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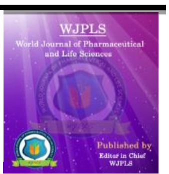

HAIL-FALL PARAMETERS RELATED TO CROP INSURANCE COMPENSATIONS IN NORTHERN GREECE

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ABSTRACT

The Greek National Hail Suppression Program (GNHSP) is a cloud-seeding program applied with aerial means (airplane) by the Hellenic Agricultural Insurance Organization (ELGA), as an action to mitigate the losses from damages caused by hail in agricultural cultivation. To evaluate the program, a network of hailpads is used to measure a range of parameters of hail-fall in the national administrative region of Central Macedonia of northern Greece. A statistical analysis of the hail-fall data and associated crop insurance data reveals a linear relationship between the natural logarithm of the total kinetic energy per square meter of the hailstones and the natural logarithm of the ratio of the corresponding compensation paid for damage caused by the hail-fall to the total insured value of the crop production. This indicates that the kinetic energy of hailstones can be used as a performance index for the GNHSP in accordance with the requirements of the international standard ISO 9001:2015.

KEYWORDS: Hail, hailpad, kinetic energy of hail, crop damage, linear regression, Hail Suppression Program, ISO.

INTRODUCTION

Hail damage is one of the most devastating category of crop loss. Researchers worldwide have found that hail fall variables like the impact kinetic energy per unit area, hail mass per unit area, momentum, mean diameter and number of hailstones per unit area are correlated to the crop injuries.[1,2,3,4] The objective of the present study is the statistical analysis of a range of hail-fall variables obtained from data measured in the field, in order to reveal the least number of parameters necessary to appropriately express the data set. Furthermore, a preliminary examination is done to determine the relationship between hail-fall parameters and associated crop insurance data. For the statistical analysis the IBM SPSS v22 software package is used.[5]

A goal of the study is to define a performance index for the Greek National Hail Suppression Program (GNHSP) that meets the requirements of the International Organization for Standardization standard ISO 9001:2015.[6] More specifically, the aim is to investigate which hail-fall parameters that are measured using a hailpad network could be related to recorded crop damage and insurance payments in the area protected by the GNHSP in northern Greece.

The Hellenic Agricultural Insurance Organization (ELGA) is the main insurance carrier of plant production and livestock in Greece. The insurance provided by ELGA is fulfilled by assessments of crop losses with the payments of corresponding compensation and additionally by the establishment of programs for active protection.

The GNHSP, which is a cloud-seeding program with aerial means (airplanes), is applied by ELGA as an action in the framework of active protection to mitigate the damages caused by hail in agricultural cultivation. In the national administrative region of Central Macedonia in northern Greece a hailpad network was installed and operates in order to evaluate the program.

MATERIALS AND METHODS

Hailpad network and hail measurements

Within the study period the GNHSP operates a network of 154 hailpad stations.[7] in an area of 2,700 km^2, with each hailpad corresponding to a mean spacing of 4.2km. During the hail period, from March 20th to September 30th every year, the network is under continuous service. Every hailpad is replaced when is affected by a hail storm or when is exposed in the field for more than 30 to 35 days.[8] The hailpad network was established in the context of evaluating the GNHSP during the period 1984

– 1988 and has continued operating for this purpose up to the present day.

The hailpad is a simple yet effective meteorological instrument for the study of hail-fall. The instrument was introduced in 1959,[9] and has been used subsequently by many researchers, for the study of the characteristics and climatology of hail and in the evaluation of hail suppression programs.[8,10,11,12,13]

The hailpad used within the GNHSP and used in this study consists of a pad of Styrofoam mounted horizontally in a metal case at the top of a pole, about 1.5 m above the ground, so that the upper surface of the Styrofoam, with a dimension of 0.27m×0.27m, is exposed to the hail. The exposed upper skin of the Styrofoam is smooth and is painted with an aqueous mixture of white wall-paint emulsion for protection against the solar radiation.[7,8]

The response of the instrument is a dent formed on the surface of the pad, caused by the impact of an individual hailstone. Using the dents observed, the researcher has to draw conclusions about the characteristics of the individual hailstone and the calibration of the instrument is an essential stage in the measurement of certain characteristics of the hailstone. The calibration is done using the "Energy-Matching - EM" technique,[9] which depends on the assumption that "spheres of equal diameters create dents of equal minor axes when the spheres have equal impact kinetic energy". This assumption has been validated experimentally.[11] Furthermore, the calibration of the hailpads and data reduction assumptions stated in the literature.[8,9,14] are accepted and have been used in the GNHSP.[7] These assumptions are summarized briefly as the following: (a) hailstones have a spherical shape; (b) hailstones that impact the ground are rigid; (c) the density of all hailstones is ρ_h=890kg/m^3; (d) the drag coefficient of hailstones is C_d=0.6; (e) hailstones fall vertically onto a hailpad with their terminal velocity and (f) hailstones hit the hailpad once. After the calibration procedures are done a mathematical relationship of the form $y=\beta_0+\beta_1\cdot x$ is derived between the calibration standards (steel spheres) used - and the responses of the instrument.[2,7,8] This mathematical relationship is used to transform the responses of the instrument (the minimum diameters of the dents left on the surface of the pad) to estimate the diameters of the hailstones responsible for the formation of the dents. Within the GNHSP an inverse regression method is used to derive the calibration equation, according to which the minimum diameter of the dent is considered to be the independent variable "x" and the diameter of the steel ball is considered to be the dependent (response) variable "y".[15,16,17]

Measurement of the diameters and other parameters of the dents like the area, shape and orientation at impact, is done using an application built on the Image-Pro® Plus software.[18] The minimum diameters of the dents recorded are used with the calibration equation to estimate the diameters of the hailstones. Consequently, we are able to estimate other parameters of the hailstones including Mass and the vertical component of the Kinetic Energy and the Momentum.

After the estimation of the diameters and other parameters of all the hailstones hit a hailpad, all the results are included in a record containing the date of the event, the number of the hailpad, the sampling area, the minimum, maximum and median diameter of all hailstones, the total number of hailstones, the total mass, total momentum and total kinetic energy of all hailstones and the classification of the hailstones in size classes differing by 1mm, starting from 5mm, which is the minimum diameter of precipitated ice that is characterized as hail [19]. The number of a size class is the center of the class, for example all the hailstones with diameters from 7.500mm to 8.499mm are classified in the size class of 8mm. The values of the parameters mass, momentum and kinetic energy are calculated from the exact value of the diameter of each hailstone. Summing the values of each parameter for all hailstones the total values of the parameters total mass, total kinetic energy and total momentum which recorded on the surface of the hailpad are calculated. The values of the parameters number of hailstones per square meter, mass per square meter, kinetic energy per square meter and momentum per square meter, are calculated by dividing the total value of each parameter by the area of the hailpad (the sampling area).

Hail-fall and crop insurance parameters

The present study examines the following hail-fall parameters:

1. HAF: The ratio of the area with dents to the sample area,
2. MD: The total mass of hailstones per square meter (SI),
3. KED: The total kinetic energy of hailstones per square meter (SI),
4. MOD: The total momentum of hailstones per square meter (SI),
5. MaxD: The maximum diameter of hailstones in mm,
6. HFD: The number of the hailstones per square meter.

Each observation refers to a hail event that is recorded on a hailpad for a specific day with the values of the above hail parameters.

The parameter variables are characterized by examining their frequency distribution, descriptive statistics and inter-parameter correlations. Additionally, a Principal Component Analysis (PCA) is applied in order to reduce the dimensions of the data set and to examine the representation of each parameter in the entire data set.[20] The above analysis is done using the IBM SPSS v22 statistical software package.[5]

In the sequence, the crop insurance parameters are examined. The first crop insurance parameter is the sum of individual compensations in Euros that are paid by the insurance organization ELGA within each Municipal local community for any damages arising from natural causes that are covered by its insurance regulations. At present this covers hail events that cause documented damage to plant production during a specific seasonal period. The second insurance parameter is the sum of the insured value in Euros, for the crop production within each Municipal local community each year, according to the annual cultivation statements submitted by the growers to the insurance organization ELGA.

The ratio of the compensation paid (due to damage by hail on a specific date in a Municipal local community) to the total insured value of the crop production in that local community is the parameter named as "LOSS". In the present study the parameter LOSS is used to describe the damage caused by hail to crops.

Finally, the relationship between the hail-fall and crop insurance data sets is examined with a regression analysis.[15,16,21] To normalize the data prior to doing a linear regression analysis a natural logarithm transformation is used for all the hail-fall variables and the crop-damage variable.[2,15,16,21]

A Linear Regression is done using six different models, where each model uses one of the hail-fall parameters as an independent variable and the crop-damage parameter LOSS is used as a dependent variable. The regression analysis is done using the IBM SPSS v22 statistical software package.[5]

RESULTS

A data set of 204 observations is obtained during the hail period extending from March 20th to September 30th during the 6 years (2011 to 2016) of the study period. This data set is consisted from the values of the six hail-fall variables HAF, MD, KED, MOD, MaxD and HFD, and the corresponding crop-damage variable LOSS.

Hail-fall data set

The measures of central tendency and variability of the examined hail-fall variables are shown in Table 1. The values of skewness and kurtosis indicate the spread and shape of the distribution of each variable.

Table 1: Measures of the central tendency and variability for the hail-fall data.

	HAF	MD	KED	MOD	MaxD	HFD
Mean	.035	.378	31.28	4.77	11.86	1584
Std. Error of Mean	.004	.036	3.57	.49	.32	142
Median	.011	.139	8.53	1.52	10.86	731
Mode	.000[a]	.001[a]	.052[a]	.011[a]	5.59[a]	23.7[a]
Std. Deviation	.051	.517	51	7	4.56	2024
Variance	.003	.267	2601	49.1	21.1	4097589
Skewness	2.09	1.99	2.98	2.36	1.76	2.31
Std. Error of Skewness	.17	.17	.17	.17	.17	.17
Kurtosis	4.26	3.93	11.56	6.68	3.86	6.12
Std. Error of Kurtosis	.34	.34	.34	.34	.34	.34
Range	.256	2.737	347	43.26	26.51	10995
Minimum	.000	.001	.052	.011	5.596	11.88
Maximum	.257	2.738	347.05	43.27	32.11	11006
Percentile 25%	.003	.037	2.41	.42	8.95	261
Percentile 75%	.053	.540	38.91	6.51	13.26	2103

a. Multiple modes exist. The smallest value is shown

A descriptive summary of the hail-fall variable KED is given in Figure 1, which shows a graphical frequency histogram and summary box plot of the data collected in the study period. Similar distribution patterns are observed in the other five hail-fall variables.

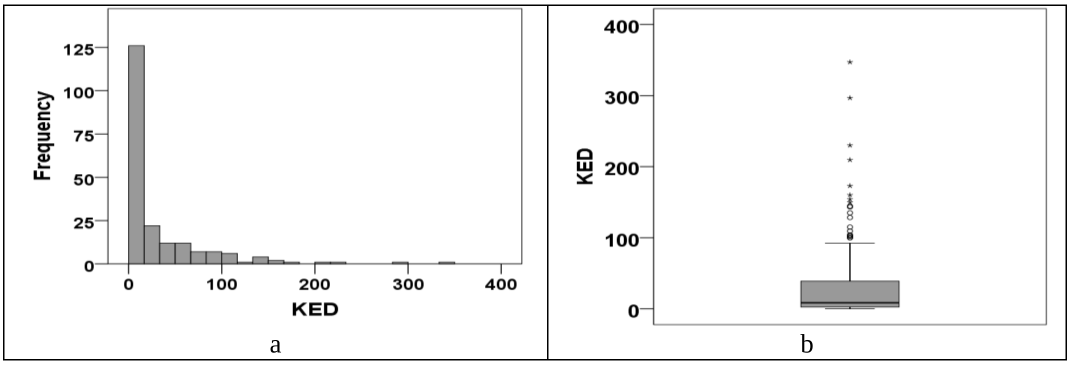

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Figure 1: Histogram (a) and Box plot (b) for the hail-fall variable KED.

Table 1 and Figure 1 show that the mean values of all variables examined in this study are greater than their corresponding median value and that the maximum values lay far apart from the 75% percentile. The values of skewness and kurtosis show the data are respectively right-skewed and form leptokurtic distributions.

The six hail-fall variables examined in this study are expected to show positive correlations between each other. The strong natural associations are confirmed by the values of the non-parametric Spearman's rho correlation coefficients shown in Table 2 (two tailed p-values <0.001).

Table 2: Non parametric Spearman's rho correlation coefficients (p<0.001 in all cases).

	HAF	MD	KED	MOD	MaxD	HFD
HAF	1					
MD	.993	1				
KED	.992	.994	1			
MOD	.994	.998	.998	1		
MaxD	.831	.810	.857	.834	1	
HFD	.915	.932	.893	.914	.606	1

Furthermore, the Principal Component Analysis (PCA) is conducted in order to reduce the dimensions of the data set [20]. Taking into account the strong correlation between the hail-fall variables, is examined how much representative could be every one of the variables for the whole data set. As expected, the solution expressed by only one component, which accounts for 84% of the total variance.

Table 3 shows that all six hail-fall variables are contained in this one component with high values of loadings. Additionally, the explanation of the parameters by the unique component is shown from the high values of the Communalities and specifically from the values greater than 0.92 for the first four parameters, which are MD, MOD, HAF and KED. As a result, each of these four variables could express the whole data set.

Table 3: Table of Component of PCA.

	Component 1 Loadings	Communalities
HAF	.981	.963
MD	.991	.982
KED	.960	.921
MOD	.989	.978
MaxD	.744	.553
HFD	.784	.614

Crop-damage data set

Similarly, the measures of central tendency and variability of the corresponding crop-damage variable LOSS are shown in Table 4. The values of skewness and kurtosis indicate the spread and shape of the distribution of the variable.

Table 4: Measures of the central tendency and variability for the LOSS variable.

Mean	.036	**Variance**	.004	**Range**	.375
Std. Error of Mean	.004	**Skewness**	3	**Minimum**	.00008
Median	.012	**Std. Error of Skewness**	.17	**Maximum**	.375
Mode	.00008[a]	**Kurtosis**	9.88	**Percentile 25%**	.003
Std. Deviation	.062	**Std. Error of Kurtosis**	.34	**Percentile 75%**	.036

a. Multiple modes exist. The smallest value is shown

A descriptive summary of the data set for the LOSS variable is given in Figure 2, which shows a frequency histogram and the box plot for the data collected in the study period.

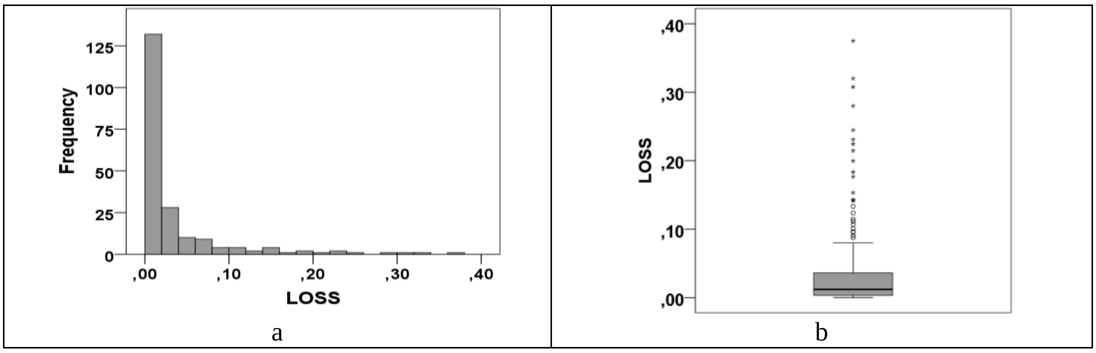

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Figure 2: Histogram (a) and Box plot (b) for the LOSS variable.

The LOSS data shown in Table 4 and Figure 2 are analogous to the hail-fall data in Table 1 and Figure 1. As with the hail-fall data the mean value in the LOSS data is greater than the median and the maximum values lay far apart from the 75% percentile. Similarly, the values of skewness and kurtosis also show the LOSS data are respectively right-skewed and form a leptokurtic distribution.

Relationship between hail-fall and crop-damage variables

According to the results of the descriptive analysis of the hail-fall and crop-damage variables presented above, further analysis of the relationship between those variables is done with a natural logarithm transformation to normalize the data. The coefficient of determination R^2 for the six linear regression models using a natural logarithm transformation are shown in Table 5.

Table 5: The coefficient of determination R^2 for the six linear regression models.

Model	R^2
LnHAF - LnLOSS	0.397
LnMD - LnLOSS	0.396
LnKED - LnLOSS	0.413
LnMOD - LnLOSS	0.406
LnMaxD - LnLOSS	0.350
LnHFD - LnLOSS	0.293

Table 5 shows that the linear regression model with LnKED as the independent variable and LnLOSS as the dependent variable gives the highest value of R^2 (0.413). This result is in line with previous findings, which show that the kinetic energy of hailstones is associated strongly with resulting crop damage.[1,3,4,14,21]

Figure 3 shows box plots of the variables LnKED (a) and LnLOSS (b).

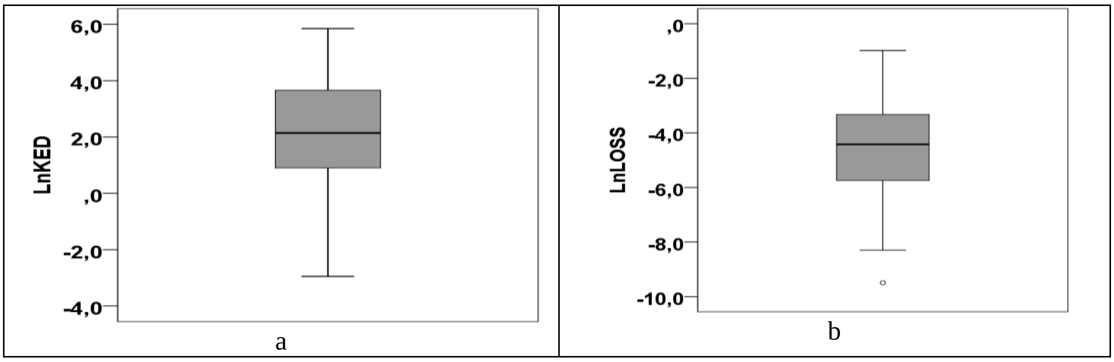

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Figure 3: Box plots of LnKED (a) and LnLOSS (b).

Figure 4 shows the result of a linear regression with the independent hail-fall variable LnKED and the dependent crop-damage variable LnLOSS with the equation: LnLOSS = -5.78 + 0.59*LnKED

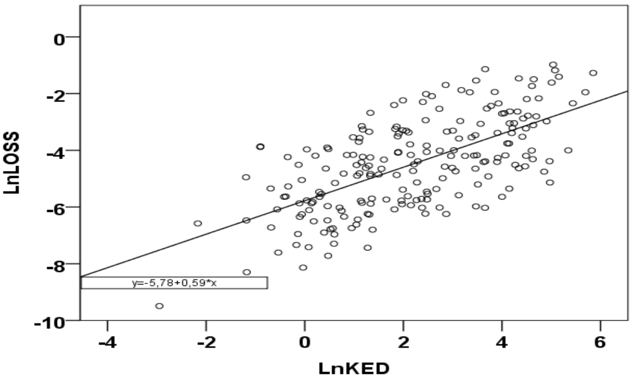

Figure 4: Scatter plot of LnKED and LnLOSS with the fitted linear regression.

The R^2 value of 0.413 ($p<0.001$) shows that the independent variable LnKED contributes significantly to the proposed model and could be used to determine the value of the dependent variable LnLOSS. Additionally, the assumption of normality in the transformed data is confirmed ($p=0.05$) with a Kolmogorov – Smirnov normality test of the residuals.

Figure 5 shows the normality of the residuals in a plot of the standardized residuals. In addition, a scatter plot of standardized residuals with the predicted values confirms the linearity and homoscedasticity of the data as the residuals are distributed randomly around zero and their variances are almost constant along horizontal axis.

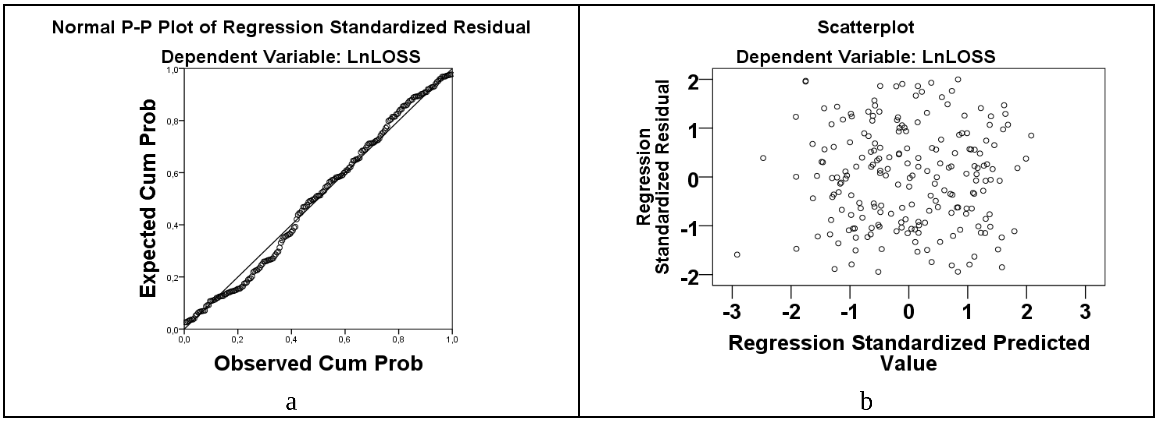

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Figure 5: Normal P-P plot of the regression standardized residuals (a) and scatter plot of the regression standardized residuals with the predicted value (b).

DISCUSSION

The statistical analysis of the hail-fall data set incorporates six hail-fall parameters and comprises 204 observations of individual recorded hail events over the six years period 2011-2016. Parameters measured in the 204 hail events include the ratio of the area of hail dents to the sampling area (HAF), the total mass of hailstones per square meter (MD), the total kinetic energy of hailstones per square meter (KED), the total momentum of hailstones per square meter (MOD), the maximum diameter of hailstones (MaxD) and the number of hailstones per square meter (HFD). The analysis reveals that the six parameters are highly correlated with each other. As a consequence, only one parameter is needed to adequately represent the data and further analysis shows that the total kinetic energy of hailstones per square meter (KED) is the best variable for this purpose. The parameter KED is used in an effort to relate hail-fall characteristics with the crop-damage LOSS parameter, which is derived from an associated data set involving crop insurance and compensation payments.

A linear regression with all the hail-fall parameters shows that the natural logarithm of the total kinetic energy of hailstones per square meter (LnKED) provides the best predictor of the dependent crop-damage variable (LnLOSS). Measurement of hail recorded in the hailpad network (specifically the kinetic energy of hail) can therefore be used with a linear regression equation to calculate the value of the crop-damage variable LOSS. An important result is this equation can also be used to make early predictions of the corresponding compensations a crop insurance organization (eg. ELGA in Greece) would have to make to growers in a local community due to crop damage caused by a hail event on a particular day.

A limitation of the linear regression model, noted from the data used here, is that the value of the determination coefficient is relatively low (R^2=0.413). This is because the hail-fall data (originating from the hailpad network) are point data while, in contrast, the insurance data apply to a wider area, in this case a municipal district. In the future, an attempt should be made to collect matching insurance data at a distance closer to each hailpad to improve the model and help make early predictions using the model more reliable. The possibility of developing a more reliable model is supported by the encouraging results of the present study, which confirm the results of similar studies in other countries and also highlight the specific relationship between the kinetic energy of hail and degree of crop damage that results from a hail event.

CONCLUSION

Finally, it is concluded that the kinetic energy of hailstones provides a suitable performance index that can be used in accordance with the requirements of an international standard[6] to evaluate hail suppression programs, such as in the Greek National Hail Suppression Program (GNHSP). More specifically the total kinetic energy of hailstones (the sum of the kinetic energy of hailstones for every hail event recorded on a hailpad on specific days) can be calculated to express an annual value of the performance index for a given hail period. For example, the hail period in the region of this study in northern Greece occurs between March 20th and September 30th. Additionally, an annual value of the performance index can also be compared with the average annual value of a suitable period, for example with the previous five years, as a way to further evaluate a hail suppression program.

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