# EFFECTIVENESS OF HAIL CONTROL IN SERBIA

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Abstract. The artificial modification of hail formation in the SR of Serbia has been organized and operating according to principles similar to those developed in the U.S.S.R. The hail control system in Serbia covers about 4 million hectares of agricultural surface, which is one of the largest connected areas protected by such a system in the world.

After a period of 17 years of continuous operation an evaluation of its effectiveness has been made. This evaluation is based on the statistics of the size of hail-swept areas, percentage of the damaged crops and the frequencies of hail occurrences observed in the regular network of meteorological stations.

The size reduction of hail-swept areas in protected territory show a decrease of an estimated 63% when compared to unprotected territory. A 22% reduction in hail frequency is suggested by the data analysis according to observations at meteorological stations.

## 1. INTRODUCTION

Almost a quarter of a century ago Russian scientists (Karcivadze, 1964; Fedorov, 1965; Gajvoronskij and Seregin, 1965; Sulakvelidze, 1967) reported some very promising results from their hail control operations. These results were not based on the present day knowledge of the physics and dynamics of clouds, but on the hypothesis of the competition of nuclei of crystalization, which are generally deficient in hailstorm clouds. For that reason, many specialists in cloud physics and weather modification in other countries were sceptical about the results reported by Soviet scientists.

In order to prove the real efficasy of the Soviet hail control operating method, several hail suppression field experiments were organized; i.e. the National Hail Research Experiment in Colorado and Grossversuch in Switzerland. These randomized experiments did not show any significant hail control results (Knight et al. 1979; Federer et al. 1986). However, the methodology and the seeding technique used in the NHRE and the size of target area in Grossversuch were not the same as those applied in the U.S.S.R.

On the other hand, the Soviet sciences have constantly reported very optimistic results from their hail control operations (Izrael, 1983; Sedunov, 1986). So, a dilemma on a hail control problem, which is of a great scientific and economic value, remains. The aim of this paper is to contribute to the solution of this problem.

## 2. METHODOLOGY OF HAIL CONTROL IN SERBIA

The hail control system, developed in the U.S.S.R. and applied in Serbia, had four basic components (Radinović, 1972).

1) Determination (by radar) of the place of initiation of hail formation and growth in cloud;

2) Selection of reagent, which causes crystallization and freezing of supercooled drops in clouds;

3) Timely delivery of the reagent into the hail formation zone in the cloud; and

4) Evaluation of the results of the action.

Determination of the position of the growth zone in clouds, in the beginning of the hail control operations (1969-1977), had been made by Soviet radar, MRL-1, on wave length of 3.2 cm, and by military radars, 3MK-7, of wave length 10.0 cm. During the period 1978-1980 eight military radars were replaced by Japanese meteorological radars, RC-34A, of wave length 10.0 cm. In the period 1981-1984, four more radars of the same type were replaced.

In the first half of the period (1969-1978) anti-hail rockets, the Sako-6, produced in Yugoslavia, were used. These rockets had a range of 3,500 m and carried 400 g of silver iodide mixed with the burning mixture. Discharge of the reagent took place along about 400 m of the last part of the rocket path, giving $10^{11}$-$10^{12}$ ice niclei per gram of the mixture.

In 1979 new anti-hail rockets, Tg-10, were introduced in the hail control system of Serbia. The range of these rockets was 8,500 m, and the weight of the silver iodide mixture was the same. However, the reagent was greatly improved giving about $10^{13}$ ice nuclei per gram.

At the same time, the methodology of radar identification and seeding of the place of initiation of hail formation and growth was improved. That zone was precisely determined as a half a ring in front of the Cb cloud comprising the layer between $-8^{o}C$ and $-12^{o}C$ with the radius dependent on the speed of cloud. The goal was to have each $m^3$ in that zone seeded by $10^5$-$10^6$ artificial ice nuclei.

On the basis of the above mentioned changes, it may be concluded that the hail control system in Serbia in the period 1978-1980 was greatly improved. Another important feature of that system was its continued extenssion until 1985 when about 95% of the agriculture surface of Serbia became covered by the hail control system. So, in recent years the hail control system has consisted of the 12 radar centers (hail control polygons) and about 1,300 hail rocket launching stations. These stations were connected by radio communications with the radar centers.

3. DATA USED IN EVALUATION

The hail control system in Serbia was not organized in a way to produce any particular data to set aside for evaluating the effectiveness of the system itself. Therefore, the evaluation of the effectiveness of hail control in this case has been based on two sources of data, which have been obtained independently of the hail control system. These are:

1) The size of the hail-swept agriculture area in hectares;

2) The percentage of the crops damaged; and

3) Frequency of hail occurrences observed at the regular network of meteorological stations.

The statistics of the size of the hail-swept area and percentage of the crops damaged have been obtained in a very specific way. Namely, the Parlament of SR Serbia many years ago established a law which required farmers income taxes be reduced in proportion to the percentage of hail damaged crops. Particular execution of has been taking place through qualified commissions, which have been set up by local authorities (the municipalities). Copies of the reports, made by these commissions, were sent to the Republic Hydrometeorological Institute of Serbia, which is conducting the hail control operations.

The quality of these data may be estimated in a following way. The typical size of a hail-swept area takes a few hundred to a few thousand hectares, and a typical size of an individual farmer's property is a few hectares only (in average less than 3 hectares). Since every individual farmer's property should be estimated, the possible error in determining the size of the hail-swept area is usually less than 1% of the total hail-swept area.

The estimation of the percentage of damaged crops is more delicate. It depends on the sort of crops as well as on its pheno-phases, which are usually not homogeneous. As a consequence the possible errors in this kind of data are estimated to be up to 10% of their total values.

Another problem connected with this data source was their collection. Every year certain municipalities did not send their reports to the Republic Hydrometeorological Institute of Serbia. Their data were missing in this analysis, particularly in the first part of the hail control operating period.

The network of meteorological stations in Serbia was reconstructed after World War II and started to work regularly 1949. From that year the total number of synoptical and climatological stations was changing from 47 as a minimum to 72 as a maximum. The average for the whole 37 year period (1949-1985) was 57 stations. The observations of the frequencies of hail occurrences have been published by the Federal Hydrometeorological Institute of Yugoslavia (Meteorological annual I - series 1949 to 1985).

In addition to these two aforementioned sources of data, the statistics of interruptions in the hail control operations in this analysis were used. These interruptions were caused partly by technical difficulties and partly by the Air Control Agency. Also, the statistics of the changes in methodology and technique of the hail control system were used to some extent.

4. EVALUATION BASED ON THE SIZE OF HAIL-SWEPT AREAS

The data used for the evaluation of the hail control system effectiveness, based on the size of hail-swept areas, are presented in Table 1. The hail-swept areas in protected territory in the cases when the system was not operating ($S_p^+$, column 4) are contained in the hail-swept areas, when the system was operating ($S_p$, column 3). The size of the observed territory $O_u$ is defined as the part of the unprotected territory $T_u$ for which the municipalities were sent commission reports about the hail damages. The calculations in this paper, concerning the hail damages in the unprotected territory, have been in relation to $O_u$ and to $T_u$ as the most unfavorable variant.

From the Table 1 it may be seen that the total agricultural area of Serbia (protected and unprotected) during the period 1971-1987 has been changed very little. It was decreased by 80,683 hectares or about 2%. A second important feature, that can be noted from Table 1 is the nearly steady increase of protected and decrease of unprotected territories. At the beginning of the period concerned, the protected territory amounted to about 28%, while at the end of the period it reached 95% of the total agricultural area. In spite of an increase of the protected territory by about 3.3 times, the size of the hail-swept area has been not changing very much and even shows some decrease.

Also, it may be noticed that the hail-swept area in the protected territory when the hail control system was not operating ($S_p^+$) was very large in the first half of the period. In that time the Air Control directed the aircraft by the radio beacon; as a result the prohibition of the anti--hail rocket launching were frequent and long lasting. At the same time, the hail control system was in a developing phase and frequently was not working.

Using the data shown in Table 1, the percentage R of hail-swept area in the protected and unprotected teritories has been calculated as

$$R_{p,i} = \frac{S_{p,i}}{T_{p,i}} 100\%, \quad R_{u,i} = \frac{S_{u,i}}{O_{u,i}} 100\%,$$

$$r_{u,i} = \frac{S_{u,i}}{T_{u,i}} 100\%$$

and corresponding mean values

$$\bar{R}_p = \frac{1}{N} \sum_{i=1}^{N} R_{p,i}, \quad \bar{R}_u = \frac{1}{N} \sum_{i=1}^{N} R_{u,i},$$

$$\bar{r}_u = \frac{1}{N} \sum_{i=1}^{N} r_{u,i}$$

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Table 1. Sizes of protected ($T_p$) and unprotected ($T_u$) territories, hail-swept areas with ($S$) and without ($S^*$) operations and observed territory ($O_u$) in Serbia

| Years (1) | $T_{p}$(2) | $S_{p}$(3) | $S^*_{p}$(4) | $T_{u}$(5) | $O_{u}$(6) | $S_{u}$(7) |
|---|---|---|---|---|---|---|
| 1971 | 1130350. | 52003. | 30671. | 2909232. | 1750899. | 162424 |
| 1972 | 1093255. | 47526. | 25399. | 2948352. | 1889942. | 129823. |
| 1973 | 1137978. | 52762. | 37620. | 2879347. | 1198894. | 99519. |
| 1974 | 1184775. | 40818. | 23115. | 2839379. | 1260940. | 103398. |
| 1975 | 1648612. | 33727. | 13978. | 2375157. | 1733315. | 147994. |
| 1976 | 1888658. | 25936. | 2274. | 2126470. | 992721. | 54831. |
| 1977 | 2326575. | 120969. | 53023. | 1669271. | 1226792. | 112721. |
| 1978 | 2455712. | 67050. | 11783. | 1542450. | 622468. | 49972. |
| 1979 | 2912735. | 48387. | 940. | 1083221. | 711785. | 20370. |
| 1980 | 3079377. | 64043. | 2003. | 914658. | 462653. | 31920. |
| 1981 | 3133651. | 61767. | 25855. | 852049. | 299149. | 20488. |
| 1982 | 3330067. | 64823. | 0. | 657126. | 344121. | 38068. |
| 1983 | 3385784. | 31217. | 0. | 580994. | 266323. | 8800. |
| 1984 | 3753002. | 39313. | 0. | 220549. | 107181. | 1259. |
| 1985 | 3760870. | 23669. | 0. | 198029. | 0. | 0. |
| 1986 | 3760870. | 54837. | 3938. | 198029. | 28412. | 682. |
| 1987 | 3760870. | 33719. | 0. | 198029. | 28412. | 18. |

Table 2. Percentages of hail-swept areas at protected ($R_p$) and unprotected ($R_u$, $r_u$) territories as well as their ratio ($Q$, $q$)

| Years | $R_p$ | $R_u$ | $r_u$ | $Q$ | $q$ |
|---|---|---|---|---|---|
| 1971 | 4.60 | 9.28 | 5.58 | 0.496 | 0.824 |
| 1972 | 4.35 | 6.87 | 4.40 | 0.633 | 0.989 |
| 1973 | 4.64 | 8.30 | 3.46 | 0.559 | 1.341 |
| 1974 | 3.45 | 8.20 | 3.64 | 0.420 | 0.948 |
| 1975 | 2.05 | 8.54 | 6.23 | 0.240 | 0.329 |
| 1976 | 1.37 | 5.52 | 2.58 | 0.249 | 0.531 |
| 1977 | 5.20 | 9.19 | 6.75 | 0.566 | 0.770 |
| 1978 | 2.73 | 8.03 | 3.24 | 0.340 | 0.842 |
| 1979 | 1.66 | 2.86 | 1.88 | 0.580 | 0.883 |
| 1980 | 2.08 | 6.90 | 3.49 | 0.301 | 0.596 |
| 1981 | 1.97 | 6.85 | 2.40 | 0.288 | 0.821 |
| 1982 | 1.95 | 11.06 | 5.79 | 0.176 | 0.337 |
| 1983 | 0.92 | 3.30 | 1.51 | 0.279 | 0.609 |
| 1984 | 1.05 | 1.17 | 0.57 | 0.892 | 1.842 |
| 1985 | 0.63 | **** | **** | ***** | ***** |
| 1986 | 1.46 | 2.40 | 0.34 | 0.607 | 4.294 |
| 1987 | 0.90 | 0.06 | 0.01 | 14.152 | 90.000 |

The last formulas are not the best ones for estimating the mean R, as they weight all years equally even though, e.g., $T_p$ in 1987 is 3.3 times $T_p$ in 1971. We use, therefore, additional formulas

$$\bar{\bar{R}}_p = \Sigma S_{p,i}/\Sigma T_{p,i}, \quad \bar{\bar{R}}_u = \Sigma S_{u,i}/\Sigma O_{u,i}$$

Here i=1,2,...,N denotes year in the period and N the number of the years in the period. Further simple formulas for evaluating the effectiveness of hail control are

$$Q_i = \frac{R_{p,i}}{R_{u,i}}, \quad \bar{Q} = \frac{\bar{R}_p}{\bar{R}_u}, \quad \bar{\bar{Q}} = \frac{\bar{\bar{R}}_p}{\bar{\bar{R}}_u}$$

which give the ratio between the percentage of hail-swept areas in the protected and unprotected territories.

The results obtained by these calculations are presented in Table 2. In this Table it may be readily seen that from the beginning to the end of the period of operation the percentage of size of hail-swept area in the protected territory was gradually decreasing. During first few years it amounts to about 4% and in the last few years it amounts to about 1%. The percentage of hail-swept area in the unprotected territory from 1971 to 1982 was all the time rather high, from 5.5 to 11.0% except for the 2.9% in 1979. During the last 4-5 years the percentage of hail-swept area suddenly dropped. That could be a result of drastic decreasing of the size of unprotected territory. In that time it was already reduced to about 5% of the total agricultural area in Serbia and became surrounded by much larger protected territory.

The mean percentage of the hail-swept area in the protected territory amounts to $\bar{R}_p$ = 2.41% ($\bar{\bar{R}}_p$ = 1.97%) and in the unprotected territory $\bar{R}_u$ = 5.80% ($\bar{\bar{R}}_u$ = 7.60%). It gives mean ratio $\bar{Q}$ = 0.42 ($\bar{\bar{Q}}$ = 0.26) and an effectiveness expressed by formula $E = 1-\bar{Q}$ of 0.58 or 58% ($\bar{\bar{E}}$ = 0.74 or 74%).

In order to analyse the characteristics of the series of percentages of hail-swept areas in protected and unprotected territories, we shall apply the Abe's statistical test to investigate the trend of decreasing the size of hail-swept areas. This test uses the formula

$$q = \frac{\Sigma(X_{i+1} - X_i)^2}{\Sigma(X_i - \bar{X})^2}$$

where $X_i$ denotes a member and $\bar{X}$ mean value of the series considered. The existence of trend is characterized by small and non-existence by high value of q.

As a consequence of improvement of methodology and spreading the hail control system to greater territory, in the case that the hail control system has been efficient, a trend of percentage of hail-swept area decrease in the protected territory should exist. On the contrary, such a trend in the unprotected territory should not exist.

In application of Abe's test, the periods of 17 years for $R_p$ and 14 years for $R_u$ and $r_u$ are used. Namely, in the last three years of the period considered the unprotected territory became very small so that the percentages of hail-swept area were unrepresentative. After the abovementioned formula the results obtained as follow:

$R_p$: q=0.405 n=17(1971-1987) $P(q \leq 0.405) \leq 0.005$

$R_u$: q=0.790 n=14(1971-1984) $P(q \leq 0.790) = 0.210$

$r_u$: q=0.980 n=14(1971-1984) $P(q \leq 0.980) = 0.470$

These data show that a significant trend of percentage of hail-swept area decrease exist in the protected territory with a probability of 99% to be true. At the same time such a trend in the series of percentages of hail-swept areas in the unprotected territory has been not noted.

Further, the sign test is applied using null hypothesis Ho: no difference in number of negative (-) and positive (+) signs is true, than

$$P(-) = P(+) = 0.5$$

with an alternative that $P(+)>0.5$. If T represents the number of negative signs than small number of signs (-) is characteristic for Ho.

The difference $Z = R_u - R_p$ is positive in all years, i.e. T=0 and according to this test the probability that hail control system in Serbia is efficient amounts to 100%. However, if we take the most unfavorable case, i.e. that in the part of the unprotected territory for which the reports were not received, $Z = r_u - R_p$, we obtain

$$T = 2 \quad n = 14 \quad P(T \leqq 2) = 0.0065$$

That means that between the percentages of hail-swept areas in the protected and unprotected territories a significant difference exist.

In order to be more confident in the aforementioned conclusion, the Student's test for investigation of the mean value of difference (coupled samples) to series $Z = r_u - R_p$ is applied. This test is made using the formula

$$t_o = \frac{\bar{Z} - m}{\bar{S}_z} \sqrt{n}$$

where $\bar{Z}=0.96$ represents the arithmetic mean value of the series considered and $\bar{S}_z = 1.45$ is standard deviation.

This test has $t_{n-1}$ distribution, i.e. Student's distribution with n-1 degrees of freedom. Simbol m in formula is assumed (theoretical) mean value. In our case we consider the series Z for which according to Ho is taken to be m=0. In that way we obtain

$$t_o = 2.48 \quad \text{and} \quad P(t_o \geqq 2.48) \leqq 0.01$$

showing that between $\bar{r}_u$ and $\bar{R}_p$ a significant difference exist. Also the Wilcoxon matched-pairs signed-ranks test, which utilizes both the direction and the relative magnitude of the differences within pairs, gives

$$n = 14 \quad T = 14 \quad P(T \leqq 14) < 0.01.$$

That means that the difference between the percentage of hail-swept area in the unprotected territory taken as the most unfovarable case, and the percentage of hail-swept area in the protected territory is significant.

In the previous section it has been mentioned that great differences in technical means, efficiency of reagent and size of protected and unprotected territory exist between the periods 1971-1977 and 1978-1984. For that reason the Student's test has been applied to series $\bar{R}_p$, $\bar{R}_u$ and $\bar{r}_u$ separately to each of these two periods.

The Student's test for comparison two independent characteristics $X_1$ and $X_2$ and Ho: that $X_1$ and $X_2$ have the same mean value, is used by formula

$$t_o = \frac{\bar{X}_1 - \bar{X}_2}{\tilde{\delta}\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}} = t_{n_1+n_2-2}$$

Here, $n_1$ and $n_2$ denote the sizes of samples and $\delta$ is standard deviation obtained by formula

$$\tilde{\delta} = \sqrt{\frac{(n_1-1)\tilde{S}_1^2 + (n_2-1)\tilde{S}_2^2}{n_1 + n_2 - 2}}$$

where

$$\tilde{S}_x^2 = \frac{1}{n-1} \Sigma (X_i - \bar{X})^2$$

The above formula for $t_o$ is used under assumption that the difference between $\tilde{\delta}_1 = S_{x_1}$ and $\tilde{\delta}_2 = S_{x_2}$ is not significant. In the case when the difference between $\tilde{S}_1^2$ and $\tilde{S}_2^2$ is significant, $t_o$ is calculated by formula

$$t_o = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{S^2}{n_1} + \frac{S^2}{n_2}}} = t_k$$

where k denotes the number of degrees of freedom, which may be obtained by formula

$$k \approx \frac{\left(\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}\right)^2}{\left(\frac{S_1^2}{n_1}\right)^2 \frac{1}{n_1+1} + \left(\frac{S_2^2}{n_2}\right)^2 \frac{1}{n_2+1}} - 2$$

On the basis of above shown formulas, the results are obtained as follow:

| Period 1971-1977 | | Period 1978-1984 | |
|---|---|---|---|
| $\bar{R}_p = 3.67$ | $\tilde{\delta} = 1.45$ | $\bar{R}_p = 1.77$ | $\tilde{\delta} = 0.62$ |
| $\bar{R}_u = 7.99$ | $\tilde{\delta} = 1.35$ | $\bar{R}_u = 5.74$ | $\tilde{\delta} = 3.45$ |
| $\bar{r}_u = 4.67$ | $\tilde{\delta} = 1.56$ | $\bar{r}_u = 2.70$ | $\tilde{\delta} = 1.69$ |

Using these data in comparison of the series $R_p$, $R_u$ and $r_u$ for the periods 1971-1977 and 1978-1984 we obtain the results

| | | | |
|---|---|---|---|
| $R_p$: | $t_o = 3.19$ | $k = 11$ | $P(t_o \geqq 3.19) \leqq 0.005$ |
| $R_u$: | $t_o = 1.61$ | $k = 8$ | $P(t_o \geqq 1.61) \leqq 0.070$ |
| $r_u$: | $t_o = 2.27$ | $k = 12$ | $P(t_o \geqq 2.27) \leqq 0.025$ |

These results show that there is a significant difference in the series $R_p$, i.e. in percentage of hail-swept area in the protected territory between the periods 1971-1977 and 1978-1984. These difference arises due to substantial decrease of hail-swept areas in the period 1978-1984 caused by an improvment in the methodology and technique of hail control system in that period. Some tendencies of hail-swept area decrease which is seen in the same period in the unprotected territory it is supposed to be result of a great decrease of the size of unprotected territory and increase of protected territory. In that way the hail suppression influence has been transfered to unprotected territory.

## 5. EVALUATION BASED ON THE PERCENTAGE OF CROP DAMAGES

In the preceeding section it has been shown that the size of hail-swept area in protected territory in comparison to that in the unprotected territory is very much reduced. It is natural to assume that the decrease of the size of hail-swept areas has been followed by a decrease of the intensity of the hail too. In order to prove this assumption, the sizes of hail-swept area were multiplied by the corresponding percentages of crop damages in the hail-swept area and thus reduced to 100% hail damaged area.

Here it should be pointed out that due to the varieties of crops and their phases of growth, this comparison will not be accurate enough for the small areas. However, such areas as protected and unprotected teritories of a size over a milion hectares, for the sorts of crops, their phenophases and the time of hail-damaging, statistically may be considered as similar.

The sizes of hail-swept area reduced to areas damaged 100% in protected ($S_p'$) and unprotected ($S_u'$) territories, as well as corresponding percentages ($R_p'$) and ($R_u'$) and their ratio ($Q'$) are presented in Table 3. If we compare Tables 2 and 3 we can see that the decrease of the hail-swept areas damaged 100% in the protected territory is greater that the decrease in the unprotected one in 12 of the 16 years.

Table 3. Hail-swept areas reduced to area damaged 100% in protected ($S_p'$) and unprotected ($S_u'$) territories, as well as corresponding percentages ($R_p'$, $R_u'$) and their ratio ($Q'$)

| Years | $S_p'$ | $S_u'$ | $R_p'$ | $R_u'$ | $Q'$ |
|---|---|---|---|---|---|
| 1971 | 25602. | 99435. | 2.23 | 5.68 | 0.393 |
| 1972 | 22914. | 85949. | 2.10 | 4.55 | 0.461 |
| 1973 | 27231. | 56623. | 2.39 | 4.72 | 0.507 |
| 1974 | 18615. | 52443. | 1.57 | 4.16 | 0.378 |
| 1975 | 12374. | 81443. | 0.75 | 4.70 | 0.160 |
| 1976 | 13008. | 30194. | 0.69 | 3.04 | 0.226 |
| 1977 | 76912. | 65093. | 3.31 | 5.31 | 0.623 |
| 1978 | 36349. | 22743 | 1.48 | 3.65 | 0.405 |
| 1979 | 21710. | 9254. | 0.75 | 1.30 | 0.573 |
| 1980 | 25153. | 10525. | 0.82 | 2.27 | 0.359 |
| 1981 | 23724. | 5791. | 0.76 | 1.94 | 0.391 |
| 1982 | 24884. | 21205. | 0.75 | 6.16 | 0.121 |
| 1983 | 14010. | 5856. | 0.41 | 2.20 | 0.188 |
| 1984 | 13802. | 751. | 0.37 | 0.70 | 0.525 |
| 1985 | 6765. | 0. | 0.18 | 0.00 | ***** |
| 1986 | 22721. | 538. | 0.60 | 1.89 | 0.319 |
| 1987 | 14856. | 12. | 0.40 | 0.04 | 9.353 |

The mean percentage of the hail-swept area reduced to 100% of damage in the protected territory is $\bar{R}_p' = 1.15\%$ and for unprotected territory $\bar{R}_u' = 3.08\%$. Their ratio is $\bar{Q} = 0.37$ and value of effectiveness $E' = 0.63$ or 63%. These values show that the effectiveness of the hail control system in Serbia expressed through the decrease in hail intensity may be estimated as 5%.

In order to find out whether a decrease trend in series $R_p'$, $R_u'$ and $r_u'$ exist, the Abe' test has been applied. The results obtained are as follow:

$R_p'$: $q = 0.504$ $n = 17$ $P(q \leqq 0.504) \cong 0.01$

$R_u'$: $q = 0.720$ $n = 14$ $P(q \leqq 0.720) \cong 0.14$

$r_u'$: $q = 0.890$ $n = 14$ $P(q \leqq 0.890) \cong 0.34$

These results show that in series $R_p'$ a significant trend of decreasing of hail-swept area in the protected territory. Such a trend in series $R_u'$ and $r_u'$, which relate the unprotected territory, has not been noted.

The Student's test applied to the signes of series $Z' = r_u' - R_p'$ yields

$T = 2$ $n = 14$ $P(t \lesssim 2) \leq 0.0065$

This test shows a significant difference between the percentage of hail-swept areas in which the percentage of crop damages is taken into consideration compared to sizes of hail-swept area in the unprotected territory.

Application of Student's test to coupled samples of series Z' gives

$Z' = 0.68$ $\tilde{\delta}_{z'} = 0.911$ $n = 14$ $t_o = 2.8$

$P(t_o \gtrsim 2.8) \leqq 0.01$

This shows that the difference between mean values of the size of hail-swept areas in which the level of damages in protected and unprotected territories is significant.

A comparison of the mean values of series $\bar{R}_p'$, $\bar{R}_u'$ and $\bar{r}_u'$ for periods 1971-1977 and 1978-1984 yields the results as follow:

| Period 1971-1977 | | Period 1978-1984 | |
|---|---|---|---|
| $\bar{R}_p' = 1.84$ | $\tilde{\delta} = 0.94$ | $\bar{R}_p' = 0.76$ | $\tilde{\delta} = 0.36$ |
| $\bar{R}_u' = 4.95$ | $\tilde{\delta} = 0.85$ | $\bar{R}_u' = 2.60$ | $\tilde{\delta} = 1.82$ |
| $\bar{r}_u' = 2.70$ | $\tilde{\delta} = 0.95$ | $\bar{r}_u' = 1.25$ | $\tilde{\delta} = 0.94$ |

Using these data we obtain:

$R_p'$: $t_o = 2.89$ $k=7$ $P(t_o \geqq 2.89) \cong 0.01$

$R_u'$: $t_o = 2.62$ $k=10$ $P(t_o \geqq 2.62) \leqq 0.025$

$r_u'$: $t_o = 2.62$ $k=12$ $P(t_o \gtrsim 2.62) \cong 0.01$

From these values if follows that a significant difference in mean values of $R_p'$, $R_u'$ and $r_u'$ between above mentioned periods exist. That means that during the last years of hail control operation in the unprotected territory decrease of the hail intensity has been greater than decrease in the size of the hail-swept area.

6. TRENDS IN SIZES OF HAIL-SWEPT AREAS

Let we consider that the total agricultural surface in Serbia, which amounts about 4 million hectares, has been constant during the whole period of hail control operations. Then, if we assume that this system has been efficient, the following conditions should be fulfilled:

1) A decreasing trend of the percentage of hail-swept area in the total agricultural surface of Serbia, as a consequence of the hail control system spreading from year to year, should be shown.

2) A decreasing trend of the percentage of hail-swept area in the protected territory, as a consequence of the improvement of technology, particularly introducing the new reagent, during the

period of operations, should be observed.

3) A decreasing trend of the percentage of hail-swept area in the unprotected territory, due to radical decrease of that territory and becoming surrounded by protected territory, from which the effect was transferred, should be shown.

4) The percentage of hail-swept area in the protected territory should be less than that in the unprotected territory and the percentage in the total territory (protected and unprotected) should be between them.

In order to test these hypotheses, two techniques have been applied which will bring out the general trend of changes of the size of hail-swept area during the period of operations. Owing to the fact that there exist considerable fluctuations in the occurrences of these phenomena from year to year, both techniques are based on the time averaging of data.

The first techniques was a calculation of moving averages according to data of the annual sizes of hail-swept which were obtained by the formula:

$$\hat{R}_m = \left( \sum_{i=m}^{m+n} S_{p,i} / \sum_{i=m}^{m+n} T_{p,i} \right) \cdot 100\%$$

Here $i = 1,2,\ldots,17$ denotes the years in the period and $m = 1,2,\ldots,M$ identifies the moving average. The number of moving averages is less than 17 number of years for a smoothing interval which has been taken here to be $n=6$. The results calculated by this formula are presented in Table 4.

Table 4. Trends of percentage of hail-swept areas in total ($\hat{R}_T$), protected ($\hat{R}_p$) and unprotected $\hat{R}_u$ territories

| Periods | $\hat{R}_T$ | $\hat{R}_p$ | $\hat{R}_u$ |
|---|---|---|---|
| 1971-1976 | 3.94 | 3.13 | 4.34 |
| 1972-1977 | 4.02 | 3.47 | 4.37 |
| 1973-1978 | 3.78 | 3.21 | 4.23 |
| 1974-1979 | 3.43 | 2.71 | 4.20 |
| 1975-1980 | 3.24 | 2.52 | 4.30 |
| 1976-1981 | 2.83 | 2.46 | 3.55 |
| 1977-1982 | 2.92 | 2.48 | 4.07 |
| 1978-1983 | 2.12 | 1.84 | 3.01 |
| 1979-1984 | 1.80 | 1.58 | 2.81 |
| 1980-1985 | 1.61 | 1.39 | 2.94 |
| 1981-1986 | 1.45 | 1.30 | 2.56 |
| 1982-1987 | 1.25 | 1.14 | 2.38 |

The second technique of averaging was the gradual average of the annual sizes of hail-swept areas obtained by the formula:

$$R_\mu = \frac{1}{\mu} \sum_{i=1}^{\mu} R_i$$

which gives the average values for each preceding period ($\mu$) of time. The results obtained by this formula are presented in Fig.1

From Fig.1 and Table 4 it is obvious that the trends of the hail-swept area decrease are fully

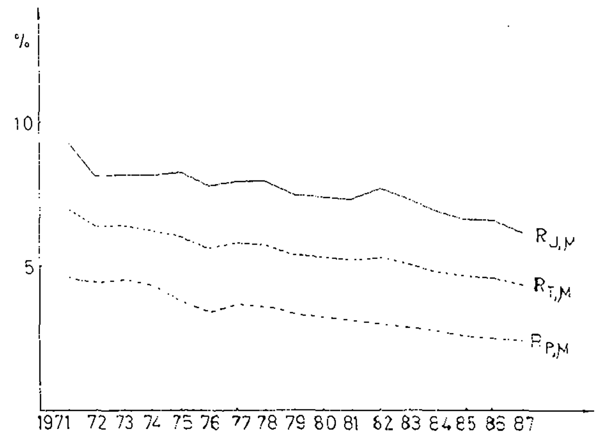


Fig.1 Graphical presentation of the gradual averages of the annual sizes of hail-swept areas at the total ($R_T$), protected ($R_p$) and unprotected ($R_u$) territories.

in accordance with above-mentioned hypotheses.

If we do not make smoothing but simply calculate the percentage of whole hail-swept areas ($S_p+S_u$) in relation to total protected and unprotected ($T_p+O_u$) territories we shall for the mean values obtain:

| Period 1971-1977 | Period 1978-1987 |
|---|---|
| $\bar{R}_T = 5.79$ $\tilde{\delta} = 1.49$ | $\bar{R}_T = 1.87$ $\tilde{\delta} = 1.03$ |

The Abe's criterion for trend gives

$q = 0.24$ $n = 17$ $P(q \leq 0.24) = 0.0007$

It shows that the trend of decrease of the percentage of whole hail-swept area in the protected and unprotected territories very pronounced. A comparison of mean values for the periods 1971-1977 and 1978-1987 yields

$t_o = 6.08$ $k=11$ $P(t_o \geq 6.08) = 0.0005$

It means that the difference in percentage of whole hail-swept areas for above-mentioned periods for total protected and unprotected territories is very high and statistically significant.

## 7. EFFECTIVENESS OF NON-INTERRUPTED OPERATIONS

In previous sections the hail-swept areas in the protected territory have been considered without taking into account the interruptions in the hail control system operations. Such cases were rather frequent and long lasting during the first half of the period (1971-1978). In such situations the protected territory or some part of it stayed practically unprotected. For that reason, the picture about the real effectiveness of the hail control system, obtained in above derived way, is not quite realistic one.

Determination of the part of territory where the system was not operating in a single situation was not practical. Two main reasons for that are: first, the part of the protected territory over which the system was not operating did not coincide with the territories of the municipalities, from which the data about the hail-swept areas in summarized from have been obtained; second, it was not possible to control the effect of operations which took place in surrounding areas. Thus, it was decided not to consider individual cases but to omit all the territories and reports of the municipalities from consideration if the hail control system was not operating in a given year for as little as a single day. Thus, consideration was only given for those territories and reports of the municipalities in which the hail control system operated without interruption. The results calculated in this manner are presented in Table 5.

Table 5. Parts of protected territory ($T''_p$) and hail-swept areas ($S''_p$) in hectares where the hail control system have been operating without interruption

| Years | $T''_p$ | $S''_p$ | $R''_p$ | $Q''$ |
|---|---|---|---|---|
| 1971 | 667061. | 21133. | 3.17 | 0.342 |
| 1972 | 534992. | 19359. | 3.62 | 0.527 |
| 1973 | 804643. | 7364. | 0.92 | 0.110 |
| 1974 | 836379. | 15961. | 1.91 | 0.233 |
| 1975 | 1084288. | 14985. | 1.38 | 0.162 |
| 1976 | 1660759. | 21762. | 1.31 | 0.237 |
| 1977 | 1686442. | 54254. | 3.22 | 0.350 |
| 1978 | 2211108. | 53672. | 2.43 | 0.302 |
| 1979 | 2879785. | 47157. | 1.64 | 0.572 |
| 1980 | 3024419. | 60336. | 1.99 | 0.289 |
| 1981 | 3050817. | 35912. | 1.18 | 0.172 |
| 1982 | 3330067. | 64823. | 1.95 | 0.176 |
| 1983 | 3385784. | 31217. | 0.92 | 0.279 |
| 1984 | 3753002. | 39313. | 1.05 | 0.892 |
| 1985 | 3760870. | 23669. | 0.63 | ***** |
| 1986 | 3742912. | 50899. | 1.36 | 0.567 |
| 1987 | 3760870. | 33719. | 0.90 | 14.152 |

The mean value of percentage of the hail-swept area when the hail control system had been operating without interruption amounts to: $\bar{R}''_p = 1.74$. Its ratio with mean percentage for unprotected territory gives $\bar{Q}'' = 0.3$.

The sizes of the hail-swept areas reduced to 100% of damages in their part of the protected territory, where the hail control system was operating without interruptions, are presented in Table 6. The mean percentage in this case is $\bar{R}^{\cdot\cdot}_p = 0.82$ and its ratio to the percentage unprotected territory gives $\bar{Q}^{\cdot\cdot}=0.26$. That means that the hail-swept area reduced to 100% of damages in the part of protected territory where the hail control system has been operating without interruptions in comparison to unprotected territory has shown an effectiveness of $\bar{E}^{\cdot\cdot}= 0.74$ or 74%.

Looking at the differences between $R_p$ and $R^{\cdot\cdot}_p$ for individual years of the series considered, we can see that these differences were significant in the period 1971-1977 when the hail control system had been frequently out of operation. The mean difference $Z'' = R_p - R''_p$ for the period 1971-1977 amounts to $\bar{Z}''=1.45$ and $\tilde{\delta}'' = 1.19$. The Student's test applied to these values yields:

Table 6. The same as Table 5 but reduced to 100% of damages

| Years | $T^{\cdot\cdot}_p$ | $S^{\cdot\cdot}_p$ | $R^{\cdot\cdot}_p$ | $Q^{\cdot\cdot}$ |
|---|---|---|---|---|
| 1971 | 667061. | 9211. | 1.38 | 0.243 |
| 1972 | 534992. | 10362. | 1.94 | 0.426 |
| 1973 | 804643. | 3092. | 0.38 | 0.081 |
| 1974 | 836379. | 6445. | 0.77 | 0.185 |
| 1975 | 1084288. | 5212. | 0.48 | 0.102 |
| 1976 | 1660759. | 11263. | 0.68 | 0.223 |
| 1977 | 1686442. | 39032. | 2.31 | 0.436 |
| 1978 | 2211108. | 29339. | 1.33 | 0.363 |
| 1979 | 2879785. | 20844. | 0.72 | 0.557 |
| 1980 | 3024419. | 23564. | 0.78 | 0.342 |
| 1981 | 3050817. | 14638. | 0.48 | 0.248 |
| 1982 | 3330067 | 24884. | 0.75 | 0.121 |
| 1983 | 3385784. | 14010. | 0.41 | 0.188 |
| 1984 | 3753002. | 13802. | 0.37 | 0.525 |
| 1985 | 3760870. | 6765. | 0.18 | ***** |
| 1986 | 3742912. | 19325. | 0.52 | 0.273 |
| 1987 | 3760870. | 14856. | 0.40 | 9.051 |

$t_o = 3.22 \quad k=6 \quad P(t_o \geqq 3.22) \leq 0.01$

It shows that the difference between the percentage of hail-swept area in the protected territory in the case when the hail control system had been operating with and without interruption was statistically significant.

During the period 1978-1987, as it has been said before, the interruptions in the hail control operations were rare and short. As a result, the differences between $R_p$ and $R^{\cdot\cdot}_p$ were rather small. These results are also supporting the theses that the hail control system in Serbia is efficient.

In order to be more sure about that conclusion we calculated the median for series $R''_p$ in Table 5, which amounts to 0.68, and made an analysis of the series of signs of deviations from the mean value. The test of number of series did not show a significant deviation from a series composed by chance. However, a more sensitive rank test has shown at a 5% of probability a significant deviation of a series composed by chance.

## 8. EVALUATION BASED ON OBSERVATIONS AT METEOROLOGICAL STATIONS

Cloud seeding with the aim of hail suppression, it is believed, do not affect much the cloud dynamics nor the general conditions of the atmosphere. Therefore, it may be expected that the number of storms on the average will stay unchanged. However, the frequency of occurrences, the length of duration and the intensity of hail phenomena should be decreased. That decrease, which should be seen in the hail observations at meteorological stations, is not so pronounced as the decrease of the size of hail-swept area and percentage of crop damaged. It is well known that in many cases the hailstones are too small and make insignificant damages; such cases were not taken into consideration in statistics of the municipality commissions. Nevertheless, such occurrences will be regularly registered by meteorological stations.

A radical decrease of the hail-swept areas in

Serbia, during the period of hail control operations, should be shown in the series of hail frequencies observed in the network of meteorological stations. In order to explore this hypothesis we used the series of number of days with hail observed in the network of synoptical and climatological stations in Serbia during the period 1949-1985. Data obtained are presented in Table 7.

Table 7. Number of days with hail observed at the meteorological stations in Serbia

| Years (1) | No of stations (2) | No of days (3) | Average No. of days (4) | Moving 5-years average of days (5) | Deviations (6) |
|---|---|---|---|---|---|
| 1949 | 48 | 39 | 0.81 | - | -0.25 |
| 1950 | 50 | 38 | 0.76 | - | -0.30 |
| 1951 | 48 | 71 | 1.48 | 1.08 | 0.42 |
| 1952 | 49 | 51 | 1.04 | 1.18 | -0.02 |
| 1953 | 52 | 67 | 1.29 | 1.27 | 0.23 |
| 1954 | 61 | 81 | 1.33 | 1.26 | 0.27 |
| 1955 | 68 | 83 | 1.22 | 1.40 | 0.18 |
| 1956 | 72 | 102 | 1.42 | 1.32 | 0.36 |
| 1957 | 69 | 121 | 1.75 | 1.21 | 0.69 |
| 1958 | 71 | 61 | 0.86 | 1.08 | -0.20 |
| 1959 | 69 | 54 | 0.78 | 1.03 | -0.28 |
| 1960 | 63 | 38 | 0.60 | 0.89 | -0.46 |
| 1961 | 63 | 72 | 1.14 | 0.89 | 0.08 |
| 1962 | 66 | 72 | 1.09 | 0.89 | 0.03 |
| 1963 | 64 | 54 | 0.84 | 1.01 | -0.22 |
| 1964 | 54 | 43 | 0.80 | 1.02 | -0.26 |
| 1965 | 57 | 68 | 1.19 | 1.15 | 0.13 |
| 1966 | 51 | 60 | 1.18 | 1.12 | 0.12 |
| 1967 | 51 | 89 | 1.74 | 1.14 | 0.68 |
| 1968 | 55 | 38 | 0.69 | 1.11 | -0.37 |
| 1969 | 53 | 48 | 0.90 | 1.16 | -0.16 |
| 1970 | 47 | 50 | 1.06 | 1.04 | 0.00 |
| 1971 | 55 | 77 | 1.40 | 1.07 | 0.34 |
| 1972 | 55 | 64 | 1.16 | 1.09 | 0.10 |
| 1973 | 49 | 41 | 0.84 | 1.25 | -0.22 |
| 1974 | 54 | 53 | 0.98 | 1.17 | -0.08 |
| 1975 | 49 | 92 | 1.88 | 1.18 | 0.82 |
| 1976 | 52 | 52 | 1.00 | 1.14 | -0.06 |
| 1977 | 53 | 65 | 1.23 | 1.16 | 0.17 |
| 1978 | 54 | 45 | 0.83 | 0.97 | -0.23 |
| 1979 | 54 | 47 | 0.87 | 0.97 | -0.19 |
| 1980 | 55 | 52 | 0.94 | 0.87 | -0.12 |
| 1981 | 64 | 62 | 0.97 | 0.87 | -0.09 |
| 1982 | 61 | 45 | 0.74 | 0.86 | -0.32 |
| 1983 | 63 | 53 | 0.84 | 0.84 | -0.22 |
| 1984 | 59 | 48 | 0.81 | - | -0.25 |
| 1985 | 59 | 51 | 0.86 | - | -0.20 |
| Average | 57 | - | 1.06 | - | - |

By dividing number of days with observed hail in the network of stations with the number of stations in each year we got the annual mean number of days with haul per station (or at a point) in Serbia (column 4). These annual mean number of days with hail, as a point value, has fluctuated between 0.60 as a minimum to 1.88 as a maximum. The average value for the whole period is 1.06 days. Here it should be pointed out that in the last 8 years (1978-1985) the mean number of days with hail was below normal. It suggests that the period in which the hail control system in Serbia was increased in size and technologically improved coincides with the period of hail frequency decrease.

The last column in Table 7 shows the deviations of the normal value of the annual number of days with hail at a point in Serbia. Let us suppose that the annual number of days with hail over the areas considered in two successive years is independent. Then, the probability that a number of successive years x in the series will have the same sign of deviation is given by

$$P(x) = (\frac{1}{2})^x$$

It means that probability that 8 successive years will have the same sign of deviation, as it has been shown at the end of last column in Table 7, is below 0.4%.

Taking into consideration some characteristics of the series of hail days in Serbia in the period 1949-1985, which are relevant for statistical tests application, this series is divided into four separate periods. First period encircles the time 1949-1970 when the hail control system did not operate. Second period encompasses the time 1971--1977, i.e. the period when the hail control system had been developing and functioning with frequent interruptions. Third period encircles the time 1978-1985 when hail control system had been technically improved, functioning nearly without interruptions and covering the greatest part of Serbia. Fourth period makes sum of first two periods, i.e. the period when the hail control system did not exist and the period when it did not operate well and covered a small part of the territory of Serbia.

If we calculate the mean number of hail days ($\bar{A}$) and standard deviation ($\tilde{\sigma}_A$) for above-mentioned periods, we obtain:

| Period | $\bar{A}$ | $\tilde{\sigma}_A$ |
|---|---|---|
| I 1949-1970 | 1.09 | 0.32 |
| II 1971-1977 | 1.21 | 0.35 |
| III 1978-1985 | 0.86 | 0.07 |
| IV 1949-1977 | 1.12 | 0.33 |

Application of Student's test to comparison of two series gives results as follow:

| | | | |
|---|---|---|---|
| I and II | $t_o = -0.84$ | k=27 | $P(t_o \leq -0.84) \approx 0.20$ |
| I and III | $t_o = 3.17$ | k=26 | $P(t_o \geq 3.17) \leq 0.0025$ |
| II and III | $t_o = 2.66$ | k= 7 | $P(t_o \geq 2.66) \leq 0.025$ |
| III and IV | $t_o = 3.98$ | k=36 | $P(t_o \geq 3.98) \leq 0.0005$ |

Those results show that the difference between the number of hail days in the periods when the hail control system did not exist (I) and when it was not operating well (II) was not significant. The difference in the number of hail days between the periods I and III, i.e. when the hail control system did not exist and when it was working well, is statistically significant. The difference between the period when the hail control system was not operating well (II) and the period when it was functioning well (III) is also statistically significant. Finally, the difference between the periods when the hail control system was operating well (III) and the joined periods when the system did not exist and not well operating (IV) is statistically highly significant.

Further, we mentioned above an interesting characteristic of the series of the annual number of hail days in Serbia, i.e. the last 8 successive years the number of hail days were below the average value for the whole period of observation. In order to test whether this event occured by chance or not we applied the median test and the test of the number of series.

Median for period 1949-1985 is 0.89 and the successive values below (-) and above (+) this value gives:

/--/++++++/---/++/--/+++/--/+++/-0/+++/--------/

According to number of series test U=11, and expected number is 19. Standard deviation is 2.96 so we have

$$Z_o = \frac{U - 19}{2.98} = -2.7 \quad \text{and} \quad P(Z_o \leq -2.7) = 0.0035$$

This test show that the deviation of the last part of the series considered compared to that one obtained by chance is significant. In other words, this test suggests that the event of decreased values of number of annual hail days during the last 8 years in the series did not occured by chance.

Another calculation has been done using the ratio between the frequency of hail occurrences before and after hail control was introduced. For this calculation we used the network of meteorological stations for which the hail control operation existed for at least five years. Data used are presented in Table 8. From this table it may be seen that mean number of days before hail operations was 23, and after hail operations 13 years. The mean frequency of hail occurences in the period before hail control was 1.32 and after was 1.03 days with hail. This suggests a decrease of 22% in the frequency of days during hail control operation years.

Let us now consider the difference between the mean number of hail days in the period before and after the hail control system was introduced (presented in Table 8). From these differences we obtain the mean difference $\bar{Z} = 0.3$ and standard deviation $\delta = 0.77$. Application of Student's test gives

$$t_o = 1.87 \quad k=22 \quad P(t_o \geqq 1.87) \leq 0.05$$

This show that the difference between the mean number of hail days in Serbia in the periods before and after the hail control system was introduced is statistically significant.

In the same way, the sign test show that at 5 out of 23 stations the number of hail days was less in the period before the hail control was introduced. So, the sign test for T = 5 gives

$$P(T \leq 5) \cong 0.013$$

The Wilcoxon test for the same data gives

Table 8. Number of days with hail observed at meteorological stations in Serbia before and after the hail control operation

| Stations | Before | | | After | | |
|---|---|---|---|---|---|---|
| | No. of years | No. of days | Mean No. of days | No of years | No of days | Mean No. of days |
| Loznica | 18 | 30 | 1.7 | 16 | 13 | 0.8 |
| U.Požega | 25 | 45 | 1.8 | 9 | 11 | 1.2 |
| Kuršumlija | 27 | 32 | 1.2 | 7 | 7 | 1.0 |
| Vrnjačka B. | 29 | 45 | 1.6 | 7 | 17 | 2.4 |
| Zaječar | 27 | 39 | 1.4 | 10 | 8 | 0.8 |
| Zlatibor | 27 | 69 | 2.6 | 9 | 23 | 2.6 |
| Bukovička B. | 18 | 21 | 1.2 | 19 | 12 | 0.6 |
| Ćuprija | 20 | 32 | 1.6 | 17 | 16 | 0.9 |
| Kragujevac | 20 | 24 | 1.2 | 17 | 13 | 0.8 |
| Kruševac | 20 | 25 | 1.2 | 16 | 6 | 0.4 |
| Negotin | 20 | 20 | 1.0 | 17 | 11 | 0.6 |
| Niš | 20 | 21 | 1.1 | 17 | 20 | 1.2 |
| Peć | 20 | 16 | 0.8 | 17 | 14 | 0.8 |
| Predejane | 21 | 52 | 2.5 | 16 | 23 | 1.4 |
| Priština | 30 | 36 | 1.2 | 7 | 4 | 0.6 |
| Prizren | 20 | 12 | 0.6 | 17 | 14 | 0.8 |
| Prokuplje | 27 | 10 | 0.4 | 10 | 7 | 0.7 |
| Kraljevo | 27 | 41 | 1.5 | 10 | 13 | 1.3 |
| Rekovac | 27 | 32 | 1.2 | 10 | 7 | 0.7 |
| S.Palanka | 17 | 17 | 1.0 | 19 | 15 | 0.8 |
| Šabac | 20 | 18 | 0.9 | 16 | 12 | 0.8 |
| Uroševac | 30 | 39 | 1.3 | 7 | 3 | 0.4 |
| Valjevo | 21 | 29 | 1.4 | 16 | 30 | 1.9 |
| Mean values | 23.1 | 30.6 | 1.3 | 13.3 | 13.1 | 1.0 |

$$n=21 \quad T=19 \quad P(T=19) \leq 0.005$$

This also shows that the number of hail days in the period after the hail control was introduced is significantly less than the number of days before it was introduced.

## 9. CONCLUSIONS

The hail control system in Serbia during its 17 year operation shown an hail-swept area decrease in the protected compared to unprotected territories for about 58%. When the percentage of crop damages taken into consideration the effectiveness of hail suppression was increased for additional 5%, amounting 63%. Further, the part of protected territory over which the hail control system has been operating without interruptions, the effectiveness amounts to 74%.

An analysis of the number of hail days in Serbia observed in the network of meteorological stations, shown a decrease of number of days in last 8 years when the hail control system was functioning well. Also, an comparison of number of hail days observed before and after the hail control system was introduced, showed an decrease of hail days during the hail control operations for about 22%.

Several statistical tests have been applied to abovementioned data and they showed the significant differences between the protected and unprotected territories. They give a strong suport the concept that the hail control system, which has been operating in Serbia, is efficient. The rate of efficiency seems to be high enough to be considered economically significant.

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