Hailfall Characteristics Related to Crop Damage

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ABSTRACT

Collection of crop loss assessment values adjacent to hailpads has allowed a comparative investigation to determine which hailfall characteristics were related to the degree of loss to wheat, corn and soybean crops in Illinois. Establishment of such relationships is important information because it indicates which characteristics must be measured, either with hailpads or other hail-sensing devices, to provide meaningful evaluations of hail suppression project results and useful data for crop-hail studies. Because of factors related to the thickness of wheat stands, wheat losses were found to be closely related to the frequency of hailstones with diameters >0.25 inch. Corn and soybean losses exhibited varying seasonal relationships with either hailstone frequency and/or hailfall energy values. Corn losses in May related only to stone frequency, whereas corn losses in later growth stages (July–August) related well to both stone frequency and energy. A given number of hailstones falling in May produced considerably less corn damage than the same number in the June–August period. Soybean losses also related to both energy and stone frequency, although marked seasonal variations existed with each characteristic. An energy value of 1.0 ft-lb ft^{-2} produced, on the average, soybean loss of 12% in May, 15% in July–August, and 61% in June. Derived relationships indicated that 100 hailstones ft^{-2} (each >0.25 inch diameter) produced a 42% soybean loss in June, but only a 13% loss in July–August. The high correlations between crop losses and hailstone frequency and/or energy values indicate that potential crop losses in uncropped areas can be estimated from hail-sensing devices that measure both hail characteristics.

1. Introduction

There is an obvious need in hail field experiments, in hail suppression projects, and in agricultural hail studies for instrument-derived measurements that relate directly to crop damage. One goal of the Illinois hail research program has been to design and evaluate hail instruments (Changnon, 1969), and one of the design criteria was to obtain measurements of various hailfall characteristics that would be closely related to crop-hail loss. Earlier qualitative results using cooperative hail observer reports indicated that stone size was only weakly related to loss, and that the volume of ice and surface winds were more directly related to loss (Changnon, 1967). A three-year operation of a network of hailpads in rural central Illinois has provided a sample of hailfall characteristics measured adjacent to hail-damaged crops that is generally sufficient to discern quantitatively the characteristics related to the degree of loss to corn, wheat and soybeans.

The only hail-measuring instrument that has been used for sufficient time to furnish a sizable sample of hailfall data is the hailpad. The hailpad is a simple passive device, composed of a flat horizontal surface made of a semi-resilient material and wrapped in aluminum foil on which hailstones leave dents related to their size and impact. Various models of hailpads were developed at about the same time in Illinois (Wilk, 1961), Colorado (Schleusener and Jennings, 1960) and Oregon (Decker and Calvin, 1961). Although the hailpads developed in these three locations differed slightly in their construction and size, they each basically furnish a measurement of the total number and sizes of hailstones per storm. The calibration of these devices involving steel and plastic balls to simulate hailstones has been used to derive reasonably accurate estimates of their size, energy of impact, momentum imparted, and the total volume of ice that occurred per storm.

A basic assumption concerning these devices was that one, all, or some combination of the hailfall characteristics measured by the hailpad would be directly relatable to crop and/or property damage; the use of a hailpad, or any hail-sensing instrument, to verify the effect of hail suppression activities assumes such a relationship. This relationship is of particular importance in hail suppression areas where there are few or no crops either during portions of the operational season or in portions of the experimental area (Schleusener *et al.*, 1965; Butchbaker, 1969). Agricultural experiments to assess hail damage to crops have largely been based on simulated plant damage, whereby reductions in stand and defoliation have been artificially produced (Camery and Weber, 1953), and no serious efforts to measure and compare crop-hail damage with objectively measured hail characteristics have been pursued.

2. Data

The operation of a dense hailpad network in a 1000-mi^2 area in central Illinois during the growing seasons

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Table 1. Number of hailpad-loss pairs and hail days in the 1967–69 period.

	April		May		June		July		August	
	Pairs	Hail days	Pairs	Hail days	Pairs	Hail days	Pairs	Hail days	Pairs	Hail days
Wheat	2	1	25	2	7	1	0	0	0	0
Corn	0	0	9	2	5	1	9	3	4	2
Soybeans	0	0	4	2	21	4	5	2	1	1

of 1967, 1968 and 1969 resulted in data that could be used to compare the hailfall characteristics with actual crop-hail losses. During this three-year study period, all hail insurance companies having policies with the farmers of this area furnished adjustor worksheets completed for each paid claim in a given farm field, generally ranging from 20–80 acres in size. These worksheets showed three or four assessment locations within each field where the insurance adjustor had made an actual assessment of loss by a careful inspection of the damage to 100 plants at each location. The assessed loss at each location is expressed as a percentage of the expected crop yield.

During the three-year period, hailfalls occurred on 967 hailpads, with the data derived from each including the number of stones in various size classes, the total impact energy for the pad, and the total momentum value for the pad. The dates of these hailfalls and the hailpad locations were then compared with the insurance worksheets to select those cases where an assessment of crop damage had been made within 200 ft of a hailpad. Studies of hailfall variability over short distances in a dense hailpad network (Changnon, 1968) indicated that significant differences in hailfall characteristics frequently occurred across distances of 600 ft, whereas hailfall characteristics were very similar over distances $\leqslant 200$ ft.

This 200-ft or less restriction for deriving comparison pairs of loss-hailfall values greatly limited the number of samples, and only 92 instances of a hailpad with a nearby location of crop loss assessment existed. The 92 pairs consisted of 34 cases of wheat loss, 27 of corn loss, and 31 of soybean loss. Although this sample was found to be insufficient to totally define the relationships between hailfall characteristics and corn losses, the data appear generally adequate for wheat and soybeans, and give some indication of what hailfall characteristic to use in defining corn losses.

The pairs of hailpad-loss values were obtained from 12 hail days in the three-year period. The number of pairs and days with pairs for each crop are shown in Table 1. Wheat losses do not occur after June because the crop is harvested in late June to early July, and soybean and corn losses do not occur in April because these crops are not planted until late April to early May.

3. Results

The data for each of the three crops were analyzed independently. The initial analyses for each crop consisted of making scattergram plots of the percentage loss against the energy values, momentum values, and the number of stones (volume of ice) of different sizes. The dates of occurrence were indicated.

The scattergrams suggested certain relationships. First, there was no relationship between crop loss and the total number of hailstones per hailpad for any of the crops. However, losses to all three crops related well to the total number of hailstones with diameters >0.25 inch. Hereafter, all stone frequency values presented in this paper refer to the number of stones with diameters >0.25 inch per square foot, and energy values are in foot-pounds per square foot. Second, the comparative results for energy values and crop loss were very similar to those found for momentum vs crop loss; thus, only the energy results are presented in this paper. Most interesting was the fact that certain hailfall characteristics that related to the loss of one crop were not the characteristics that related to the loss of another crop.

Another interesting result was the marked difference in the relationships during the growing season for soybeans and corn. This is not unexpected since it has been shown that susceptibility of these crops to hail damage varies significantly during its growing period (Changnon, 1967).

In general, the two hailfall characteristics found to relate best to the degree of crop loss were the impact energy and the frequency of hailstones with diameters >0.25 inch, and results presented for each crop are limited to these two characteristics. However, the relationship between these two hail characteristics is not strong since the correlation coefficient between the 92 hailpad values amounted to only 0.35.

a. Wheat

The 34 wheat losses plotted against the values of energy and stone frequency appear in Fig. 1. Although the months of occurrence of each pair (a point on the graph) are denoted, there is no apparent seasonal variation. All of the 34 loss-hailpad pairs of values resulted from hailstorms within a 7-week time span, 28 April–22 June, and very little temporal change in the crop character or susceptibility to hail damage existed in this time span.

Results in Fig. 1 reveal that wheat loss is well related to frequency of the larger hailstones (volume of ice), but poorly related to the energy imparted by the hailfall. The frequency-loss correlation coefficient was 0.94 with

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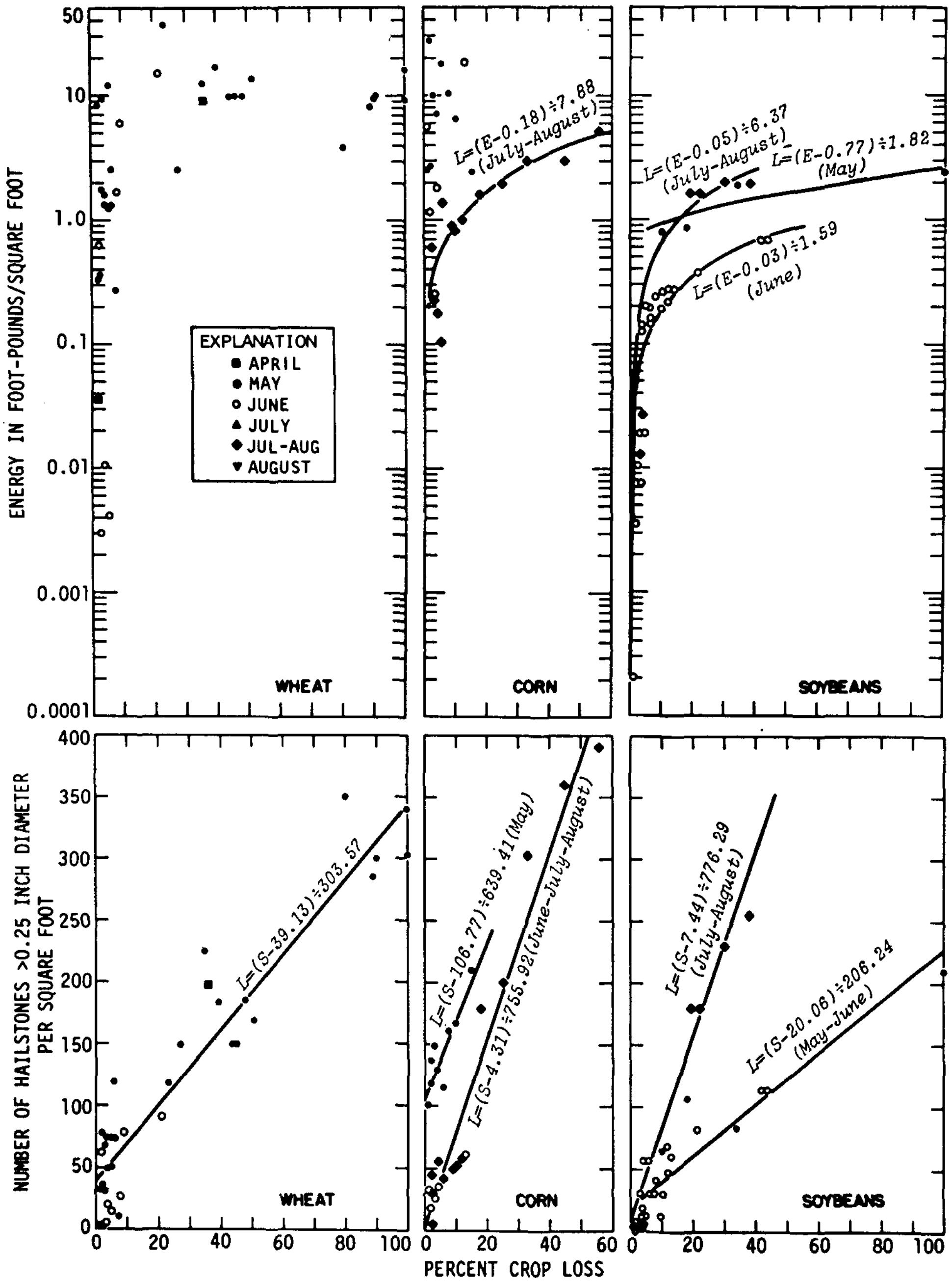

FIG. 1. Comparison of crop-loss percentages with hailfall data on frequency of hailstones (diameters >0.25 inch) and impact energy.

a standard error of 10% loss; a linear equation for this relationship is also shown in Fig. 1. As shown in Table 2, the correlation coefficient of wheat loss vs hailfall energy was low.

Reasons for a good wheat loss relationship with stone frequency, or volume of ice, and a poor relationship with hail energy appear to involve the physical nature of the crop and its planting density. Illinois wheat is normally densely planted in narrow rows (7 inches apart), resulting in a nearly uniform distribution in a field. Thus, it represents a "thick" crop compared with crops such as corn and soybeans. Since wheat is a relatively dense target for hail, it could be expected to experience greater loss as the volume of ice increases. Furthermore, wheat is also a flexible stem crop and bends easily in the wind. Thus, the high winds with hail that act to produce high hail energy values easily push the dense wheat plants over, and in this configuration they tend to partially shield each other from wind-blown hail because of their density (Hornaday and Changnon,

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1966). Hence, the energy of impact of hailfalls is not relevant as a damage-producing feature to wheat.

Canadian studies using hail observer data and qualitative reports of crop damage, largely to wheat, indicated that the maximum hailstone size and mass of ice per unit area correlated best with loss, having coefficients of 0.52 and 0.49, respectively[1]. Although these are lower correlations than found with the Illinois stone frequency data, they tend to substantiate the relationship between ice volume and stone size found for wheat loss in Illinois.

b. Corn

Graphs of the 27 corn loss values and their corresponding hail energy and hailstone frequency values appear in Fig. 1. Unfortunately, the highest corn loss located close to a hailpad was 56%. Seasonal differences appear in both graphs, and both stone frequency and energy values exhibit certain associations with crop loss.

Losses in May, when corn is emerging and quite small in Illinois, show no relationship with energy, but they do correlate well (Table 2) with the frequency of hailstones. However, the correlation must be treated cautiously since only 9 data points (pairs) were available, and no loss in May was greater than 15%.

Corn losses in the June–August period also related closely to stone frequency (Fig. 1), having a correlation coefficient of 0.98 (standard error of 3.5% loss). Curves based on the equations derived for the May and the June–August data indicate considerable seasonal difference, with a 10% loss in May resulting from 170 hailstones with diameters >0.25 inch in contrast to a 10% loss in the June–August period from only 80 such hailstones. This seasonal difference agrees with earlier results on the susceptibility of corn to hail damage which showed that the average hailstorm in Illinois in June causes three times more loss to corn than the identical storm does in May (Changnon, 1967).

June corn loss values did not relate well to energy values, but a loss-energy relationship existed in the July–August period (Fig. 1). The energy-loss correlation coefficient for this period (Table 2) was 0.96 with a standard error in loss of 4.9%.

c. Soybeans

The stone-frequency and energy-loss values to soybeans are also graphed and plotted in Fig. 1. The comparison of loss with stone frequency suggests two distinctly different seasonal relationships. The May–June and July–August correlation coefficients (Table 2) were quite high; however, the July–August coefficient must be treated cautiously because it is based upon only 6 pairs of values. Nevertheless, the results agree with earlier studies utilizing crop-hail data which indicated that soybean susceptibility to loss in June was 30–100% greater than in July and August (Changnon, 1965). Curves derived for the equations from the two-month relationships of stone frequency and soybean loss (Fig. 1) reveal that a 20% loss to soybeans in May–June was produced by 61 hailstones, whereas a 20% loss in the July–August period was produced by 163 hailstones.

Table 2. Linear correlation coefficients derived for comparisons of crop loss percentages and two hailfall characteristics.

Crop and periods	Frequency of hailstones ft^{-2} with diameters >0.25 inch	Impact energy (ft-lb ft^{-2})
Wheat		
April–June	0.94	0.38
Corn		
May	0.88*	0.26*
June–August	0.98	0.19
July–August	0.97	0.96
Soybeans		
May	0.90*	0.91*
May–June	0.91	0.87
June	0.86	0.96
July–August	0.97*	0.94*

* Based on less than 10 pairs of values.

The soybean-energy values (Fig. 1) suggest the existence of three different seasonal relationships, and their correlation coefficients (Table 2) were all high. Although only 4 pairs of May values were available, they appeared to have a distinctly different relationship than did the June values for energy and loss. For instance, a 40% soybean loss in June relates to an energy value of 0.66 ft-lb ft^{-2}, whereas a 40% loss in May relates to an energy value of 1.50 ft-lb ft^{-2}. A difference between the May and June soybean losses is not unexpected, since investigation of crop-hail insurance records (Changnon, 1965) showed that a hailstorm in June produced seven times more damage than the identical hailstorm in May in Illinois. As with frequency of stones, the July-August values for hailfall energy vs soybean loss suggest the existence of a third relationship, and a comparable loss requires a greater amount of energy in June than in July–August.

4. Conclusions

The investigation of the relationships between the degree of loss to three major crops and various hailfall parameters, as measured on hailpads, has shown that the degree of loss can be well estimated by one or two hailfall parameters. These parameters are frequency of hailstones with diameters >0.25 inch and the energy imparted by the total hailfall. One or both of these parameters related well with various crop loss values, with correlation coefficients $\geqslant 0.9$ for all three crops in all months of potential hail damage. This indicates that

[1] Summers, P. W., and L. Wojtiw, 1970: Hailfall characteristics and crop damage in Alberta. Paper presented at Fourth Annual Congress of Canadian Meteorological Society, Winnipeg.

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the hailfall parameters explained at least 80% of the variation in crop loss attributable to hail damage. The assessment of the crop-loss hailfall parameters and their mathematical relationship is especially important for hail suppression experiments where hailpads or hail-sensing devices are to be used to evaluate the effectiveness of the suppression program.

Wheat losses were found to relate only to the frequency of hailstones, but corn and soybeans losses related to both energy and stone frequency, at least in their later growth stages (July–August). The number of stones (volume of ice) damages corn and soybean plants largely by producing leaf defoliation. However, losses from the force of the hail impact (energy), which is strongly related to high wind speeds and consequently more horizontal components for hailstones, are largely a result of bruising and/or breaking of the plant stems, corn ears, or the bean pods.

Although correlations between loss and the hailfall characteristics were high, inspection of Fig. 1 reveals that many losses of less than 10% were not particularly well associated with any of the hailfall characteristics, and particularly not with stone frequency. This poor association for losses $<10\%$ was found in all crops, and it appears that such low losses are extremely difficult to assess accurately. Possibly the minor damages being assessed as hail losses are actually wind-related losses that occurred during a storm when some minor amount of hail fell.

Seasonal variations in loss-hail relationships found for soybeans and corn appeared realistic and in agreement with earlier results on the susceptibility of these crops to hailfall damage.

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