects to investigate further the use of aerial photographs to more accurately quantify individual field losses can be envisioned. They would likely be very expensive and could require several years of research before meaningful results could be obtained, if ever. Future studies should seek a capability to separate the background soil reflectances, which would require use of multi-spectral film and analyses techniques. Any future program should also collect hail damage values at the surface with emphasis on measuring the physical-structural damage which results in both a change in the reflectance and the geometry or the spatial arrangement of the individual plants. Complete knowledge of each crop stage, both at the time of the loss and at the time of photography, will be an absolute necessity.

Use of Infrared Aerial Photography in Operational Aspects of Crop-Hail Assessment

The research pertaining to the second objective, use of aerial photographs to delineate, qualitatively, severe hail damage for field

Table 1. Comparison of 32 Predicted Soybean Losses in Damage Classes, Based on a Discriminate Analysis Model, with Actual (Measured) Classes

	Bean -- total damage (%)	
Sample number	Predicted class*	Actual class**
1	20-45	0-20
2	0-20	
3	0-20	
4	45-65	
5	20-45	
6	20-45	
7	20-45	
8	0-20	
9	0-20	
10	45-65	
11	45-65	
12	45-65	0-20
13	20-45	20-45
14	20-45	
15	0-20	
16	20-45	
17	20-45	
18	20-45	
19	45-65	
20	20-45	
21	0-20	
22	0-20	
23	0-20	
24	0-20	
25	20-45	20-45
26	20-45	45-65
27	45-65	
28	20-45	
29	20-45	
30	0-20	
31	0-20	
32	20-45	45-65

*Classification of each data point according to the discriminant model

**Classification based upon adjusters' data in the field operational applications, produced very useful results. A technology was developed for use by the sponsoring agency. Although the photographs cannot be used for quantifying losses to an accuracy useful for insurance applications, they do qualitatively indicate ranges of damage, and particularly the extremes (see figure 1) of little (or no) damage and of great damage.

Visual inspection of the infrared photographs allows one, with limited training, to qualitatively classify the crop damage as light, moderate, or severe. Figure 2 provides an example of the use of the photographs. The photograph is a black-and-white rendition of an infrared photograph taken from 3000 feet above ground level. In figure 2, the minor damage appears as a darker color and the heavier damage appears as a whitish color. Thus, when viewing such a photograph, one can subjectively (and qualitatively) define the light, medium, and heavy damage areas.

It should be pointed out that these decisions cannot be made without some investigation and knowledge of damage in various fields in the area of a particular storm. It should also be emphasized that each individual storm is different, and thus each must be interpreted somewhat differently. The crops and photography from each storm in general appear different because of different crop stages, soil type in the area, amount of soil moisture, and the possible occurrence of rain just prior to a flight. The photographs can be used only as a guide and should be viewed as another tool or aid to assist the field adjuster. Nevertheless, the project sponsor adopted this approach and now routinely uses aerial photographs in its assessment program.

The Country Companies became the first firm to use aerial photographs as an aid to their adjusters and assessment operations. The Crop-Hail Claims Department formed an Aerial Survey Department which routinely takes infrared photographs (from 6000 feet) of moderate to severe hailstorms in Illinois. Copies of these photographs are supplied to crop adjusters for use in performing their field activities in individual fields. Photographs are also taken from 12,000 feet. The higher altitude photographs are used to make a mosaic of the entire storm area which is used in various ways.

The potential applications of the loss photography to insurance industry operations are described below:

A. Use of the 12,000-foot mosaics

1) Isolines of damage (light, moderate, heavy) can be drawn for an entire storm, and serve as an aid for auditing claims. The isolines, as well as the actual settlement percentages, can be drawn on an overlay of the mosaic. Any unusual adjustment will be evident and might merit re-inspection.

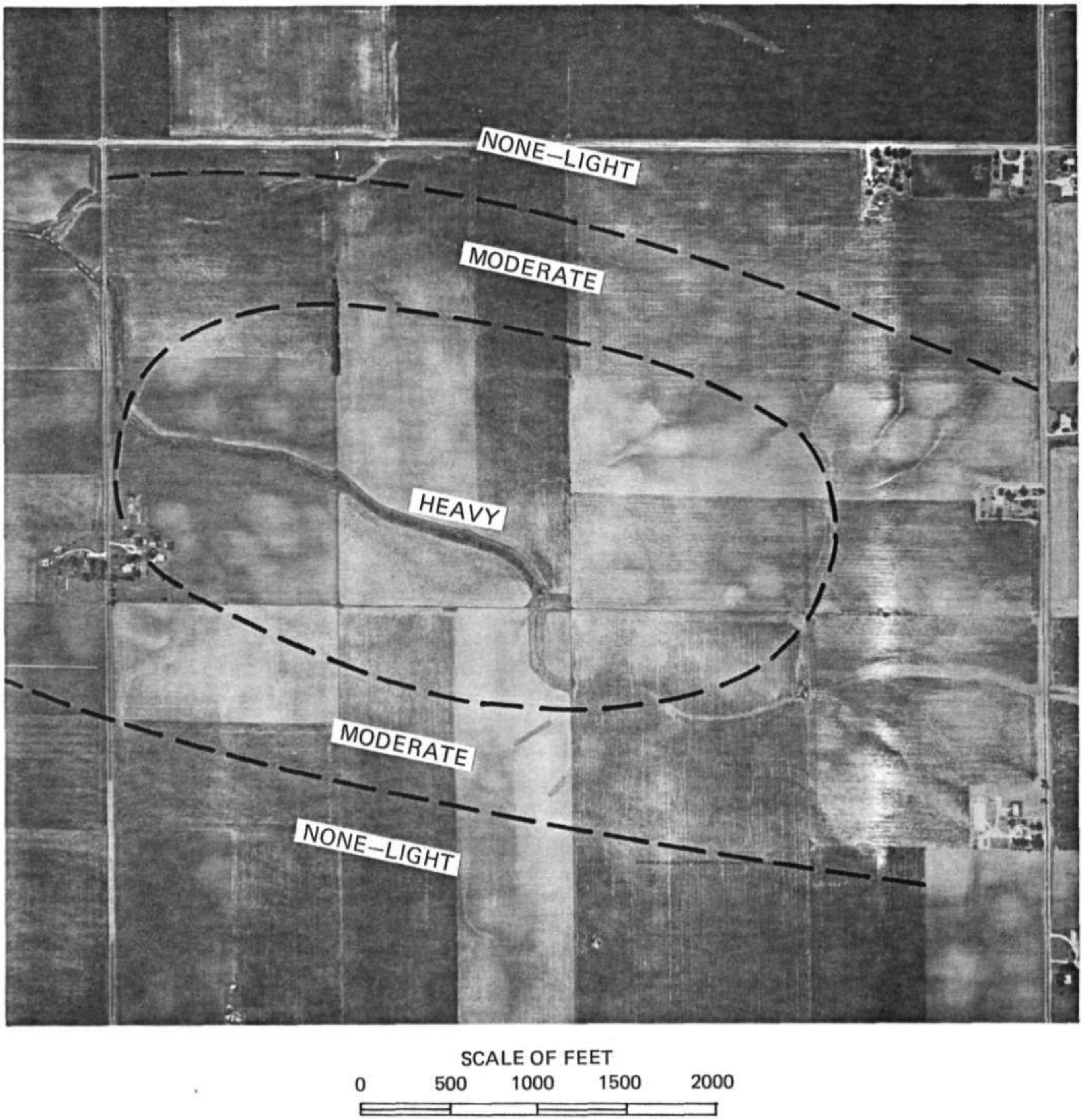


Figure 2. Black and white photograph showing qualitative ranges of crop-hail damage

2) The total liability to the company for a given storm can be quickly approximated. Insured farms may be plotted on the photographs and the number of acres in each category of damage can be estimated.

3) An estimation of the extent of the damage areas can allow supervisors to use and direct their personnel efficiently. Knowledge of approximate damage areas allows estimation of the number of adjusters needed.

4) The mosaic can help adjusters easily find fields and farmsteads relative to known landmarks, and it provides information on the individual field location relative to the severe storm damage.

B. Use of the 6000-foot photographs

1) An aerial view of individual fields should allow adjusters to assess the qualitative range of damage.

2) The photographs should help prevent "call-backs" of adjusters by the insured due to faulty assessment during the first examination. Classified ranges of damages for individual fields will prevent surprises for the adjuster as he moves within the field and from farm to farm. The photographs should increase consultation and discussion between the adjuster and the insured, leaving the insured with the feeling of being well-informed and fairly treated, and thus less likely to ask for a re-investigation.

3) Use of the photographs should increase confidence and credibility with the insured. Most farmers are receptive to new technology, and discussions with farmers when the photographs have been used indicate they accept quite well the use of the aerial photography as an aid to the adjuster.

4) If the photographs indicate wide variability of loss in a field, more loss counts need to be taken. On the other hand, consistent or light damage across a field would indicate that less counts may be taken.

5) Quite often fields are divided into two or three areas and various percentages paid. The estimation of area can be difficult and inaccurate. Working copies of photographs supplied to the adjuster will increase his accuracy because he can accurately measure areas from the photographs.

6) Spots of standing water can be identified easily and deleted from payment, if desired.

7) The photographs provide a permanent record that might be used beneficially as an aid in disputes that may arise after the crop is harvested.

8) Slides made from the original photographs of damaged fields serve as a great aid to adjusters for evening consultation between them and their supervisors.

9) In some cases, the photography can be used to help explain to farmers with adjacent fields why they receive different loss estimates and settlements. Quite often, farmers expect to receive the same payment as a neighbor. The photographs are visual proof that the damage is different and will therefore help solve the "neighboritis" problems.

The formation of the Aerial Survey Department, including the training of personnel and preparation of an instructional handbook (Dailey et al., 1976) within the Country Companies, came as a direct result of techniques developed as part of this research project. The applications in the crop-hail insurance industry and in meteorological field studies of hailstorms are indeed diverse and important.

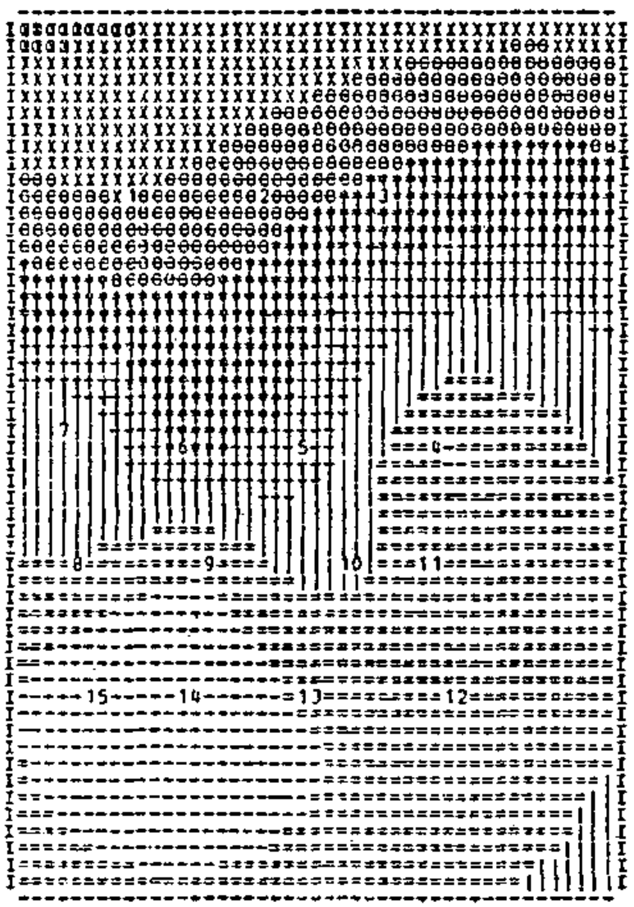
Computer Mapping of Loss and Sampling Methods

An unexpected beneficial result from the project was a computer mapping program developed as part of the first objective. It was necessary to put the information for a particular field into map form so that areas of damage, the average field yield loss, and final adjustment figures could be determined objectively and easily.

An example of a computer-drawn map, based on adjuster-obtained yield losses in a 58-acre field, is shown in figure 3. The adjuster made 15 loss assessments in the field, and the program used these input data to calculate many additional point values of losses through an interpolation-extrapolation scheme (using a multi-quadratic equation) at points between and beyond the adjuster's assessment locations. An evaluation of the interpolated values indicates their accuracy is well within 5% of the actual value. This was determined by actually examining damage at 100 computer-estimated points in 10 damaged fields during 1977. In 81% of the cases, the interpolated (or estimated) loss was within 5% of the actual loss (Towery, 1978).

The program then uses all of the values to calculate a weighted average loss in the field. It also determines the number of acres, calculates final adjustments figures, and produces a map of the loss along with other statistical data. The only limitation is the accuracy of its input information. The loss-of-yield estimates must be accurate and they must be evenly and widely distributed throughout the area of interest.

FIELD MAPPING OF CHARLESTON HAIL STORM -- JULY 17,1975



SYMBOL	CLASS (% DAMAGE)	FREQUENCY (%)	AREA (ACRES)
	0- 10	0.0	0.0
---	10- 20	12.22	7.10
===	20- 30	32.18	18.68
|||	30- 40	11.97	6.95
+++	40- 50	8.80	5.11
‡‡‡	50- 60	12.82	7.44
θθθ	60- 70	11.88	6.90
XXX	70- 80	9.57	5.56
&&&	80- 90	0.56	0.32
###	90-100	0.0	0.0

58.06 = TOTAL ACREAGE

FIELD: C09
PHOTO: 7-018
ALTIMETER: 3C00
FILM TYPE: MS
SCALE: 1"= 530.1
CROP: CORN
CROP STAGE: TASS
NO OBS: 15
XMIN: 0.0
XMAX: 2.50
YMIN: C.C
YMAX: 3.60

X-COORDINATE	Y-COORDINATE
0.43	0.72
1.04	0.73
1.54	0.73
1.75	1.73
1.17	1.73
0.69	1.72
0.18	1.70
0.22	2.21
0.77	2.22
1.36	2.23
1.73	2.23
1.82	2.81
1.18	2.81
0.66	2.80
0.27	2.79

Z-VALUE
70.00
63.00
57.00
19.00
48.00
55.00
31.00
31.00
21.00
36.00
21.00
21.00
21.00
11.00
13.00

AVERAGE OF % DAMAGE FOR ENTIRE FIELD BASED ON ALL EVALUATED MAP POINTS= 40.12 %

INSURED VALUE OF EACH ACRE= $200.00

TOTAL ADJUSTMENT= $ 4658.54

Figure 3. Example of computer-drawn map

The computer mapping routine was originally developed for mapping loss in rectangular fields, and was later adapted for mapping loss in irregular-shaped fields. Therefore, it could also be used for mapping loss patterns from entire hailstorm areas, all of which have irregular shapes.

This capability has proven to be extremely useful to the insurance industry. The Country Companies now uses the computer mapping technique as a standard procedure for mapping all storms. Storm maps are prepared soon after each storm and prior to actual field loss settlement by having supervisory personnel obtain loss estimates at many locations throughout the storm area. The mapping routine is then used to compute an average loss for the storm. The loss values can be combined with information on acres insured in the storm and the approximate insured value per acre to estimate the total dollar loss of the storm, information valuable to the industry. The adjusters use the storm map in a variety of ways, e.g., the storm map provides information on the location of heavy losses, storm shape, and range of loss.

The potential use of the mapping program to obtain better estimates of field losses, as based on adjuster values, was also investigated. The objectives of the research were: to develop a computer mapping system (described above) suitable for mapping crop-hail losses within a field, based on loss assessments of an adjuster; and to discern optimum field sampling procedures. In this latter objective, several questions were addressed: 1) what is the number of sample points per unit area necessary for an accurate assessment of damage; 2) how do errors vary with varying number of sample points; and 3) does the computer mapping routine provide a better field loss estimate than a simple straight average of point values?

The details of the various testing procedures and results are contained in another report (Towery and Olson, 1977). Considerable analyses were performed with the computer mapping routine and statistical tests to determine the best sampling methods to be used by the adjuster. After careful assessment of the results, the following procedures for field data collection are recommended:

1) A systematic field sampling method is important. It should include dividing a field into equal parts and taking loss assessments from the center of each part. Care should be taken to insure that the loss assessment sites are at the correct (center) location. The adjuster should measure (by pacing) his distance to the assessment locations.

2) Use of the mapping routine will produce slightly more (~2%) accurate results than a simple average of input points, especially in fields with a high degree of variability of loss. The actual in-field implementation of the mapping routine is too cumbersome, logistically, for the adjuster.

3) A procedure among many adjusters of taking only four adjustment samples in a field should not be used, except for extremely small (<10 acres) fields.

4) Six point samples should be taken for fields in the 10 to 40 acre range.

5) Eight point samples should be used for fields in the 41 to 80 acre size.

6) There were few test fields larger than 80 acres and firm conclusions cannot be made concerning such large fields; however, it seems appropriate to have at least one loss assessment per 10 additional acres.

7) If aerial photographs are available and a high degree of variability in the damage is indicated, more assessments than those recommended above (perhaps 1 per 5 acres) should be taken.

RESEARCH APPLICATIONS

This research provided information and techniques useful to the meteorological research community as well as the insurance industry. Two research papers were published in the meteorological literature (Towery et al., 1976b; Towery and Morgan, 1977). One paper dealt with the effect of wind on crop hail damage, and showed that hail accompanied by wind causes significantly more damage than hail with no wind. The effect is shown in a soybean field in figure 4. The area immediately adjacent to the trees had only 20-30% loss of yield, while areas outside the "protected" areas sustained 2 to 3 times more damage.

A second paper was based on aerial photographs taken in 1976 (Towery and Morgan, 1977) which revealed very small-scale (50- to 100-foot wide) stripes or swaths of damage. Figure 5 is a black-and-white rendition of the original infrared photograph (color copies appeared on the cover of the referenced publication). The photograph shows the very thin northwest-to-southeast lines of varying damage (differing by as much as a factor of 2) extending at a slight angle from left to right. The lines are particularly visible in a corn field southeast of the interstate highway. The small-scale variation of damage on this scale had not previously been noted. It reveals new information on hailstorm structure and the wind-hail relationships near the surface.

SUMMARY

This research program provided useful results. Point loss quantification with aerial photographs failed to be as accurate as

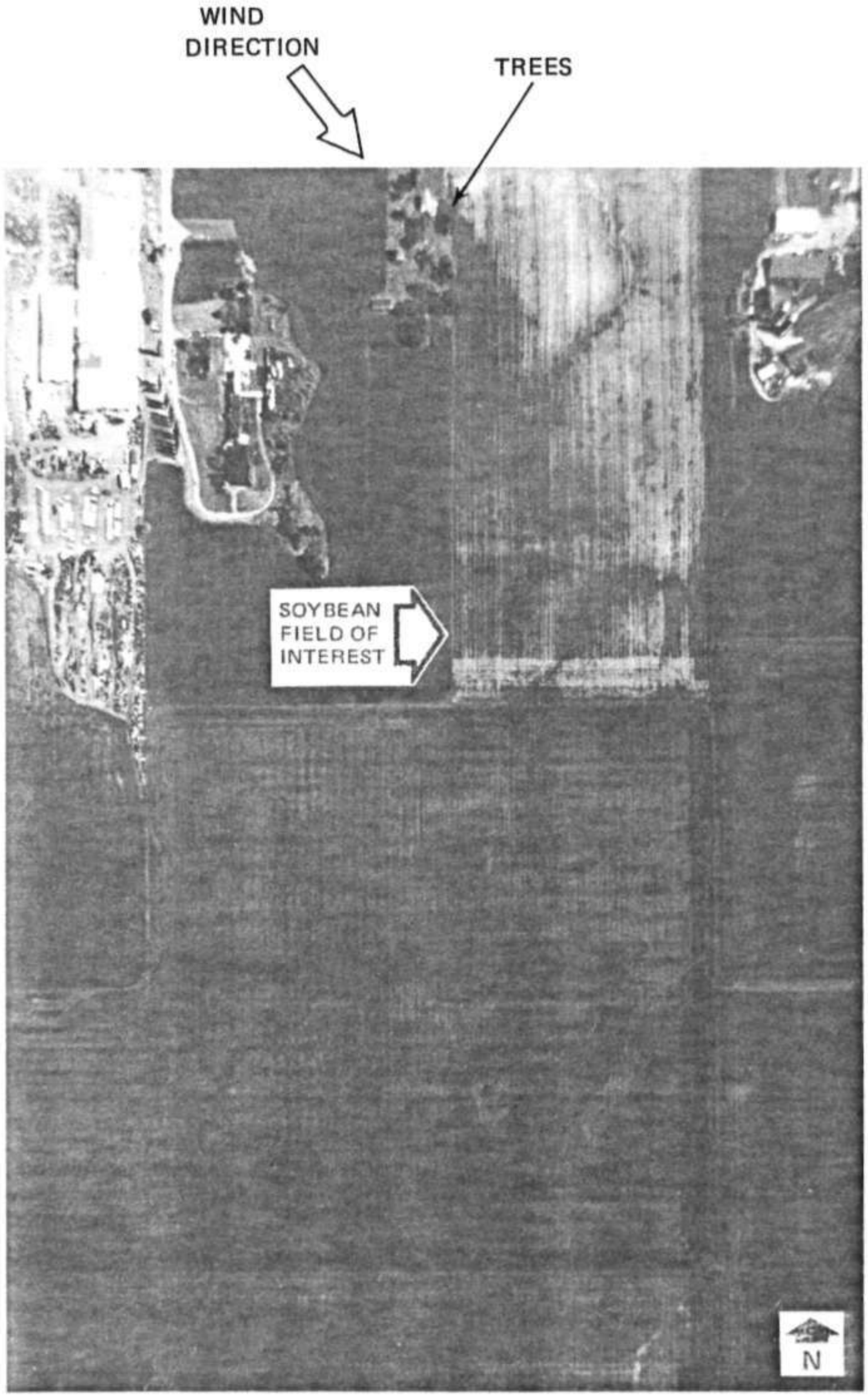


Figure 4. Aerial photograph taken from 3000 feet above ground of crops damaged by hail from a 14 June 1975 hailstorm

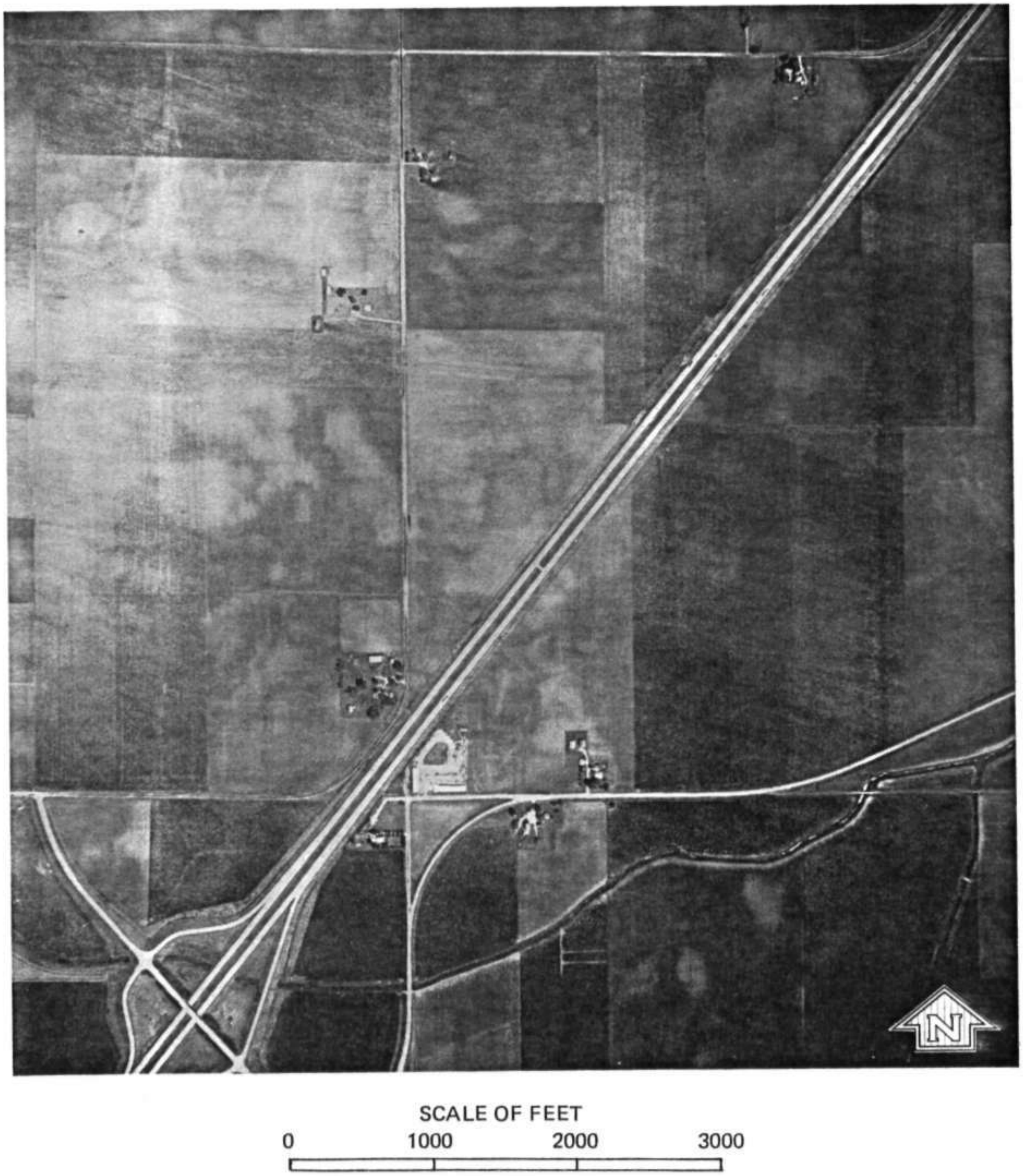


Figure 5. Aerial photograph showing thin stripes of varying degrees of damage called hailstripes

desired for insurance application, but as is often the case with research, unexpected benefits resulted. Several operational techniques were developed and are being used by the Country Companies. The research provided information and techniques useful to the meteorological research community and to the insurance industry. The study of aerial photographs of crop-hail damage demonstrated quite dramatically the effects of wind on crop damage, and also led to the discovery of certain unique very small-scale patterns in crop-hail damage and storm structure.

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