ON THE DAMAGE REDUCTION IN BULGARIAN AND HUNGARIAN HAIL SUPPRESSION PROJECTS

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Abstract. The lower confidence bound of mean damage reduction in continuous operative hail suppression activities is estimated. The investigations are based on historical comparison of crop-hail insurance data. Several statistical tests, both classic and permutation ones, are applied in parallel, and their suitability under different climatological conditions is compared. A short overview is given of the insurance systems and hail suppression techniques in the countries in question.

1. INTRODUCTION

Due to its complexity, the problem of evaluation of operative hail suppression effects is still topical and often controversial. Some recent papers (e.g. Federer et al., 1982) have criticized Soviet and other Eastern European evaluations based on historical comparison of insurance data.

The main reason for these uncertainties is the problem of control data. As is well known, researchers answer the question "what would have happened without seeding?" using one of the following methods or a combination thereof: randomization, control area and historical comparison. In commercial seeding projects, however, randomization is impossible because of the nature of the operation itself. Similarly, there are unavoidable difficulties in the selection of an appropriate control area for any weather modification activity. This is especially true in the case of hail suppression projects, since they operate on the most hail-threatened territories. Thus, historical comparison seems to be the only possible solution. We fully share the opinion of Gabriel (1979): in many non-randomized operations "...the operational period is of considerable length - we will henceforth refer to it as a year - and is decided on well before it begins. It would seem valid to compare such years statistically to previous, and subsequent, unseeded years, and I strongly urge, that such comparisons be made for all suitable operations."

Insurance data are also used in the investigation of hail suppression effects (Miller et al., 1976, Goyer and Renick, 1980). Crops are very good indicators of hailfall area and hailfall intensity because of their dense exposure. It is considered that some integral characteristics of crop damage reflect accurately, though indirectly, the integral physical hailfall characteristics, in spite of some external factors like wind, heavy rain, different sensibility and stage of growth. In this paper the changes in physical characteristics and the relation between them and losses are not dealt with. This latter relationship is considered here as the "black box". The external behaviour of hail loss is investigated under the influence of an external factor (seeding). In our case there is another reason for using insurance data: Hail suppression is sponsored by the insurance companies in these countries, and these companies are interested in the final effect of seeding upon losses.

Of course, the reliability of results depends on the representativeness of insurance data and appropriateness of applied statistical methods. The recently more and more widely used permutation tests (e.g. Miller et al., 1979, Hsu et al., 1981, Federer et al., 1982) seem to be the most effective aids in evaluation. One of the aims of this paper is to shed light upon their reliability with respect to Bulgaria and Hungary. In the present study an attempt is made to estimate the lower bound of confidence interval of mean efficiency of continuous operative hail suppression activities for periods longer than 5 years. The change in crop damage expressed in terms of seasonal values of insurance losses is evaluated. Several statistical tests are applied in parallel and also their suitability under different climatological conditions is investigated.

Some papers have already been published on the history, technique and organization of hail suppression operations in these countries, but less has been written on the insurance system from the point of view of hail suppression evaluation. Therefore a brief review is presented in the following section of this paper. It is intended mainly to show what data our investigations are based on.

2. MAIN FEATURES OF HAIL SUPPRESSION AND INSURANCE SYSTEMS IN BULGARIA AND HUNGARY

2.1 Hail suppression

In Bulgaria one of the first established hail suppression polygons was selected from the now existing system of 9 polygons. The term "polygon" refers to a treatmemt area with its own radar centre and 10 to 15 launching sites. In this territory seeding operations began on 25th June, 1969, using Soviet "Oblako" and "PGI-M" rockets and covering an area of 600 square kilometers /40 % of the present polygon area of 1460 sq km/. Because of the small number of seeded areas and the late beginning date, 1969 is assigned to the historical (control) data in this investigation. In 1970 the work was not done fully as prescribed, because of technical and organizational problems.

Therefore, this year may be considered neither seeded nor control and is excluded from this analysis.

Since 1971 hail suppression operations have been carried out over an area of 1480 sq km using "Oblako", "Alazan" and "PGI-M" rockets. X-band radar and the complex K-index (Borovikov et al., 1967) based on radar parameters were implemented for hail-cell location until 1975. In 1976 an S-band radar and A-index were implemented, based on a discriminanat function (Petrov and Boev, 1977).

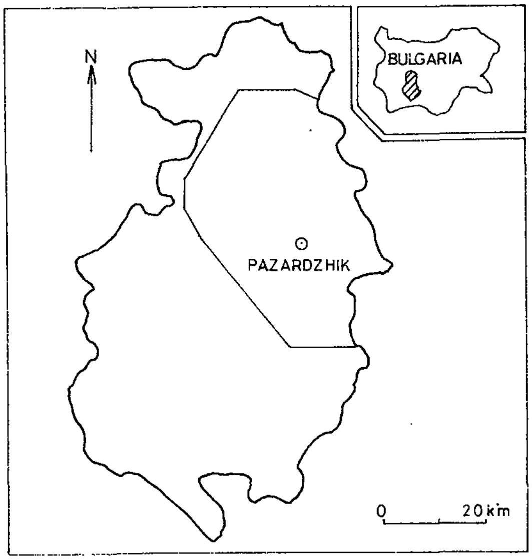

Figure 1a: Pazardzhik county (Bulgaria) with the protected area of the Gelemenovo polygon.

In Hungary hail suppression began at the end of July, 1976. The system consisted of eleven launching sites equipped with "Oblako" and "PGI-M" rockets, the seeded area was about 1200 sq km. The convective cells were selected by means of the K-index. The conditions did not change until 1982. In 1983 the system was strenghtened with four new launching sites and an S-band radar. Also the seeding criterion was substantially changed that year.

In both countries the seeding reagent is lead iodide /PbI_2/. During the operation every suitable cell is seeded unless it is impossible due to technical reasons (aircraft flights, equipment break-downs, etc.). However the losses of these cases are also taken into account, since the effects are investigated under long-term working conditions. It must be stressed that the described hail suppression activities are not experimental but operational ones. In spite of this the terminology of experiments is used in Section 3.1.

2.2 Insurance system

In Bulgaria and Hungary, State Insurance Institutes deal with insurance matters, so the systems are unified within both countries.[x] Since the overwhelming majority of all agricultural land belongs to collective property, only the data of agricultural cooperatives and state farms are dealt with in this paper. On the investigated areas the crop-hail insurance coverage for these lands is about 90 percent. Multiple-peril crop insurance is applied in both countries[x] but the losses are recorded according to perils. In Bulgaria, however, this latter holds only for the protected area (since 1982).

Liability and loss, used in the investigations which follow, are determined essentially according to the folowing formulas:

liability= insured area x unit price

loss= damaged area x crop x unit price x percent of loss.

insured area: self-explanatory

crop: equals the planned crop multiplied by a factor in Bulgaria. This factor is fixed annually by the Insurance Institute, in the range of 50-60 %.

In Hungary this quantity is a matter of agreement between the Insurance Institute and agricultural cooperatives upon implementation of the policy but must exceed 70% of the planned crop. However, if the estimated crop is less than that insured, the former is taken into account upon determination of loss.

unit price: is fixed in the beinning of the crop season. In Bulgaria it equals the price that the state purchase agencies would pay for the crop. In Hungary this equality holds only roughly.

damaged area and

percent of loss are determined by adjusters of the Insurance Institute according to well defined rules. If this percent does not exceed 5%, the loss is not paid, otherwise the full loss is paid.

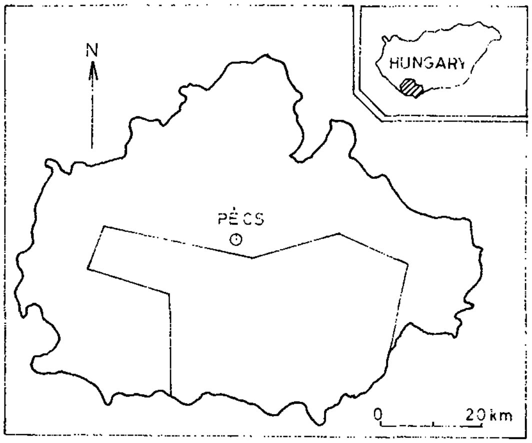

Figure 1b: Baranya county (Hungary) with the protected area.

Although there are also other rules for calculation of loss (e.g. in Hungary quality losses are paid in certain cases), their contribution to the yearly loss is negligible. The insurance system changed twice in both countries during the investigated period but these changes did not affect the above formulas.

3. IS THERE ANY REDUCTON IN DAMAGES ?

3.1 The experimental unit and the response variable

The calendar year was chosen as the experimental unit and the yearly hail losses of the investigated areas as the response variable. Our experimental unit may seem a bit long to weather experimenters accustomed to days, storms

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[x] The situation has since changed in Hungary.

or convective bands, but it has great advantages and offers the possibility of unbiased analysis (for a good summary of experimental units used in weather modification see Gabriel, 1979) because:

- The no-hail winter months admirably separate the subsequent suppression periods and yearly hail losses.
- The suppression of a given year has no effect on the hail losses of the succeeding year because of the five months inactive winter period.
- Totals over 20-30 hail-days cause the yearly losses to show muchess relative variability than the daily data.
- Our experimental units can be regarded much more independent from one another than the ones above mentioned, although Changnon (1977) reports on multi-year trends in hail activity in the United States. On the basis of the available data the existence of such trends in our countries can be neither ruled out nor confirmed for such small areas.

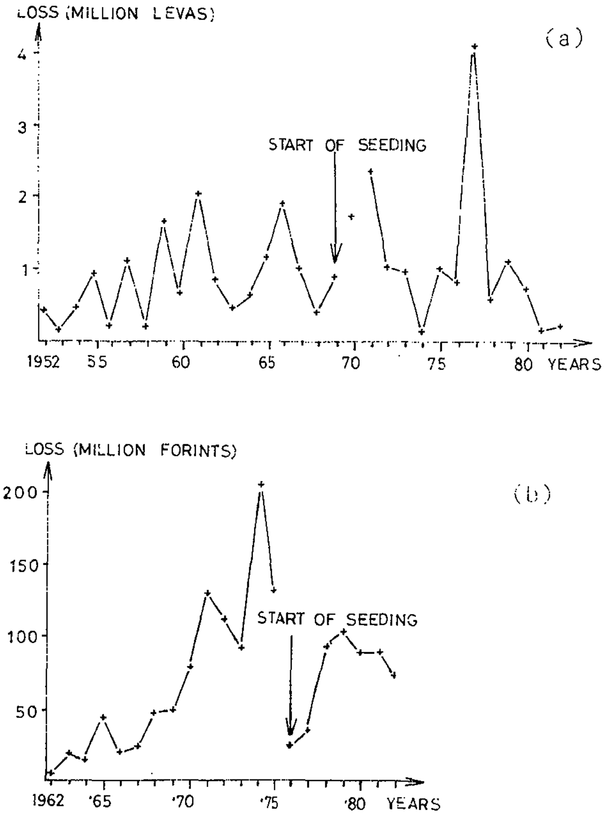

Figure 2: The yearly hail losses on the Gelemenovo area (a) and in Baranya (b).

In Bulgaria only the losses of the experimental area (Fig 1a.) are investigated. Compared to the historical data given in Stanchev and Simeonov (1982), the series here is extended back to 1952 with the aid of insurance archives. Earlier data are not available. In Hungary historical data are available from 1962 and only for the entire county of Baranya (area 4500 km^2, Fig.1b.). The latter is not a great porblem, however, and may even have some advantages:

a. a relatively large portion of the agricultural production in the county is concentrated in the experimental area
b. for the entire county only the experimental area was damaged regularly by hail
c. there is a wide "dead" zone on the southern perimeter of the experimental area. About 50% of the convective cells move from S or SW in our region (Győre and Söver, 1984) and, inasmuch as it is forbidden to launch rockets over the Jugoslav border, cells penetrating the area from Jugoslavia can be seeded only when they are already above the outermost launching stations (Fig. 1b.)
d. because of the downwind effect the damages are also expected to decrease on the non-experimental part of Baranya.

The response variable can not be used in its original form since it is evidently affected by the growth of crops and prices (Fig. 2.). This effect can be demonstrated by the relation of hail losses to liability (amount of insurance). This relation is quite strong is Hungary (Fig. 3b.) and can be assumed to also exist in Bulgaria (Fig. 3a.).

In the present paper two methods are used to eliminate these economical changes from the data. The first is to characterize the experimental units by the loss cost, that is the percentage of losses in liability (Fig. 4.). The other is the use of liability as a predictor variable. The predictor function ought to be linear since in the case of given crop and hail characteristics the loss is in direct proportion to the liability, the size of loss being dependent only on the noted factors.

In Gelemenovo (Bulgaria) the "half-seeded" year 1969 was designated a historical one so the predictor function was constructed on the basis of eighteen historical data points (1952-69, see Section 2.1) using least squares regression. The function is:

$$P = 0.02 \cdot L + 264 \qquad (1)$$

and

$$\mathrm{var}(R - P) / \mathrm{var}(R) = 0.946$$

where L denotes liability, and P and R are predicted and real losses, respectively. (The data are in thousand Levas[1].) The correlation coefficient of the sample is 0.22, so the real correlation coefficient does not differ from zero at the 95% significance level. (Ezekiel and Fox, 1959.) The relation is very weak, and the causes of bad fitting are evident if one looks at Fig. 2a.: the Bugarian loss data show a great variability. Because of this weak connection the fluctuations of losses can be explained by the heterogeneity of the weather.

It is worth noting that in Gelemenovo the seeded year 1977 produced unusually high losses. This datum is an outlier in the statistical sample of losses, however, the loss cost of this yer is extreme but can not be considered as an outlier. Hence for the sake of comparison two variants are investigated for Bulgaria: both with and without

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[1] 1000 Levas = 1144 US Dollars at the Bulgarian National Bank on 17th March, 1987.

1977 (1st and 2nd variant). The data for 1970 were always rejected (see Section 2.1.).

In Baranya county (Hungary) the year 1974 produced extra high hail losses. To avoid the overestimate of the expected losses, this year was regarded as an outlier and was not taken into account. Nor were the last years (1983-86) used in order to preserve the homogeneity of the data (see Section 2.1.). This allowed the predictor function to be calculated from the data for eleven years at

$$P = 0.08 \cdot L - 59477 \qquad (2)$$

P fits highly to the data (Fig. 3b.) and

$$\text{var } (R - P) \;/\; \text{var } (R) = 0.106$$

(Every datum is in thousand Forints[2].) The correlation coefficient of the sample is very high: 0.95, which means that the real correlation coefficient is not less than 0.81 at the 95% significance level. (Ezekiel and Fox, 1959).

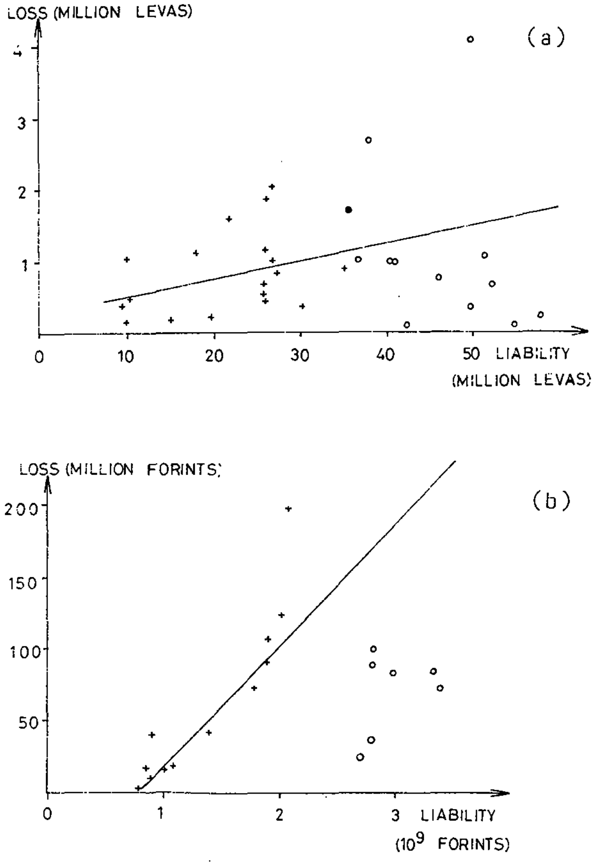

Figure 3: The dependence of hail losses on liability on the Gelemenovo area (a) and in Baranya county (b). (x: unseeded years, ● : experimental year, o: seeded years) Regressions (1) and (2) are also showed.

The above mentioned regressions are assumed to take into account all economical changes in the investigated period. In this way the deviations from the regressional line originate from the variability of hail. Attempts were made to find meteorological predictors (Wirth et al., 1984) but without success. For this reason, in addition to the loss costs, the residuals of regressions (1) and (2) are used hereafter to characterize the experimental units.

3.2 The applied statistical tests

Very little is known about the stochastic behaviour of yearly damage from hail. This is the reason we perform five parallel tests, each having special assumptions about the investigated quantities. Seeding is expected to reduce hail loss, thus one-tailed versions of the tests are used.

3.2.1 Treatment intervention

Since this random assignment procedure is quite unusual in weather modification experiments, it is dealt with in detail here. If the experimental units are allocated subsequently in time, one may randomly choose one of them for the beginning of seeding, that remains in effect over all the subsequent units. This way one has a control and an experimental (seeded) period. Although the individual experimental units are not randomly selected for seeding, the randomization tests can produce valid significance values for the difference of the two periods if they follow the above assignment procedure at the re-randomizations.

These experimental conditions perfectly fit our operations. The only requirement is that the beginning year of the hail suppression be chosen randomly. Given that preliminary steps and also the decision for introduction of suppression had been made well before the first rockets were launched (Wirth, 1984, Stanchev and Simeonov, 1981), and that the length of preparatory period from the original idea to the beginning of the operative work depended on a variety of human factors, the beginning date may be regarded as random.

The difference of means can be used as a test statistic:

$$TS_1 = \frac{X_C}{N_C} - \frac{X_S}{N_S} \qquad (3)$$

where X_C and X_S denote the sum of investigated quantities (loss cost or residual) for control and seeded units, respectively , and N_C and N_S denote the number of units. Its distribution is computed on a re-randomization basis. Naturally, the re-randomizations must imitate the experimental randomization. In the case of treatment intervention this means that the original order of successsion of experimental units must be maintained, a year is chosen randomly and the test statistic is evaluated as if this year were the first one with seeding. Since one needs at least one seeded and one control year, there are seventeen possible assignments of intervention in Hungary and 30 (31) in Bulgaria (1st, 2nd variant), thus the smallest possible values are $1/17 \approx 0.059$ and $1/31 \approx 0.032$ ($1/30 \approx 0.033$), respectively.

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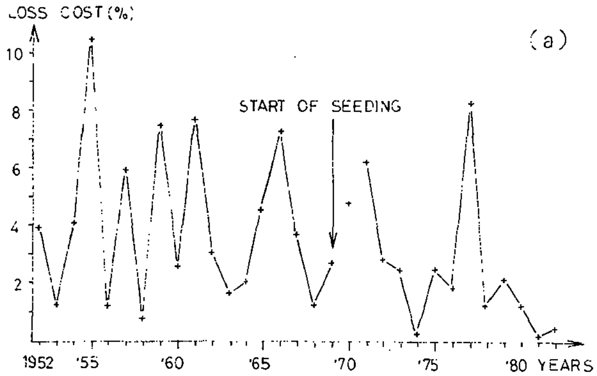
[2] 1000 Forints = 21.17 US Dollars at the Hungarian National Bank on 16th March, 1987.

This small number of possible randomizations is a great disadvantage of the method and in our case the result can be taken as a general indication only. In spite of this, the test is performed and is intended to persuade experts of the possibility of scientific evaluation of non-randomized weather modificaton operations.

Edgington (1980) mentions treatment intervention as a one subject method used sometimes in behaviour modification studies. Although the experimental units have a similarly natural order in our case, no one would state that the weather of a territory is one subject in as strict a sense as a human being or an animal is. The interdependence of our experimental units is weak if it exists at all, and in the following tests their order is not preserved.



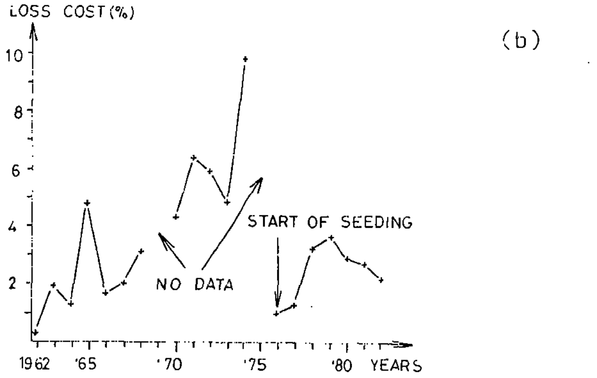


Figure 4: The yearly loss costs on the Gelemenovo area (a) and in Baranya (b).

3.2.2 Wilcoxon test

This well-known method has already been applied to loss costs in Bulgaria (Stanchev and Simeonov, 1982). It requires only randomness and independence. These questions were discussed in the work noted and the test may be performed without further comment. The test statistic (the sum of ranks) will be denoted by TS_2 henceforth.

3.2.3 Sum test

Why not use, as a test statistic, the sum of investigated quantities themselves over the seeded period, instead of the sum of their ranks? The test statistic

$$TS_3 = X_S \tag{4}$$

is expected to be more sensitive than TS_2 since it uses more information from the seeded sample. The approximate distribution of TS_3 is determined by 5000 re-randomizations of the whole data set. During these calculations the number of "seeded" units remains unchanged as in the case of Wilcoxon test.

3.2.4 Student's t-test

As is well known this test can only be applied to normally distributed data with equal variances. The available data are unsufficient to check whether these requirements are met and the application of this test is merely performed for the sake of comparison, with its reliability assumed as a matter of faith.

3.2.5 The randomization version of t-test

If the assumptions of the above test are not met, the t-value still can be used as a measure of inequality of expected values, but its distribution differs from that given in the tables and can be obtained by re-randomizations of the data. Throughout the re-randomizations both the order and the number of experimental units may change. The subsequent years are regarded as seeded or control independently of each another with a probability of 0.5, and the only requirement is that there must be at least two seeded and two control units. The distribution of $\underline{t}$ is approximated here using 5000 re-randomizations.

To summarize, treatment intervention, Wilcoxon test and Student's t-test are applied for special reasons noted above and the remaining two tests are considered both correct and effective.

3.3 Results, discussions

Results of statistical tests are shown in Tables 1 and 2. These tables contain one-sided p-values for different presumed damage reductions according to the five applied tests. p-value is the probability that the observed value does not exceed the predicted value. In particular, when the aim is to point out the mere existence of some seeding effect, p-value is the probability that there is no desired change in the investigated quantities (rows of zero reduction in the tables).

Using residuals of regression (1) and (2) almost every test yielded positive results for every variant (Table 1.). However, p-value exceeded 0.05 only in the case of treatment intervention for all three investigated series.

The situation is similar with respect to Bulgarian loss costs (Table 2.). At the same time, surprisingly, it is not possible to demonstrate any reduction on the basis of Hungarian loss costs: every test supports p-values greater than 0.05. This shortcoming must be caused by the expressed trend which is a very intersting and, for the time being, unexplainable feature of Hungarian loss costs (Fig. 3b.). One can take this trend into consideration by choosing quadratic predictor function, instead of linear, to estimate loss from liability. This produces a very good fit: the ratio of variation is 0.076. In spite of this the linear estimation is maintained since theoretical considerations lead to this model.

The results support the existence of some demonstrabe relationhip between cloud seeding and damage reduction, so one can step further and ask the question:

4. HOW GREAT IS THE DAMAGE REDUCTION ?

4.1 The measure of reduction

First of all let us define the measure of the damage reduction:

$$E = \frac{N - R}{N} \cdot 100\% \qquad (5)$$

where E denotes damage reduction in percent, N the natural loss without suppression and R the loss actually incurred (Wirth et al., 1984, Stanchev and Simeonov, 1980). From a certain point of view this quantity could also be called the effectiveness of hail suppression. From (5)

$$N = \frac{100}{100 - E} \cdot R \qquad (6)$$

That is, the effect is assumed to be multiplicative. A given value of E belongs to the confidence range of reduction if (6) gives a realistic N value in the sense that the loss cost and the residual computed with N as loss do not differ significantly from that of control years. Since this paper aims at proving the use of hail suppression, lower confidence bounds are given, exceeded by the reduction with great probability, and consequently only the lower one-sided p-values are determined. For this purpose the above five tests are used again.

There is a problem, however. Although the multi-year mean damage reduction is investigated, the application of the mentioned methods (apart from Student's t-test) demands the determination of N for every year separately and involves the naming of yearly damage reductions. A great variety of these can result in the same mean reduction. One can see that greater mean reduction could be proved by supposing greater reduction in years with fewer losses. In spite of this, in the absence of a better well-grounded solution to date, equal reductions are assumed for every year. There are opinions that seeding is more effective in weak storms and less effective in more severe ones, which may result in different damage reduction in different years. In Stanchev and Simeonov (1980) some differences in effect are shown using energetic predictors, though only for a short period. Using the same data-base, an attempt was made to find some theoretical explanation for the different degree of efficiency when seeding hail processes of varying severity, according to the concept of competition (Buykov et al., 1981). But still no reliable quantitative criterion exists for such classification of clouds, hail days or seasons. Nevertheless, one fact remains which supports the assumption of equal damage reduction,namely, that the suppression method remained unchanged during the entire period investigated in Hungary and was changed only once in Bulgaria. Thus investigations were carried out with the assumption of equal damage reductions.

4.2 Results, discussions

Results of statistical investigations are shown in Tables 1 and 2. The assumed damage reductions are increased in five-percent steps until p exceeds 0.1. There is no point in refining this scale, for two reasons. First, if it is not possible to state that the reduction <u>is</u>, say, 40 percent (and one may not expect such a declaration from statistics), in the present case it hardly matters whether 30 or 32 percent is exceeded with great probability. Second, in our experience, two re-randomizations under the same circumstances typically result in p-values differing by 0.01 - 0.02.

In Bulgaria both loss cost and residuals suggest reductions exceeding 10-15 percent for the first variant and 30-35 percent for the second variant. The similarity of results given by the different method is very encouraging.

There is a great difference between reductions obtained on the basis of the 1st and 2nd variant. One unusually high loss, the extraordinary data of ther year 1977, decreases the provable reduction by about 20 percent. If, however, we rejected the assumption about the equality of damage reductions in years of suppression, then our results would be better. If we assumed that in the year 1977 the polygon worked less effectively and the damage reduction was less than in other years, the natural loss derived by formula (6) for year 1977 would not be so extreme as it was before, and for this reason tests would support better results than they did in our basic case. So it is very likely that the real damage reduction is between those obtained for the 1st and the 2nd variant.

The situation is quite different in Hungary. The results do not suggest any reduction using loss costs. On the other hand, residuals of regression (2) support a damage reduction not less than 50-55 percent, which is the best result of this investigation. At first glance this great difference is very surprising, but it might be explained by causes mentioned in Section 3.3.

The Bulgarian results are not as encouraging as those for Baranya, but, in spite of this, one can not say with certainty that the damage reduction is higher in Baranya than in Gelemenovo, since the significance of difference is not investigated. The different results might be explained by the different features of hail phenomenon in these two territories. This situation might be improved by using meteorological predictors.

One may notice that the results given in this article are not as promising as those previously published (Stanchev and Simeonov, 1980, 1981, 1982). This is not a real contradiction, however. It has already been mentioned that the aim of the present paper is to give the least acceptable damage reductions and if the object were to construct a confidence interval then this interval would probably contain the earlier published results. For example a confidence interval at the 90 percents level constructed for the first variant of Bulgarian data using randomization variant of t-test is (0.1, 0.75).

damage reduction	treatment intervention	Wilcoxon test	sum test	Student's t-test^x	randomization t-test
Bulgaria (Gelemenovo, Pazardzhik county) without 1970					
0	.484	.006	.048	.040	.046
5		.010	.070	.062	.067
10		.021	.110	.097	.107
15		.023		.158	
20		.055			
25		.069			
30		.111			
Bulgaria without 1970 and 1977					
0	.367	.001	.002	.001	.001
30		.052	.057	.053	.056
35		.087	.108	.100	.105
40		.155			
Hungary (Baranya county)					
0	.059	.000	.000	.000	.000
20	.118				
50		.050	.014	.008	.004
55		.110	.060	.090	.057
60			.161	.181	.135

Table 1: The one-sided p-values for different supposed damage reductions on the basis of residuals of regressions (1) and (2).
(x: interpolated values)

damage reduction	treatment intervention	Wilcoxon test	sum test	Student's t-test^x	randomization t-test
Bulgaria (Gelemenovo, Pazardzhik county) without 1970					
0	.258	.017	.026	.022	.004
5		.029	.034	.029	.016
10		.037	.052	.044	.049
15		.048	.069	.065	.067
20		.069	.100	.090	.093
25		.129		.151	.134
Bulgaria without 1970 and 1977					
0	.162	.004	.004	.004	.004
30		.067	.048	.043	.041
35		.098	.071	.068	.071
40		.144	.113	.109	.111
Hungary (Baranya county)					
0	.059	.230	.172	.158	.170
5	.118				

Table 2: The one-sided p-values for different supposed damage reductions on the basis of loss costs.
(x: interpolated values)

5. CONCLUSIONS

The above results strongly suggest a hail damage reduction on the investigated territories However, the degree of reduction is not determined as clearly. Moreover, there is no exact proof, that this reduction is caused by hail suppression only.

The present evaluation should only be considered a preliminary, a first step toward the estimation of the effectiveness of hail suppression in these countries. These results should be confirmed at a later date.

The difference of methods giving the best results and the difference of results themselves are caused probably in part by the different climatological and agricultural charateristics of Bulgaria and Hungary. This strongly indicates the necessity of choosing the response variable according to the local conditions and then choosing the statistical method according to the characteritics of the response variable.

This topic needs further investigation. The most burning question is that of the meteorological predictors for yearly losses. Also the problem of assuming equal damage reductions for every year should be examined and the presence of the noted trend in Hungarian loss cost data should be explained.

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