Project 'Climatite'[1])

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Summary. – Description is made of a non-randomized experiment carried out with the aim of assessing the hail-suppressing effects of some newly-developed, giant condensation and ice-forming nuclei. A further aim consisted in testing, by those means, the practical feasibility of performing a hail-suppression operation by the use of ground-based generators alone. The operational area chosen was the Italian Province of Asti whose extensive vineyards, and regularly-recurring hailstorms, were found to meet the prerequisites of an excellent hailgauge, situated under a reliable hail generator. The project lasted for three consecutive summer periods covering the 153-day intervals between May and September 1969–1971 incl., during which 43.7 tons of nucleator material were dispersed into advancing convective cells. *Continuous-historical* computations indicated significant reductions of losses to the vineyards of Asti, while *multi-control-target* computations yielded a 99.9% probability of success with 99% confidence limits situated between 51% and 85% of the prospected losses. The average savings were of about 76% of vineyard values, with a corresponding benefit-to-cost ratio of 62, covering manpower, material and communications used *during* those fifteen months.

1. Introduction

Research, aimed at developing self-sustaining combustible generators of mono-disperse giant condensation and ice-forming nuclei, was initiated in our Institute during the first half of 1961; this was followed by a preliminary period of laboratory evaluation and by the testing, in the field, of the two types of compositions obtained. Those field tests were started during autumn 1961 and were increased with time, in terms of both, size of projects and quantities of material used. References [1–3][3]) thus contain a description of some work which dealt with the testing of those nucleators for purposes of artificial stimulation of rain in an essentially orographic area, as well as for purposes of warm fog dissipation. These References also include information on the literature which contains the description of both, some earlier tests and chemical compositions of the material which was since called 'Climatite' (mark of the compositions). Inasmuch the chemical proportions and ingredients, of the two types of materials used, have already been described in detail in the afore-

[1]) Parts of this paper were presented at the 18th and 19th annual meetings of the 'Società Italiana di Geofisica e Meteorologia' in Genoa, on the days of April 3rd and 17th, 1970 and 1971 respectively.

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[3]) Numbers in brackets refer to References, page 249.

mentioned and related References from our Laboratory, some further remarks aimed at providing a brief summary of our earlier thought may, at this point, prove useful to a reader unfamiliar with this branch of chemistry.

a) The combustion of a suitable preparation which consists of powdered sodium (or potassium) nitrate and aluminum metal yields, essentially, a microspherulized aerosol dispersed by a flow of nitrogen generated by the reaction. The resulting particulates are composed of alumina (insoluble) and sodium aluminate (soluble), according to:

$$6\,NaNO_3 + 10\,Al = 6\,NaAlO_2 + 2\,Al_2O_3 + 3\,N_2 .$$

If a suitable excess of aluminum is used and NaCl added to the mix, the solid matrix generated also contains sodium chloride and both, unreacted Al and traces of alkali metal. The addition of sodium azide to the original mixture obviously enhances the rate of nitrogen evolution; it also increases the content in elementary sodium of the aerosol, since sodium azide decomposes into elements at about 700°C and since sodium metal is soluble in molten sodium chloride. Lastly, since part of the above mentioned matrix is insoluble, the process of hydration – which is here accompanied by the evolution of hydrogen – is suitably retarded. As stated in our earlier contributions, the nuclei are thus giant, monodisperse ($\emptyset = 1.5 \pm 0.5\,\mu$) and emit tribo- and photo-electrons before their surface collapses because of hydration.

b) The well known reaction, of a stoichiometric powdered mixture of aluminum metal and sulfur, proceeds with a large liberation of energy and the formation of Al_2S_3 slag. We found this compound to be an excellent nucleator of ice at about -3°C; hence the addition of sulfur to a proper mix of Al and $NaNO_3$ was thereafter found to yield an aerosol whose matrix contains the sulfide of aluminum therein imbedded. The destruction of the Al_2S_3 sites may clearly proceed here by their well known slow hydrolysis which is accompanied by the evolution of hydrogen sulfide. Thus, an aerosol obtained on this basis has both, properties of giant ice-forming and condensation nuclei of prolonged activity, and a particle size which is practically identical with that of the one described in the previous paragraph.

c) Mixes of both types described may easily be shaped under pressure in suitable containers and may thereafter safely be stored and transported at will. Any orthodox high-temperature primer may be used for their ignition; due precautions are, however, to be taken by the operator, since the charges burn vivaciously with a large development of energy, and since it clearly is impossible to extinguish them by orthodox outside means. With some analogy to thermits and explosives, the preparation of those compositions should not be attempted on a do-it-yourself basis by people unfamiliar with this sort of work, if dangerous deflagrations and explosions were to be avoided.

The encouraging results obtained clearly called for an attempt at testing those nucleators against hail. The added attraction consisted, obviously, in trying to help the local economy by executing the experimentation in an area both known for its hailstorms and covered by valuable produce. A further aim was to show that sufficient knowledge on weather-active nuclei now appears to be available (see, for example Ref. [4]) to warrant a weather control project whose immediate usefulness would be more obvious to the scientifically-untrained observer than a local enhancement of precipitation, or an areal increase of horizontal visibility during conditions which favor the formation of warm fog. Our search for an appropriately hailed-on area in Italy indicated that the Province of Asti possesses many attractive prerequisites for a test of this type. A study of the environmental conditions, upon which this conclusion was based, has already elsewhere been published in detail [5–6]. The Province has an area of 151 thousand hectares and, according to an estimate which was obtained last autumn from the 'Provincial Inspectorate of Agriculture', 20% of this is covered by grapevine with peak coverages of up to about 70% in some of its 120 communes. Since grapevine is particularly vulnerable to all types of hail and since hail is quite recurrent in that area, a tri-annual project was put into practice there, in collaboration with the Asti Chamber of Commerce. From the start of the operation, the test had to be planned so as to be carried out on an annum-by-annum basis and to be extended to a maximum of three years in case the annual results obtained were deemed to be encouraging. After those three years have elapsed the decision, if any, on what to do with their local hail problem, was to be left to the local authorities.

The project thus covered the fifteen summer months of May through September incl., 1969–1971 incl. and the object of this paper consists in describing the work done and the results obtained, and also in providing some qualitative data on the Asti thunderstorm events and on their consequences in Piedmont, during this time.

2. *The pattern of the test*

a) *The operational area*

The whole territory enclosed within the boundary of the Asti Province was considered as target area and the adjacent Provinces were used as control. Original thoughts of extending our operations to some contiguous territories were abandoned because of lack of public interest there and also because of a paucity of itemized and detailed data on the past damages, caused by hail, in those areas. Inasmuch some of our aerosolizing sites were situated well outside this Province (see later) this was merely in order to enable aerosol dispersions to be carried out in the path of the advancing thunderstorms, so as to obtain large concentrations of nuclei in the developing convective cells, upon their entering Asti territory. Therefore, although there is ground to believe that damages due to hail were also reduced in some of those adjacent places, no further mention of those possible decreases will be made in this paper.

Figure 1 shows the location of Asti Province within Piedmont; it also shows the location of the stationary sites from which aerosolizations were carried out during the years 1970–1971. Since all hail events, which occured within this Province, were evaluated *in terms of losses to its vineyards*, a defencer belt was extended across the area of the major concentration of these vineyards (5), during those two latter years. A number of sites was also placed along both, the Northern and the Western boundary of the Province; this was in accordance with the trajectory distribution of the local thunderstorms, as substantiated by References [5] and [6].

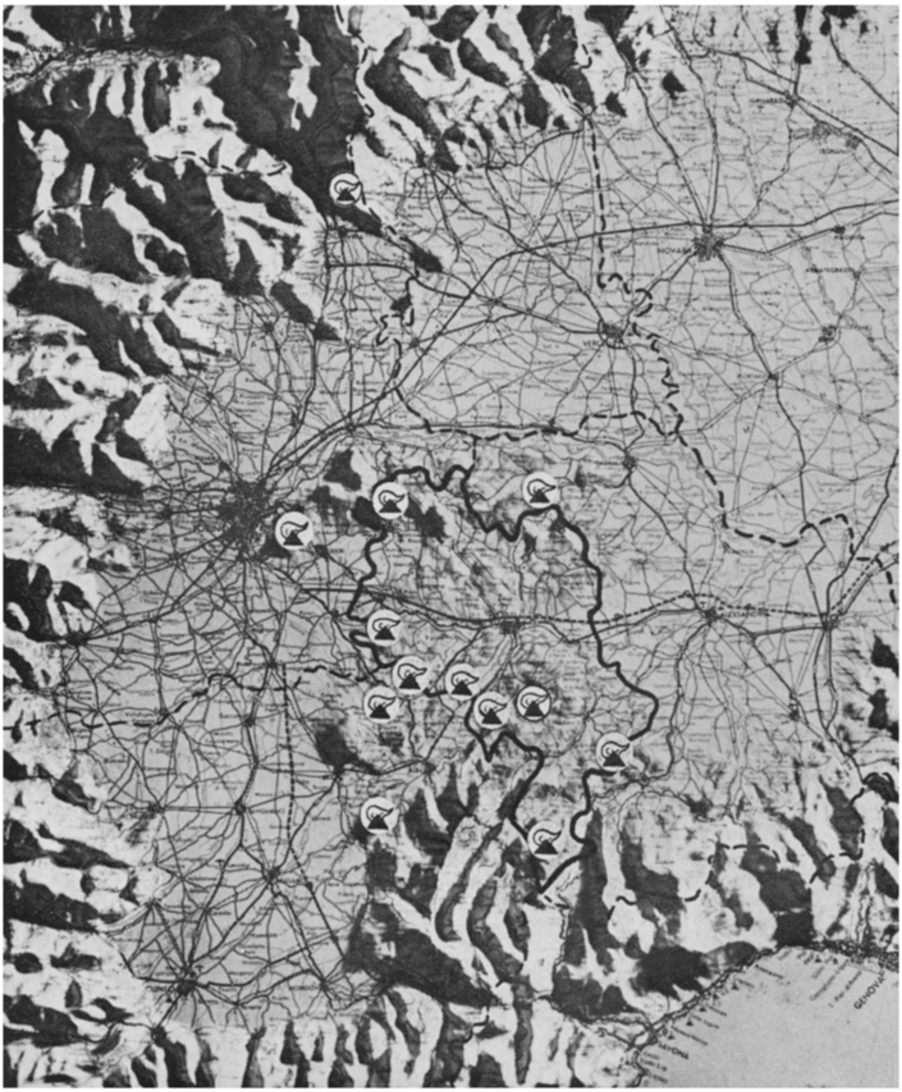

Figure 1
The Region of Piedmont with Asti Province at Center-South. Surrounding Provinces are (clockwise from SSW): Cuneo (CN), Torino (TO), Vercelli (VC) and Alessandria (AL)

b) *The static defence*

Headquarters of operation where some rudimental equipment was also positioned (baro-, thermo-, and humigraphs, potential gradient indicator and a conventional, double-Gerdien recording gauge for measuring concentrations of ions of both signs in the air) were situated at Agliano d'Asti (center-south of the Province, Fig. 1). All sites were on tops of hills; this choice enabled a 360°-observation to be carried out continuously during all days which presented a danger of thunderstorm. It also enabled to diminish effective losses, of aerosol material, which could have been caused by settling on circumjacent vegetation. Since the first year of operations (1969) was meant to be exploratory, only seven stations operated at that time. Those included Agliano, the three sites at the Northern boundary and the two stations placed within the Cuneo Province to the South-West of Asti territory. They also included the northermost site (Andrate) above the outlet of Aosta Valley. This latter zone is known to be a birth area of a devastating type of storms which approach from the North and which gain momentum, on their way, upon passing over the hot ricefields to the North of Asti. Also, since the City of Turin is situated in the path of a large part of thunderstorms which strike at that Province from the West, an evaporator of elementary iodine substance (7) was positioned on the roof of this city's meteorological observatory (12th floor) and was operated in the absence of rain, during the days of high thunderstorm probability. The meteorological observatory is about-centrally located within Turin and its position is not shown in Figure 1.

c) *Hail data*

As mentioned by Gori *et al.* [5], it was deemed counter-producing to attempt ourselves an evaluation of Asti's damages to hailed-on vineyards. Those are readily available from the 'Provincial Inspectorate of Agriculture' of that Province and the part which covers period 1961–1968 incl. was already previously shown [5]. Those data will be quoted, in a reduced form, later-on in this paper, and will be inclusive of the figures which cover the operational period of time, 1969–1971. Inasmuch we have taken care to base our previous computations (5) on the official records which dealt with annual surface covers in terms of vineyards, thus obtaining a value of 43,480 hectares with an $SD = 646$ and with barely significant and consistent changes with time ($r = -0.68$) during period 1961–1968 incl. – and inasmuch the data taken from the Chamber of Commerce indicate an annual average production of $304 \pm SD = 51$ thousand metric tons of grapes, with no signs of a decline in production ($r = 0.05$) during the same period of time – we were surprised to learn *during the end of 1971* that a recent local survey (apparently performed in 1970) seems to have yielded a cover of a mere 30,379 hectares of vineyards within this Province. Since it was clearly not up to our Institute to enter into the details of this discrepancy, we have assumed, for the purpose of our 'historical' computation and following the advice of the 'Inspectorate', that a *linear* decline of those vineyard surfaces has effectively taken place with time and between the years of 1961–1970 incl. (44,653 and 30,379 hectares respectively). We have also found that those changes, if real, would have affected but very slightly some of the parameters used for a 'continuous-historical' type of evaluation which will later-on be presented; in view of the above inconsistencies, however, the results of both types of computations shall here be given to the reader.

Raw data for a 'multi-control-target' estimate were obtained by the courtesy of the 'Provincial Inspectorates of Agriculture' of the four Provinces circumjacent to Asti (Fig. 1). Those data consisted of monetary-loss-equivalents of *all* hailed-on crops and were found to intercorrelate in a straightforward manner, on an annual basis, during period 1964–1968 incl., with the monetary-loss-equivalents to hailed-on *vineyards* of Asti. Two of those binomial correlations were taken from Ref. (5). A third excellent correlation may readily be arrived at if it is assumed that an exponential change occurs, from year to year, between the losses to Asti vineyards and the destruction, by hail, of *all crops* in the surrounding Provinces. Details on this correlation will later-on be given in this paper together with the discussion of the results obtained by means of this 'multi-control-target' method of evaluation. It is clear that those intercorrelations may, to any practical purpose, be regarded as independent from the fluctuations, with time, of crop surface covers and their prices within those Provinces, since a similarity of changes, if any, may be expected to occur parallely in the whole area of Piedmont.

d) *Forecasting and the general situation*

Daily weather forecasts and probability estimates of thunderstorm and hailstorm occurrences were provided each morning by telephone, from the Meteorological Office of Turin, by Dr. Ivan Barla. A broad classification was made, on the basis

Table 1

Monthly distribution of broad atmospheric disturbances which passed over Piedmont area during the duration of project described. The data are by the courtesy of Dr. Ivan Barla, *Meteorological Office, Turin*

	YEAR	1969					1970					1971				
	MONTH	M	J	J	A	S	M	J	J	A	S	M	J	J	A	S
Fronts	Warm	–	–	–	–	–	1	1	–	–	–	–	–	–	–	–
	Cold	6	5	4	5	3	4	8	4	4	5	5	6	6	6	4
	Occluded	3	3	1	1	7	3	1	–	–	–	2	1	1	1	–
	Instability lines	–	–	1	7	2	–	2	1	2	–	–	3	–	–	–
Provenance	N	–	–	–	2	4	–	–	–	2	1	–	2	1	–	1
	NE	–	–	–	1	1	–	–	–	–	1	–	–	–	–	1
	E	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	SE	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–
	S	–	–	–	–	–	1	1	–	–	–	–	–	–	–	–
	SW	–	1	–	–	2	2	3	–	–	–	1	1	1	–	1
	W	5	2	–	4	4	2	2	1	2	–	3	–	3	3	–
	NW	4	5	6	5	1	3	6	4	2	3	3	7	2	4	1

of his reports, of the atmospheric disturbances which passed over Piedmont during those three summer periods; this classification is shown in Table 1. The Table is exclusive of information on precipitation events over Asti during that period of time; those events will separately be discussed at a later date and as soon as the data related to Asti, of the Po-Parma Hydrographic Office become available.

3. The execution of the experiment

a) *Operating routines and personnel involved*

Six people only were available, for the year 1969 of the test, since the main goal was, at that time, to obtain a consistent indication of an effective decrease of damage, by means of the method used, and to decide whether to expand the project. Depending on the morning forecast and on the subsequent development of the situation 'in loco', as compared to the distribution of danger with time (5), the operators followed the routine of fanning out by automobile from Agliano, at a suitable time of the day (usually around noon). The cars were provided, at all times, with one hundredweight (Kg) of 'Climatite' charges. Additional observation was carried out, by every operator, upon reaching the site and for the rest of afternoon. Operations of aerosolization were being initiated, individually, at the first signs of appearance of convective systems in advancement or in organization. Those aerosolizations were as evenly-spaced as possible since the aim was to provide a *steady* inflow of nuclei into the convective system. Maximal frequencies were up to one 5-kg charge every 5 minutes, for durations of up to a couple of hours, per site; the maximal expenditure of material reached 715 kg. dispersed from all sites during an extensive thunderstorm (Aug. 21, 1970).

After the onset of rain the operator usually retreated in the general direction of Agliano and tried to maintain himself ahead of the advancing storm. Further dispersions of aerosol were carried out on his way and upon reaching rain-free areas. Since the Asti tempests are of short duration and since the danger of having more than one thunderstorm per day is quite high, this was usually followed by his return to the site in order to await another possible vigorous convective cell. During dangerous days the return to Agliano base was usually between 9–10 pm, in accordance with the daily distribution of danger (5). No dispersions of aerosol were done at nighttime or during rainy periods of the day. The routine was carried out during 1969 by a team of five people; because of distances involved, the sixth person was permanently stationed at Andrate and operated there according to his judgement after having received a briefing each morning from Agliano, by telephone. Of all positions used during this tri-annual period, Andrate sustained the highest frequency of thunderstorms and hence also the largest expenditures of material. Those frequencies sometimes reached twelve separate thundery-cells per day, there.

Enlistment, on a part-time basis, of local farmers who lived in villages situated near the sites of operation (Fig. 1) and who relied on their own automobile transportation, was done, during years 1970–1971, on the basis of experience gained in 1969 and with the aim of streamlining the tactics used as much as possible within this situation. During the last week of April, those local operators were given a short course in the art of recognizing the local types of clouds and associated signs of danger, as well as in the handling of the aerosolizing charges. The new routine enabled to supplement, during those two years, the evaluation of the local situation (at Agliano) with a report from each operator on his local atmospheric conditions, wind direction etc. Those reports were daily telephoned by each operator between 11–12 hrs, and were recorded by an automatic device which was wired to the phone. Prior to this, a short message which contained both, a summary of the daily forecast and the instructions for standby, was delivered to each operator by the same recording device. The original mobile crew of six was thus enabled to spare some time for a further training of, and the assistance to, the above operators in the field; it was also enabled to fill some of the gaps in the static defence belt. The strenghtening of some sectors, according to the direction followed by a particular storm, was thus also made possible. An extensive and detailed record of all daily activities was kept by everyone involved in the project; the farmers-operators were provided with soecial printed forms which required simple checking every hour or so, and on the basis of which their situation and activities could readily be reconstructed. Notwithstanding an excellent work which, understandably, was carried out by most of this local personnel, and also because of the fact that the two operating seasons of 1970–1971 were, hail-wise, rather disturbed, those tactics involved substantially larger expenditures of energy on our part than the season of 1969 required. The original plans for this first season called for massive dispersions in the morning, at suitable pre-selected points of the area, during days believed to be dangerous. Those original plans were changed to mobile tactics which were aimed at obtaining larger concentrations of nuclei in the path of the advancing storms, after a hailswath cut, at the beginning of that season,

Table 2

Summary of data regarding manpower, thunderstorm-days, operations and material used during the project

Year	1969	1970	1971
Operators, Research Council and Chamber of Commerce	6	6	6
Local Farmers	–	12	17
Thunderstorm-days	52	50	60
Days without thunderstorm but with preventive action	47	51	45
Number of days × stations which operated, with a thunderstorm at close range	96	315	374
Number of days × stations which operated during thunderstorm-days, but with no storm nearby	43	101	137
Number of days × stations which operated preventively during no-thunderstorm days	120	207	213
'Climatite' used (metric tons)	9.83	16.52	17.35
Iodine evaporated (kg)	165	220.5	233.5

into one of the richest vineyards of the area. Table 2 illustrates the manpower available for the project and it also contains data on the number of thunderstorm-days, material used, days of operation etc.

b) *Materials and thunderstorm-events*

Inasmuch, during 1969, we have used standardized 10-kg. charges of 'Climatite' which were identical with those previously described [3], we availed ourselves of 5-kg. units of the same diameter and composition during the two years which followed. The charges were thus of two different types and yielded condensation and ice-forming nuclei, respectively. The two types were always fired alternately. The expenditures of this material, with time, are shown in Figure 2 (see also Table 2). Figure 3 shows a burning charge under pre-thunderstorm conditions. The nucleator material was manufactured for us, under licence, by the Montecatini-Edison Company; its conversion into aerosol was of about 80%, with an approximate yield of 10^{14} giant nuclei per generator.

The term 'thunderstorm-day' is meant to denote here a midnight-to-midnight 24 hr period during which a thunderstorm was observed visually and/or acoustically by at least one operator *and* during which aerosolizations were carried out to face its possible danger of hail. The distribution of those days, with time, is given in Figure 4. An evident tendency, of those days, to aggregate into packages of more than one, may readily be noticed from that figure. This situation is consistent with some of the observations due to SUMMERS and PAUL [8] and related to the hail events in Alberta, Canada. An idea, about the frequency distribution of those packages, may be obtained from Figure 5 which, unlike the content of Figure 3 and Table 2, is based on thunderstorm-day values observed over the Asti Province (i.e. excluding Andrate). The curve is clearly found to follow a simple law of probability with good approximation and may be fitted with an equation of the type:

$$p = p_0 \exp(-Ai), \tag{1}$$

where A is a constant, p stands for the probability of an occurrence of a group of i consecutive thundery-days and p_0 is the probability of having one or more non-thundery consecutive days. The integral, between zero and infinite values of i, should here clearly be equal to unity, so that $p_0/A = 1$. Our least-square values, according to which the curve of Fig. 4 was fitted, were found to be:

$$p_0 = 0.454 \pm \mathrm{SD} = 0.075$$

$$A = 0.640 \pm \mathrm{SD} = 0.054,$$

and are, hence, in reasonable agreement both, with the above mentioned prerequisite and with the observed value of $p_0 = 0.511$. Since our distribution was based on 66 packages of thunderstorm-days which consisted of one day or more, and of 69 packages of no-thunderstorm days, the probability of the occurrence of a group, during

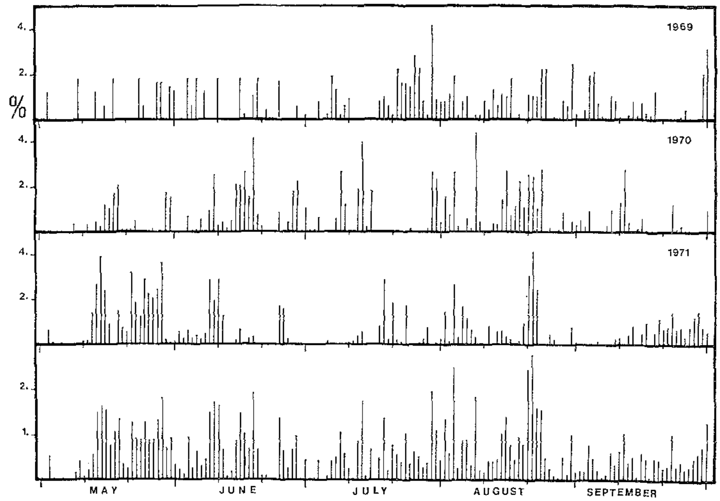

Figure 2
Percentual values of nucleator material used during the project. Bottom scattergram illustrates the tri-annual data wich were cumulated on the basis of corresponding dates.

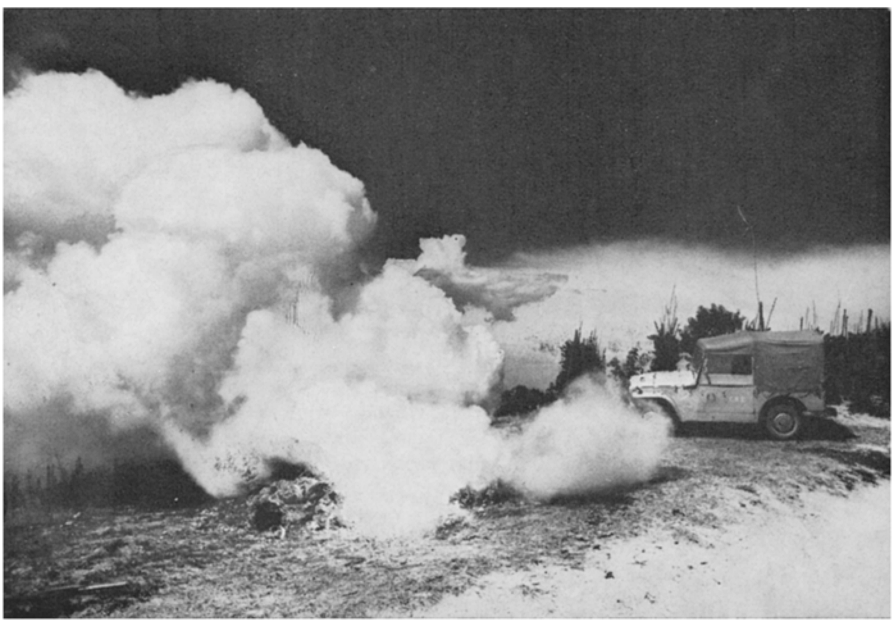

Figure 3
Combustion of a 'Climatite' charge, on the Western border of Asti Province, under pre-thunderstorm conditions, Aug. 21, 1970; 1; 50 hrs. p.m.

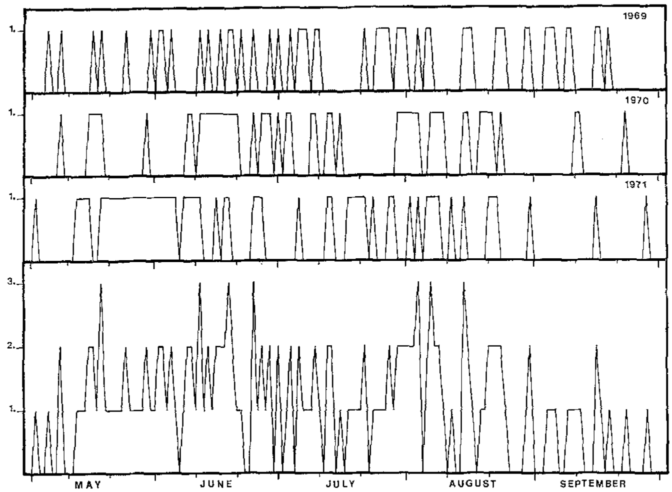

Figure 4
Dates of thunderstorm-days observed at Andrate and over the area of Asti Province, and during which nucleator material was used. Bottom part illustrates the tri-annual data which were cumulated by corresponding dates

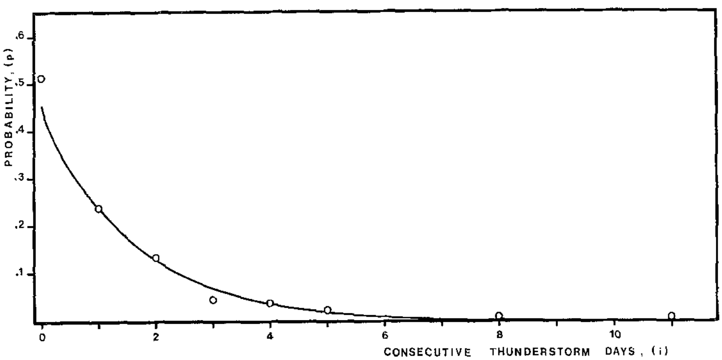

Figure 5
Change of the ratio of the cumulated integers, representing consecutive thunderstorm-day events, to the sum of all packaged events – with the length of a packet. Values refer to Asti Province alone and are based on 15 summer months of observation, covering 140 thunderstorm-days which were encountered during the period of operation. The highest two values of i were excluded from the curve-fitting procedure

those years, may easily be computed from the curve of Fig. 4 by multiplying the corresponding value times ($135 \times i$) and dividing by the total number of days involved (459). Characteristically (for Piedmont), an attempt to extend the same treatment to no-thunderstorm days yielded much less consistent results with the probability function decreasing erratically from 0.1 to zero for values of i spread between 1 and 17, respectively.

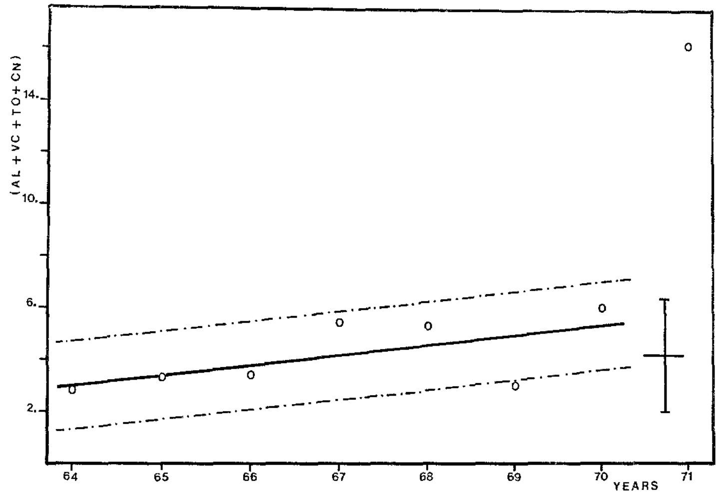

Figure 6
Available data on the monetary equivalents of losses caused by hail (billion lire) to the crops of four Provinces circumjacent Asti. Regression line and average (right) are shown with 95% one-tailed confidence limits of a normal distribution and exclude the value of 1971. Linear correlation coefficient is 0.63

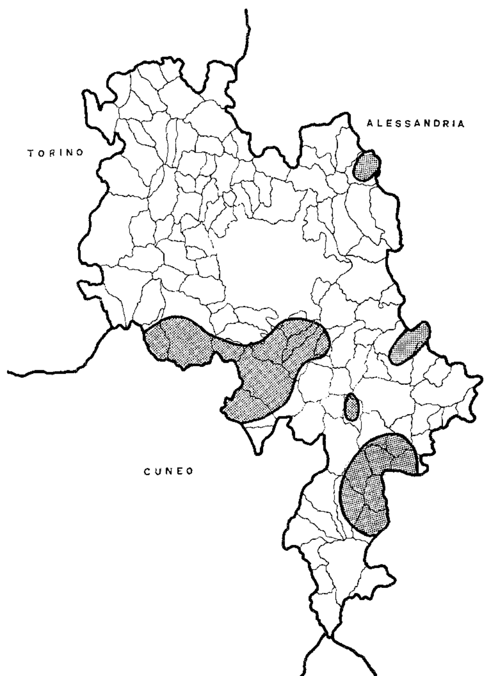

Figure 7
Smoothed data on areal damages, due to hail, to Asti vineyards, during the 5-monthly season of 1969. Raw data were obtained by courtesy of the Asti 'Provincial Inspectorate of Agriculture'

4. *Results*

a) *The overall trends of damage*

The monetary equivalents of losses, which were wrought by hail during years 1964–1971 incl. to the agriculture of the four Provinces circumjacent to Asti, are shown in Figure 6. There is an indication of a barely significant increase of those damages during this period of time and the values may be termed as quite compact, for this type of distribution. An outstanding exception consists of last year's ravages: the devastation brought about in 1971 may, in fact, be regarded as both, exceptionally high and indicative of an abnormally hailwise disturbed season. This nothwithstanding the values related to the years 1969 and 1970 clearly indicate the absence of any such abnormal hail occurrences in that area. This appears to be of interest because of available evidence on the possibility of obtaining counterproducing effects as a result of ground-based uses of some nucleator materials (see (6) for References) for the suppression of hail.

b) *The damages to Asti Province, 1969–1971*

The areas of Asti which were hit by hail during this period of time, are shown, year

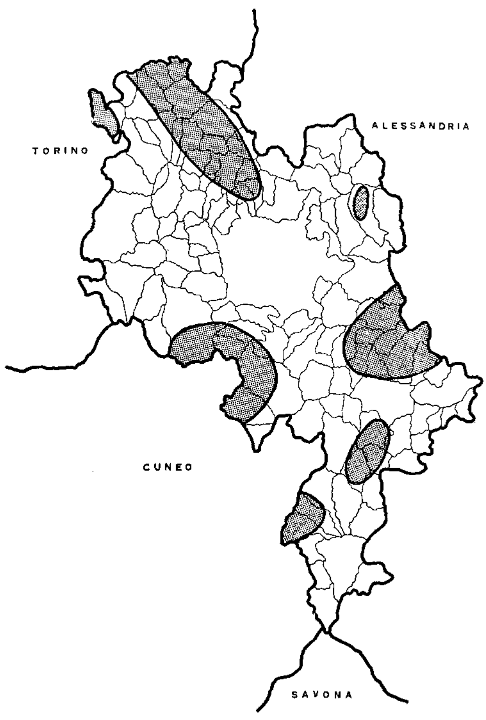

Figure 8
Smoothed distribution of areal damages caused by hail to the vineyards of Asti during 1970. Data are from the same source as in previous Figure

by year, in Figures 7–9. It may be seen that the location of those areas is not at variance with the usual geographical distribution of Asti's hailstrikes (5), this distribution being probably due to recurrent patterns of storm mergers. Figures 10 and 11 furthermore show the two consistent hailswaths which occurred during the above-mentioned period of time. It is recalled, at this point, that the swath shown in Figure

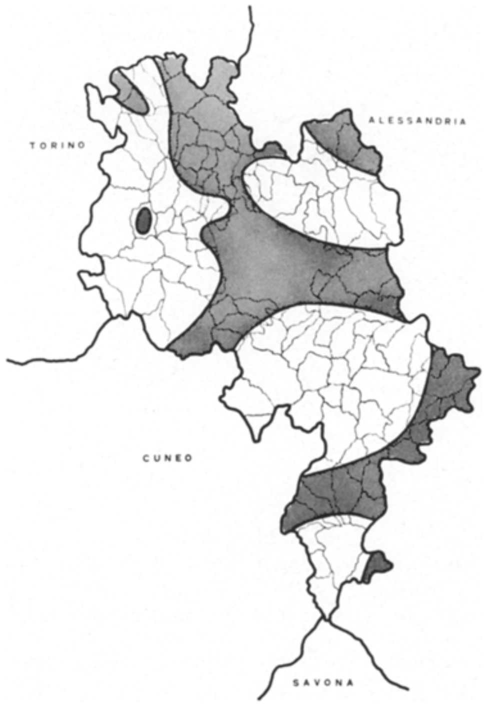

Figure 9
Smoothed areal damage distributions related to 1971. Data on hail-events were obtained from the Asti 'Provincial Inspectorate of Agriculture'

10 took place before the tactics of 'aerosolization ahead of the advancing thunderstorms' were put into practice; as a matter of fact a mere 60 kg of aerosol were dispersed preventively during that day and from the Andrate station (Fig. 1) alone. Both, this episode and the necessity of economizing aerosol materials during June 1971 (see later) are thought to have largely contributed to the change, in 1969–1971 incl., of the monthly distribution of Asti damages (5). Maximal average monthly monetary losses have, in fact, then occurred there during the periods of June (62% of the cumulated total); it is unfortunate that this shift has here to be merely regarded as a curio since it cannot be analyzed in terms of monthly losses of the surrounding Provinces. Monthly distributions of damages are not available for most of those Provinces because of the sporadic practice of cumulating hail-damage data by the area, there.

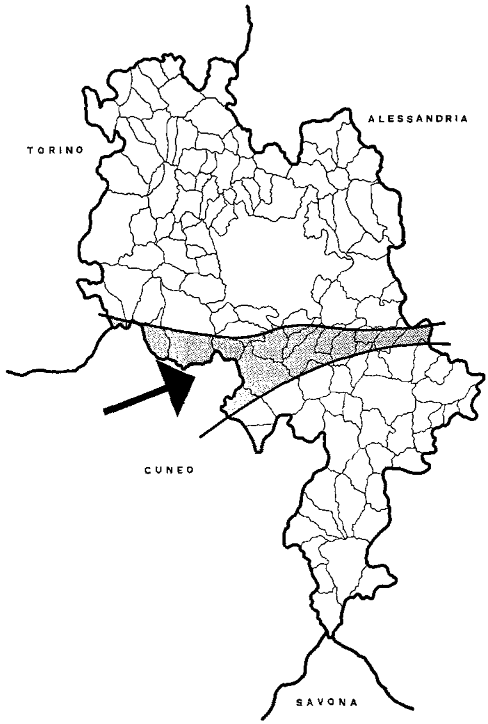

Figure 10
Smoothed hailswath, 4.6.1969; 11 communes hit for a total of 0.57 billion damage of vineyard produce.

c) *Past Asti data on losses due to hail and the 'continuous-historical' estimate*

Table 3 shows the reduced historical values available and the 1969–1971 data; those are here presented in terms of various local parameters by the means of which we have attempted to evaluate the hail phenomena in that area. All those parameters relate *solely* to vineyard values. Inasmuch computations of a straightforward historical type mentioned above are known to illustrate a weather-control project but incompletely, the data of Table 3 are quoted here because of their general interest. They also indicate that, notwithstanding a hailwise disturbed season of 1971 (cf. fig. 6) which could well have been expected to introduce a strong bias into any straightforward historical estimate, the losses of Asti maintained themselves, at all times of the experiment, well below the average of past values.

d). *'Multi-control-target' computation*

Annual data on losses due to hail and sustained by Asti and the circumjacent Provinces, are given in Table 4 in terms of monetary equivalents. On the basis of those numbers, the previously-mentioned diagrams of intercorrelation (5) may be supplemented. The results are shown in Figure 12 while Figure 13 illustrates a good exponential relationship between the monetary loss equivalents of Asti, as a function of

Table 3

Available data related to hail damages at Asti, according to the 'Inspectorate of Agriculture'. Computations, amended according to the indications of a recent survey (see text), are given in brackets. Last column gives t-levels of effective differences. Geometric averages of those levels are 95% and (93%) respectively

	1961–1968					1969–1971		
	Average	SD	1969	1970	1971	Average	SD	t probability, %
Haildays	11.125	2.53	6	10	8	8.0	2.0	94
Communes hit	71.625	24.456	22	47	60	43.00	19.31	93
Surface hit (hectares)	7,818.3	4,415.9	1490	4255	4333.5	3,359.5	1,619.5	96
Surface hit, %	17.73	9.90	3.44	9.82	10.00	7.75	3.74	96
	(20.49)	(12.21)	(4.66)	(14.01)	(14.14)	(10.94)	(5.44)	(89)
Loss of produce, %	7.94	5.44	1.56	2.05	3.31	2.31	0.90	98
	(8.96)	(5.87)	(2.12)	(2.92)	(4.67)	(3.24)	(1.30)	(97)
Total loss (billion Lire)	2,159.9	1,429.6	603.6	724.9	1,409.7	912.7	434.6	95
Loss per hectare (million Lire)	0.050	0.034	0.014	0.017	0.033	0.021	0.010	95
	(0.057)	(0.039)	(0.019)	(0.024)	(0.049)	(0.031)	(0.016)	(85)

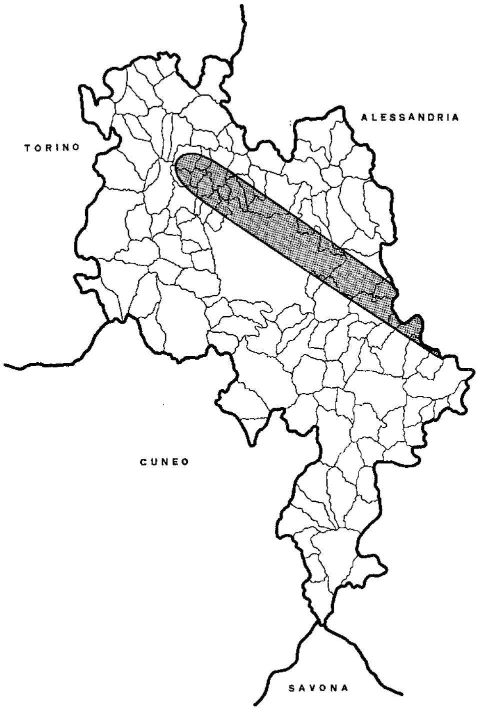

Figure 11
Smoothed hailswath pattern of storm dated 18.7.1971; 14 communes hit to the extent of 0.203 billion lire damage to vineyards

Table 4

Losses, caused by hail (billion Lire), to the vineyards of Asti and to all crops of circumjacent Provinces. Data are by courtesy of the corresponding 'Provincial Inspectorates of Agriculture' and cover the whole period of time during which those estimates were concomittantly made in all Provinces quoted

Year \ Province	AT	CN	TO	VC	AL	CN + TO + VC + AL
1964	0.7826	0.8854	0.9621	0.9849	–	2.8324
1965	0.9732	1.5663	0.1057	0.5503	0.9870	3.2093
1966	1.3403	1.9697	0.3313	0.9074	0.2182	3.4266
1967	3.4241	1.7931	1.6129	0.1875	1.8600	5.4535
1968	3.6507	3.9697	0.5210	–	0.8149	5.3056
1969	0.6036	1.1070	0.8840	–	1.0568	3.0478
1970	0.7249	3.2233	1.9000	0.1650	0.7543	6.0426
1971	1.4097	7.4939	3.1300	0.5161	5.1065	16.2465

losses of the circumjacent Provinces and covering years 1964–1968 incl. It appears here to be obvious that, in order to allow for the extent of the atmospheric disturbances one was expected to cope with, the evaluation of the results should here be

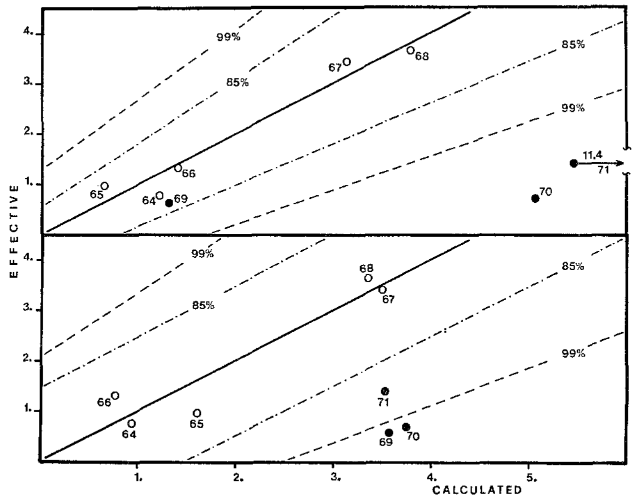

Figure 12
Plots of effective losses to Asti Province, against the losses calculated from binomial correlations (5) between AT; (TO, CN) – (above) – and AT; (TO, VC) systems, covering period of time 1964 – 1968 incl. (fitted line). Full circles stand for years during which the test was carried out. Value corresponding to year 1971 of upper diagram, has 1.41 and 11.40 for ordinate and abscissa, respectively. Confidence limits are one-tailed, normal

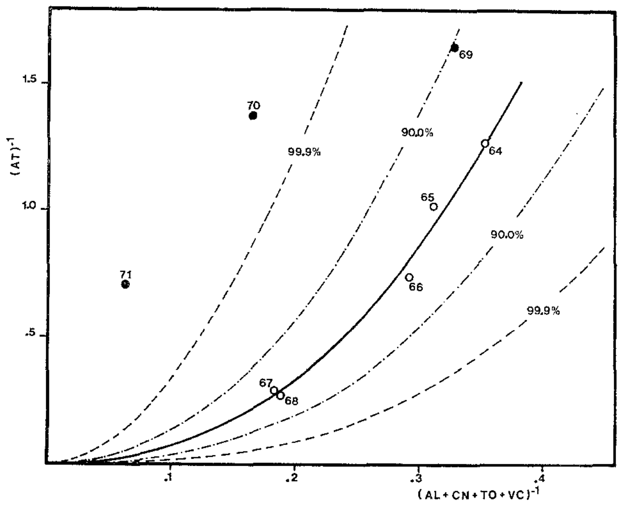

Figure 13
Change of Asti's loss equivalent to hailed-on vineyards, with the loss equivalent, due to hail, of all produce and sustained by the four circumjacent Provinces. Least-squares line was fitted through values representing years 1964–1968 incl. (empty circles); the corresponding equation is:

$$Y = (14.78 \pm \mathrm{SD} = 2.95)\, X^{(2.35 \pm \mathrm{SD}=0.14)}.$$

Dotted lines show one-tailed limits of normal distribution; full circles stand for years of test carried out in terms of *ratios* of prospected-to-effective losses, rather than in terms of their differences. Those ratios may readily be calculated from the correlations shown in Figures 12 and 13, as well as from the data of Table 4. They are given in Table 5 which also contains a set of ratios similar but obtained from the historical average 1961 – 1968 incl. (Table 3). Since the last value of this series appears to be unreasonably high (and roughly corresponds to a complete destruction of Asti vineyards) and since it, moreover is larger than the average $+2 \times SD$ of the remaining values, this number will here be discarded for the purpose of this computation. The eleven ratios considered

Table 5

Ratios of prospected-to-effective monetary loss equivalents according to the type of computation used

Year	Historical average	Correlation		
		AT vs CN and TO	AT vs TO and VC	AT vs (CN+TO+VC+AL)
1969	3.5784	2.1912	5.9180	1.5442
1970	2.9796	6.9938	5.1534	6.4374
1971	1.5322	8.0882	2.4985	33.9591

yield a mean of 4.265 with a standard deviation of 2.339. This average hence differs from unity at a 99.9% t-level for ten degrees of freedom and corresponds to savings of 76.6%, with 99% t-confidence limits of 50.7% and 84.6%. A similar computation carried out by the use of logarithms, indicates a geometric average value of 72.6% for savings, with both 99% confidence limits being respectively and to any practical effect, identical with those given above.

Average savings of 76.6% over those three operational years correspond, in our case, to a benefit: cost ratio of 62. This ratio is calculated here in terms of Asti vineyards alone as far as benefits are concerned, and in terms of the materials, logistics, salaries, communications etc. for the 15 months of operation. It hence excludes the expenses incurred into during the time outside of those 15 months (salaries, instrumentation, reports etc.). An analysis of an average weighed 1, 2 and 3 for columns 2, 3 and 4 and 5 of Table 5 respectively, and in tentative accordance with the weight of those columns, leads to yet more attractive results.

5. *Concluding remarks*

The project described in this paper was designed and executed as a test of the nucleator material, to be dispersed from the ground for purposes of hail-suppression. It, of course, is gratifying that this test also appears to have brought some savings to the Asti farmers. This notwithstanding, it is perfectly clear that a *functional defence* of this or any other area in Italy against hail, should not have been run the way this project was. Efficient and centralized radio communication between operators, the employment of well-trained, motivated full-time personnel and the continuous availability of weather charts, would have undoubtedly led to better results. A functional central laboratory-headquarters containing equipment for the monitoring of storm trajectories, and other instrumentation which modern technology has placed at the disposal of the scientist, would obviously have further improved the situation. Those facilities were, unfortunately, unaccessible to us under the present circumstances. Also, as things were, both, allocations of funds for the material and the decisions to prolong the test for another year, had to be done on a year-to-year basis until the maximum of three seasons was reached. This created difficulties in planning the expenditures of material and made the establishing of suitable nucleator reserves, virtually impossible. Thus, for example, the situation became quite acute during the last year of operations where, after 25 seeded thunderstorm days which occurred during the period of time covering May 12th–June 8th incl. (Figures 2 and 4), calculated risks had to be taken in order to face, with adequate supplies still on hand, the hailwise worst months of July and August (5).

6. *Acknowledgements*

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