Use of Remotely Sensed Data for Assessing Crop Hail Damage

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Abstract
Crop hail damage is a major problem in the Great Plains, causing substantial losses to farmers. Traditional crop hail loss adjustment is very labor-intensive. The loss adjuster must physically survey the damaged field, which is time consuming and subject to considerable error due to the difficulty in determining the relative size and location of the damage. We describe a tool based on remote sensing technology that can be used to help standardize the sampling procedure, estimate areas of similar damage, and speed the selection and location of field sampling. While it is not likely that loss adjustment can be done without ground reference information, it is possible that considerable improvements and cost savings could be made with the assistance of this technology. The NASA Affiliated Research Center (ARC) at the University of Nebraska-Lincoln working with IGF Insurance Company used airborne multispectral imagery and close-range hyperspectral data to evaluate the impact of artificially induced hail damage on corn and soybean fields. Additionally, a Landsat Thematic Mapper scene, covering a severe hailstorm in western Iowa on 02 July 1999, was evaluated for its potential contribution in evaluation of hail damage on crops. The results showed that broadband multispectral imagery is adequate for detection of the ground area and relative level of hail damage in corn and soybean crops. We believe that damage assessment based on remote sensing techniques would be faster and more accurate than currently used field-oriented procedures.

Introduction
Hail is a unique weather phenomenon that is spatially random and varies in degree of intensity from hardly noticeable to catastrophic. Topography, wind patterns, and the randomness of the hail in a thunderstorm can cause non-uniform spatial distribution of hail size and intensity. In addition, the vulnerability of growing crops and their capacity to compensate for hail damage varies with the growing season and plant-growth stage (Hillaker and Waite, 1985). Crop-hail insurance, in general, provides coverage on a per-acre basis. Therefore, each individual acre (an acre is approximately 0.4 ha) is appraised for damage. The ultimate yield loss due to hail damage as a percentage of the crop's potential prior to the hail event is determined by the growing stage of the crop; surviving plant population versus planted population; amount of plant defoliation; harvesting difficulties; and the direct amount of pod, ear, or grain-head loss if near harvest. These loss parameters are determined based on a series of sample sites (0.001 acre) that are selected and measured in the field by the adjuster. The number of samples taken depends upon the size of the field and the variability of damage. Therefore, it is crucial in crop-hail loss adjustment to get an accurate picture of the hail-damaged field so that areas with differing amounts of damage can be delineated and sample sites chosen that are representative of the delineated areas.

The crop-loss assessment procedure is fairly robust, but it is based on scientific research that assumes an average crop prior to the storm, accurate staging of the crop, accurate measurements during the loss adjustment, and average growing conditions for the remainder of the crop season (Vorst, 1984; Shapiro et al., 1985). When these assumptions are violated, inaccurate damage assessment may result. The judgment used by the loss adjuster to select the number and location of sampling sites is an art, particularly when the farmer/client accompanies the adjuster into the field. There are physical demands because the crop-growth stage may preclude motorized travel in the field, and the size of the crop and topography may preclude long-distance visual inspection. A walking search pattern that would appropriately find and accurately measure the non-uniformity in hail damage streaks is long, time-consuming, and physically exhausting. To keep loss adjustment costs low, some shortcuts are taken. For example, the farmer/client is sometimes relied upon to pre-scout the damaged field, or only a few samples ("counts") are taken to save time. Finally, despite loss adjustment procedures, the historical evidence is that an unusually high number of hail losses occur in multiples of five, ten, and "totaled" (90 percent damage or more), causing one to think that some losses are negotiated rather than determined by loss procedures. In general, the two worst loss adjusters are the inexperienced who can be bullied by clients or agents and the very experienced who think they know more about loss adjustment and second guess the procedure to make it "right." A "friendly" loss adjuster is sometimes viewed as a marketing asset. But over time, policyholders pay for overly generous awards with higher insurance premiums.

Quality assurance and oversight have been relaxed in recent years. For example, the practice of multiple-season apprenticeships and doubling-up (putting two adjusters, one senior and one junior, to work a single claim) has waned due to the perceived extra expense. Non-competitive sharing of loss adjustment information in the field was stopped under threat of anti-trust and collusion charges by state attorneys general.

In summary, the adjustment of crop hail losses is both art and science. Crop hail loss adjustment is very labor-intensive. A new tool based on remote sensing technology is needed to help standardize the sampling procedure, estimate areas of
similar damage, and speed the selection and location of sampling (Myers, 1984). While it is not likely that loss adjustment can be done without ground checking, it is possible that considerable improvements and cost savings could be made with the new technology.

**Objectives**

The project goal was to demonstrate the use of remote sensing technology and ground-based data collection to provide a fair and accurate tool for assisting with crop hail damage insurance settlements in minimal time and without conflict, while keeping expenses low. The specific objectives were to determine if the area and relative severity of hail damage in corn and soybeans could be characterized or estimated.

**Materials and Methods**

**Location**

Separate test sites for corn and soybeans were established at the National Crop Insurance Services (NCIS). The corn test site was located at the University of Nebraska-Lincoln Agronomy Farm in Lincoln, Nebraska. The experiment consisted of 30 plots planted with three corn varieties (field corn, sweet corn, and pop corn) at two planting dates or growth stages (Plate 1A). Each plot contained six rows of corn, and measured ~17 by 6 meters (~102 m²). Each of these plots was separated into five sections. Five of the plots were damaged unintentionally by over spray of Roundup™ herbicide from an adjacent field, and were excluded from the analysis (denoted “R” in Plate 1A).

The soybean test site was located at the Iowa State University Field Extension Education Laboratory located seven miles west of Ames, Iowa. The test site consisted of 20 plots planted on five different dates. Each plot measured ~15 by 10 m (~150 m²). Buffer areas were maintained between matched pairs of plots and alternate plots were damaged with hail (marked as “H” in Plate 1B).

A Landsat TM image covering the location of a severe-hail storm in Carroll and Crawford counties, Iowa on 02 July 1999 was evaluated for its utility to assist with crop hail damage assessment, and operational planning after a severe hailstorm.

**Simulated Hail Damage**

To simulate hail damage, we used machines to hurl ice pellets at the crops. In the corn test site, a total of eleven plots were haled. In some plots, all rows of corn were damaged and, in others, damage was limited to only two rows (Plate 1A). At the soybean test site, a total of ten plots were damaged completely (Plate 1B). Soybeans were much easier and took less time to damage than corn due to the more delicate structure of the plants.

**Aerial Imagery and In Situ Measurements**

Airborne images of the corn and soybean test sites were obtained by an aircraft-mounted ADAR 5500 multispectral sensor system. This instrument acquires data in four broad bands at 400 to 540 nm (blue), 520 to 610 nm (green), 610 to 690 nm (red), and 760 to 1000 nm (near-infrared). Two missions were flown at each site, one before and one after the simulated hailstorms, at 900 and 2750 m above ground level to obtain images at spatial resolutions of 0.25 by 0.25 m and 1 by 1 m, respectively.

Reference data were obtained for both field experiments. Close-range hyperspectral data were collected using a Spectron Engineering SE-590 portable spectroradiometer. The SE-590 is a non-imaging instrument that records spectral data in 252 bands with a nominal range between 356 and 1126 nanometers (nm). The average wavelength spacing between the midpoint of adjacent bands is ~3 nm, but this varies between adjacent band centers (Starks et al., 1995; Spectron Engineering, 1995). The SE-590 was positioned on a boom ~3 meters above the canopy, with the boom pointed south to reduce shadowing. The data were collected near solar noon (11 AM to 3 PM) when changes in the solar zenith angle are at a minimum. A white Spectronal reflectance panel measuring 25.5 by 25.5 cm was used to calibrate the SE-590. This panel is a near diffuse surface, which reflects 97 percent of the radiation incident upon it. The target radiance is measured as a proportion of the panel radiance (Milton, 1987). Calibration scans were taken as dictated by the changing sky conditions, and were used to convert the data to percent reflectance.

Leaf Area Index (LAI) of the canopy was measured using a Licor™ (LI-2000) LAI meter. LAI is defined as the total area of plant leaf per unit area on the ground. The LI-2000 estimates LAI based on a comparison of the diffuse incident light above and below the canopy. Our readings were taken at twilight when diffuse light conditions were dominant. A total of 15 readings were obtained at random points in each plot and averaged in order to obtain an estimate of the total LAI at each plot. All in situ measurements were made concurrently with aircraft overflights.

**Results and Discussion**

Detection and Mapping of Hail Damage in Remotely Sensed Imagery

The first objective of the project was to determine whether hail damage in corn and soybeans could be detected and mapped with remotely sensed imagery. Visual inspection of the ADAR imagery was performed as a first step, and hail damaged areas
are clearly visible (Plates 1A and 1B). Further analysis was conducted to determine why this is so. Figure 1 shows average ground-based hyperspectral reflectance curves (SE-590) for the youngest and most mature growth stages of each crop. It is evident that there are spectral differences between crops that are hail damaged and those that are not (Figure 1). The changes that occur after hailing can be explained by the amount of plant foliage that is destroyed (Gillis et al., 1990). The greater the amount of foliage damage, the closer the spectral response curve migrates toward that of bare soil. We noted this same process at all plant growth stages because near-infrared reflectance decreases and red reflectance increases after plants have been damaged by hail. The “soil line” represents the spectral response that would occur if no vegetation were present in the plot and only soil was visible to the sensor. The ground-based hyperspectral data confirm what can be seen visually on the images (Figure 1).

Additional evidence that the airborne ADAR 5500 data are accurately detecting “hail” damage is demonstrated by Figure 2 which shows a positive relationship between the Normalized Difference Vegetation Index (NDVI) \(\text{NDVI} = \frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{RED}}\) calculated from the ADAR 5500 imagery and NDVI calculated from ground-based hyperspectral data (SE-590), integrated to the identical bandwidths of the ADAR 5500. The high coefficients of determination obtained for both crops confirm the accuracy of the image data. Figure 3 shows the relationship between the LAI data, the ADAR-NDVI data, and the ADAR-NDVI data simulated with the SE-590. Coefficients of determination obtained for this test are also quite good, again supporting our belief that visual differences in the ADAR imagery are supported by measurable physical parameters on the ground.

Before “hail” ADAR-5500 imagery proved not to be as useful as originally anticipated. It was our original intent to utilize this imagery for comparison of vegetation condition pre-and-post “hail” damage. However, both the corn and soybeans were growing very rapidly at the time of our field tests. Therefore, the growth-status changes that occurred in the crops were sufficient to prevent accurate pre- and post-comparison of crop growth status. In essence, the crops imaged after hail damage were in a very different growth stage and were of no use for estimating the pre-hail growth stage of the plants. This was true even though we scheduled the imaging overflight as close to the scheduled date for “hailing” as was possible (6 and 5 days for corn and soybeans, respectively), given the constraints of weather and pilot availability. We believe this result is actually quite useful because it negates the argument that pre-hail imagery against which to compare the damaged crop is necessary for calibration of damage levels. In real-world operations, pre-hail imagery will probably not be available, and would be relatively meaningless during much of the growing season when crops are growing rapidly. Alternatively, crop growth stage confirmation could be obtained by the crop adjuster through evaluation of the condition of similar undamaged crops in the vicinity of the damaged crop.

Determining the Level of Hail Damage in Remotely Sensed Imagery

Efforts to estimate the level of hail damage in remotely sensed imagery proved to be elusive. Our intent was to compare hail damage worksheets, provided by the insurance adjusters, to the results obtained from analysis of the airborne imagery. We con-

Figure 1. Spectral profiles of corn and soybeans obtained on the ground with the Spectron Engineering spectroradiometer (SE590) on 15 July 1999 and 30 July 1999, respectively. Each line on the graphs indicates the average of all measurements for the youngest and most mature growth stages of each crop.
cluded, however, that these two data types are not comparable because the worksheets are based on evaluation of single corn and soybean plants and single plants are not discernible on the ADAR imagery, even at a 0.25- by 0.25-m spatial resolution.

We decided upon an alternative approach to ascertain the amount of hail damage in corn and soybeans with remotely sensed imagery. To demonstrate our concept, we used an unsupervised image classification technique on the hail-damaged soybean plots. The goal was to test the ability of an unsupervised image classifier to detect subtle spatial differences within each plot caused by variable rates of crop damage. Figure 4 shows the outcome of this classification procedure. Based upon careful visual examination of the imagery, one can discern spatial variability in the hail-damaged plots (Plate 1). It is the spatial variability in the image that allows the image classifier to work. There is no way to calibrate the results of this approach with the ground-based information collected during the hail school. However, in a real-world situation, a classified image of a hail-damaged field would allow the insurance loss adjuster to establish an improved plan for sampling the damage. This could be accomplished by field checking the damage level at an adequate number of locations for each image class. The actual area of damage for each image class would be determined by a pixel count.

We believe that digital image classification is a useful technique for describing the spatial variability of hail-damage levels in corn and soybeans. This could be accomplished by removal of the hail-damaged area from the rest of the image using standard digital image processing techniques. The image classification procedure could then be implemented on just the area of storm damage to contain image variance within the area of interest in the scene.

Our classification-based image processing strategy is somewhat analogous to the information shown in Figure 1 in which we demonstrate that there are spectral differences between growth stages. In other words, the SE-590 spectroradiometer is sensitive to various ratios of vegetation and soil cover in a cropped field. It is the vegetation amount remaining after a hailstorm that provides the basis for remote sensing assessment of hail-damage levels, primarily through classification or pixel-grouping techniques. We did not attempt to classify the hail damage in the corn plots due to the limited size of the damaged areas.

As noted in the introduction to this report, hail is a unique weather phenomenon that varies in degree of intensity from imperceptible to catastrophic. This inherent natural spatial variability results in distinct differences in plant damage in a given agricultural field. With additional research on actual storm damage, imaging techniques could likely be developed that could help discriminate the actual amount of crop damage as opposed to the relative crop damage levels that we have demonstrated.

Scale and Spatial Resolution Requirements

Figure 5 demonstrates the difference between airborne imagery at 0.25 by 0.25 m and that at a 1- by 1-m spatial resolution for the corn and soybean plots. Crop row spacing can no longer be clearly seen in the 1- by 1-m imagery, but the individual plots are still easily discernible. When a crop adjuster is dealing with an individual farmer, it would be helpful to have an image based measurement tool that accurately defines field boundaries. In the "real" world, particularly in the United States, agricultural lands are divided into much larger plots than the corn and soybean experiments used in this ARC project. An operational system therefore will necessarily need to have a lower spatial resolution than was used on these test plots (0.25 by 0.25 and 1 by 1 m), but at the same time have the ability to accurately define field boundaries. It is our conclusion that an operational remote-sensing system for assessing hail damage in a typical U.S. agricultural setting would require pixels at approximately 5 by 5 m. This would allow cost-effective delineation of storm damage and still define field boundaries accurately enough for insurance adjustment purposes.

Landsat Thematic Mapper and Storm Damage Assessment

Plate 2 is a Landsat Thematic Mapper image showing a portion of a "hail streak" that resulted from a severe hailstorm on 02 July 1999 in west central Iowa. This image has a spatial resolution of 30 by 30 m and shows a typical midwestern agricultural setting in the United States. Agricultural fields with crops and those in fallow are discernible (Plate 2). However, with mixed pixels at the edges of the fields, a clear demarcation of individual farm field boundaries is not possible.

In Plate 2B, we demonstrate simple image processing techniques used to isolate image features of interest. In this case we used a Normalized Difference Vegetation Index (NDVI) and used it to separate areas of high and low vegetation amount (Plate 2A). We assumed that the low vegetation areas would include the hail-damage area and fallow fields. The fallow fields are obvious because most of them have regular rectangular shapes, and the hail damage areas usually have irregular or non-rectangular shapes. In Plate 2B, we isolated the hail damage from areas with healthy vegetation using an image masking technique. This was done so that additional image processing
Figure 3. Relationships for corn and soybeans between Leaf Area Index (LAI) and NDVI obtained from the ADAR 5500 multi-spectral imaging system and from simulating the ADAR broad bands using the data gathered with the Spectron Engineering (SE-590) spectroradiometer. The squares represent the “hailed” plots while the circles represent the “unhailed” plots.

Techniques (e.g., image classification) could be applied to provide useful information on the hailstorm (e.g., highlighting levels of vegetation damage) that could be used during planning for field operations within a week to ten days after a severe hailstorm.

Plate 2B shows the result of an unsupervised image classification performed on only the pixels with the low NDVI values—primarily the hail streak and surrounding fallow fields. The classified areas (gray tones) were then merged with the original false-color composite image that shows healthy vegetation in red tones. The yellow boxes in Plate 2B indicate where IGF Insurance Company paid crop-damage claims after the storm. Based upon the spatial differences within the storm damage area depicted, it is clear that the TM data are sensitive to the amount of hail damage. It is also clear that this kind of information on storm damage (location and relative severity) would be valuable if it were available prior to sending claim adjusters to the field to settle with farmers.

Conclusions
We concluded that
- Hail damage in corn and soybeans could be detected and mapped with remotely sensed imagery,
- The relative severity of damage to corn and soybeans could be detected and mapped with remotely sensed imagery.
Figure 5. Images showing the effect of decreasing spatial resolution from 0.25 by 0.25 m to 1 by 1 m at the corn and soybeans field experiments. The data at both spatial resolutions were acquired by the ADAR 5500 system. Row spacing between the crops is not evident visually in the 1- by 1-m data, but the information content of the 1- by 1-m images remains intact.

Plate 2. (A) NDVI image (~1380 km²) obtained from a Landsat Thematic Mapper scene showing a portion of a "hail streak" resulting from a severe hailstorm in west central Iowa, on 02 July 1999. The damaged area involves portions of two counties in Iowa (Carroll and Crawford). Healthy vegetation and croplands are shown in light-gray tones. The areas of the "hail streak" and unaffected fallow fields are in dark-gray tones. (B) The hail streak is shown after an unsupervised image classification procedure. The hail streak and surrounding fallow fields were then merged with the original false-color composite image that shows healthy vegetation in red tones. The yellow boxes indicate some areas where IGF Insurance Company paid crop-damage claims after the storm.
- Remotely sensed imagery with a spatial resolution of ~5 by 5 m is adequate for detection and mapping of hail damage in soybeans and corn.
- Remotely sensed imagery with a spatial resolution of 30 by 30 m would be adequate for preliminary post-storm damage assessment and planning.

**Project Metrics**
While remote sensing technology holds great promise for reducing insurance overpayments to farmers, there is no net gain or cost savings because lower net losses result in lower insurance premiums. Lower premiums that more accurately compensate farmers for crop-hail damage could induce more farmers to use this important risk management tool. However, the more direct net gains that we anticipate from this project are improved efficiencies (lower cost) in our crop-hail damage loss adjustment process, and secondly, more equitable and efficient operation of our insurance business. These improvements might in turn increase IGF’s market share due to more competitive pricing on crop-hail premiums. For IGF Insurance Company, total loss adjustment expenses are 3.5 percent of the $100 million in crop-hail premiums, or $3.5 million. If remote sensing technology could save 10 percent of this through improved survey of damages and easier settlement, savings would be $350,000 per year for the company. If the entire industry adopted the technology, then the savings could potentially be $2.8 million per year (0.35 percent of $800 million).

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**References**

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