

GROUND SEEDING HAIL PREVENTION EXPERIMENT IN FRANCE

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ABSTRACT

The project of reducing damaging hailfalls by silver iodide seeding in the boundary layer before and during the growth of thunderstorms is still increasing in the south part of France, north of the Pyrénées. The seeding network consists now of 450 ground vortex generators in an area of about 7 millions hectares.

The scientific contribution of this project concerns the climatology and the dynamics of severe hailstorms, their forecasting, and the generation and measurement of artificial ice nuclei in the atmosphere. The economical impact is evaluated with double-mass curves of loss-to-risk insurance ratios in seeded and control areas.

INTRODUCTION

Some years after the discovery by I. Langmuir, V. J. Schaefer and B. Vonnegut of the possibility to artificially change the icing process in a supercooled cloud, H. Dessens conceived that it may be possible to affect hailstorms generation in thunderstorms by releasing silver iodide from the ground. Started on a small scale in 1951, a project aimed to suppress damaging hailfalls in the Bassin d'Aquitaine gradually increased until now. The experiment has never been randomized, but, as stated by Mather (1978), this is not a reason to keep the results unpublished; the exceptionally long duration of this experiment leads to some results that would probably not have been available with a shorter project.

This paper summarizes the scientific and practical results of the project, operated from the beginning until now on a non-commercial basis by the "Association Nationale d'Etude et de Lutte contre les Fléaux Atmosphériques" with departmental grants.

HAIL CLIMATOLOGICAL DATA

1. Spatial frequency of hail reports.

Hailsfall data are compiled every year from various sources by the Association; these data consist of reports by seeding operators, departmental agricultural offices, hail insurers and regional newspapers. An average of 500 annual reports, with place, day, time and duration of hailfalls,

and with indications about the type of stones and the damages, is available since 1952 (Association, 1952-1978). These data lead to a hail climatology by Castet (1974), Trachez (1975), and Celhay and Raynal (1977). The most typical result is the annual frequency of the very damaging hail-falls per square area of 900 km² (Fig. 1): the map shows a main core of hail 100 km north of the Pyrénées, at the same distance from the Atlantic Ocean and the Mediterranean Sea; this configuration is probably due to the effect of the Pyrénées on the upper level south airflows (jet streams), and to something like an isthmian convergence.

Every year, the most damaging hailstorms in South Western France form the subject of case studies that show there is a general rule for these storms: they are connected with cold fronts coming from the Atlantic Ocean, and they are moving in the wind about three kilometers high. Trajectories are from South-West to North-East. Lengths of the damaged hailpath are about from fifty to hundred kilometers. Many of these storms had the same trajectories because they were born in special areas just downwind the Pyrénées, for example above the plateau de Lannemezan and the plateau de Ger between Pau and Tarbes.

2. Time frequency of hailstorms

The statistics from the crops hail insurances gives informations about yearly fluctuations of the phenomenon; the variations since 1944 of the yearly loss-to-risk ratio show a succession of periods with more or less hail, and the smoothing of the graph with the yearly values of the ratio suggests a period of five or six years (Fig 2). This apparent periodicity may come from the smoothing process, but it has already been found by W. J. Humphreys (1940) and studied by R. K. W. Wong (1977). If this type of variations could be confirmed, important implications could follow for farmers, insurers, and hail research projects.

In some departments, the data of the Mutualité Agricole are daily available; they show that in a year, a very small number of days between May and September is responsible for most of the damage. For the "Haute-Garonne", for example, the first damaged day in a year causes 43% of the total damage in the year, and the second damaged day causes 23% (Fig 3).

3. Upper-Level winds

The study of the most damaging hailstorms led H. Dessens (1960) to propose a theory about the hail formation that gives a particular emphasis to the maximum wind velocity between 6000 and 1200m. According to this theory, the updraft of the cumulonimbus connects the principal sources of energy: the instability near the ground, the latent heat of condensation and freezing in the middle part, and the kinetic energy of the wind in the highest one.

Actually, the comparison of a population of damaging storm days shows a significant difference in the highest speed of the wind between the ground and the tropopause (Fig. 4).

The visual observation of the most severe hailstorms led H. Dessens (1967) to suggest a microphysical process which completes the dynamical one:

the ice crystals removed from the highest part of hailstorms by the violent winds, which give to these storms their characteristic elongated anvil form, cannot seed the lowest supercooled areas of the storm any more. It's likely that the dynamical and physical process combine together, and that the efficiency of the storm to product hailstones is the most important when there are high violent winds.

In both cases the possibility to make the hailstones smaller is to seed the updraft in its lowest part. Soulage (1963) checked in part this assumption by measuring that hailstorms are developed in air masses with an ice-forming activity below the mean background.

THE FORECASTING PROCEDURE

The seeding method must operate the ground generators 3 to 5 hours before the storms produce hail, in order that the nuclei accumulate homogeneously in the low atmosphere; for this reason a particular effort was made to forecast hail in South-Western France.

In the first operational years there was no distinctive forecast between thunderstorms without hail and hailstorms: in order that there was no failure, almost all the storms were seeded. Because every year there were more and more generators, the weight of silver iodide sent in the atmosphere increased to 4200 kg for 223 stations in 1965, corresponding to 2000 hours of running per generator.

The efforts made since then by the Regional Meteorological Office in Bordeaux led to an important progress in this area. With the reports of hailfalls from 1958 to 1970 and with the data of the nearest soundings, Molenat (1975) made a diagram giving the diameter of the hailstones according to four parameters: wind direction in middle level, index of Galway, tropopause temperature and freezing point altitude (Fig. 5). More recently, Celhay and Raynal (1977) proposed some changes to this forecasting method, suppressing the parameter of the wind direction, and including the shear between the basis and the top of the storm: this last parameter is probably important according to the hailstorm process suggested by H. Dessens.

This new method of forecast added to the decrease until 4 hours of the preseeding time, caused the lowering until about 500 hours of the running time per generator in a year. A supplementary daily radiosounding is now operated in Toulouse, from May to September, in order to use a similar diagram for the east part of the seeded area.

THE GROUND SEEDING NETWORK

For a homogeneous preseeding in a large target area, it is better to have many generators burning a small amount of silver iodide with great efficiency than to have only some generators with great output and moderate efficiency. The price "per nucleus" must be as low as possible, and the

generators must be easy to use by everybody on the ground.

The different steps in the realization of the generators needed various researchs with special equipments like dilution wind tunnels and nuclei counters. On a technical point of view, these researchs showed that a good way to produce efficient ice nuclei is to vaporize the silver iodide at a temperature of about 750°C; the thermal calculations show that the generator must exclusively burn an AgI-acetone solution, and that the generator efficiency decreases with the concentration of the AgI solution (H. Dessens, 1961). On a practical point of view, charcoal generators were used from 1952 to 1958, fan generators from 1959 to 1962 and vortex generators from 1963.

In the vortex generator now on the ground, the AgI-NaI acetone solution is supplied from a pressurized tank, injected into a chimney after the fine breakup by a nozzle, and burnt in the chimney by which the air is sucked forming a vortex (Dessens and Pham Van Dinh, 1968). The vortex generator burns 1 l/h of acetone with 8 g/l of AgI. The efficiency of this generator measured in a cold mixing chamber, is of 9×10^{14} nuclei per gram of silver iodide at -20°C, which gives an output per second of 2×10^{12} (Pham Van Dinh, 1973).

The study of atmospheric diffusion and nucleation efficiency of the nuclei released from the ground was also the subject of successive research projects; J. Dessens (1961) measured by photogrammetry a lowering of the convective clouds freezing level from -35°C to -15°C above a generators network; Soulage (1964) observed increases per 10 and in some cases per 100 of ice nuclei concentrations near the ground downwind a network. Benech (1968) measured from an aircraft or an helicopter an important ice nuclei concentration in some horizontal layers of the atmosphere above the network. Pham Van Dinh (1975) made ground measurements with a N.C.A.R. acoustic counter in the middle of a generators network, and found that the variation of ice nuclei concentrations are generally well correlated with the emissions: he observed increases by 100 or by 1000 of nuclei concentrations, and these go on after the stopping of the generators.

The Association operates now with a network of 450 generators. The data processing for the running of the generators and for the hailfalls in the target area are made by computer (Association, 1978).

AN EFFICIENCY CONTROL WITH INSURANCE DATA

From the beginning of the project, Dessens (1956) proposed that the efficiency of the project could be measured by statistical results of hail insurances. Indeed, in South-Western France, the hail insurance coverage is important (25% of the crops) and regularly sparse (10% of the total area).

An interesting parameter is the loss-to-risk ratio which is a non-dimensional value disconnected with economical disturbance like recession and inflation (Moreau, 1978). Comparing the yearly values of the ratio in the seeded area with the values in a control area, the double mass curves give an opportunity to measure the economical efficiency of seeding (Dessens

and Lacaux, 1972).

In a recent paper, Dessens (1978a) presents double mass curves in the seeded area and in two non-seeded areas for which the insurances data are available: the Rhodanian Bassin in South-Eastern France and the France except Rhodanian and Aquitan Bassins. Both curves show a slope break around 1963-1965 followed by a relative decrease of damages in the seeded area, well correlated with an increase of the seeding. These curves are summed up on Fig. 6 which compares the percents of damages in the seeded area and in the rest of France. The years before 1951 are not considered here because of important changes in the insurances coverage at this time.

The benefit to cost ratio of the seeding may be estimated as follows:

-Annual mean damage to insured crops (1971-1975):	\$15 million
-Annual mean damage to total crops (1971-1975) (estimated):	\$60 million
-Total cost of the seeding, per year:	\$ 5 million

In case of only 10% efficiency, the benefit-to-cost ratio would be already of 1000%; Fig. 6 suggests a greatest ratio of efficiency.

CONCLUSION

The most damaging hailstorms occuring in South-Western France are associated with cold fronts coming from the Ocean and pushing above the warm air near the ground when they progress inland; this is probably a typical good condition for hail prevention by preventive seeding from the ground.

The hail prevention project of the Association Nationale de Lutte contre les Fléaux Atmosphériques is probably one of the largest weather modification experiment in the world, operating now with 450 vortex generators releasing about 1 ton of silver iodide per hail season in an area of 7 millions hectares. The practical results, based on double-mass curves with loss-to-risk ratios of insurance data in seeded and control areas, show a decrease of hail damage in the seeded area this last decade, corresponding to an increase of seeding both in quality and quantity.

Although the results are not scientifically significative, we hope they are sufficiently indicative of a ground seeding effect on hailstorms to stimulate a more elaborate control project (Dessens, 1978b) in the type of N.H.R.E. (aircrafts) or Grossversuch IV (rockets). This conclusion is in accordance with Atlas (1977) who suggests that ground-based seeding may be effective despite claims by various investigators that direct injection into the cloud base is crucial to success.

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FIGURE LEGENDS

Fig. 1. Annual frequency of damaging hailstorms per 900 km² areas (1951-1972). After Castet, 1974.

Fig. 2. Loss-to-risk ratios in South-Western France. Binomial filtered series. For details, see Dessens, 1978 b.

Fig. 3. Day hail damages, per cent of the total year damage. (Haute-Garonne, 1971-1977).

Fig. 4. Frequency distribution of maximum wind at high levels for 38 hail days (solid) and 38 storm days without significant hail damages (dashed). After Dessens, 1960.

Fig. 5. Diagram for the determination of the diameter of biggest hailstones with a proximity sounding (After Molénat, 1975).

A :	diameter	≥ 20 mm
B :	"	= 15 mm
C :	"	= 10 mm
D :	"	< 10 mm

Fig. 6. Double-mass curve of loss-to-risk ratios in South-West France (seeded) and in rest of France (control).

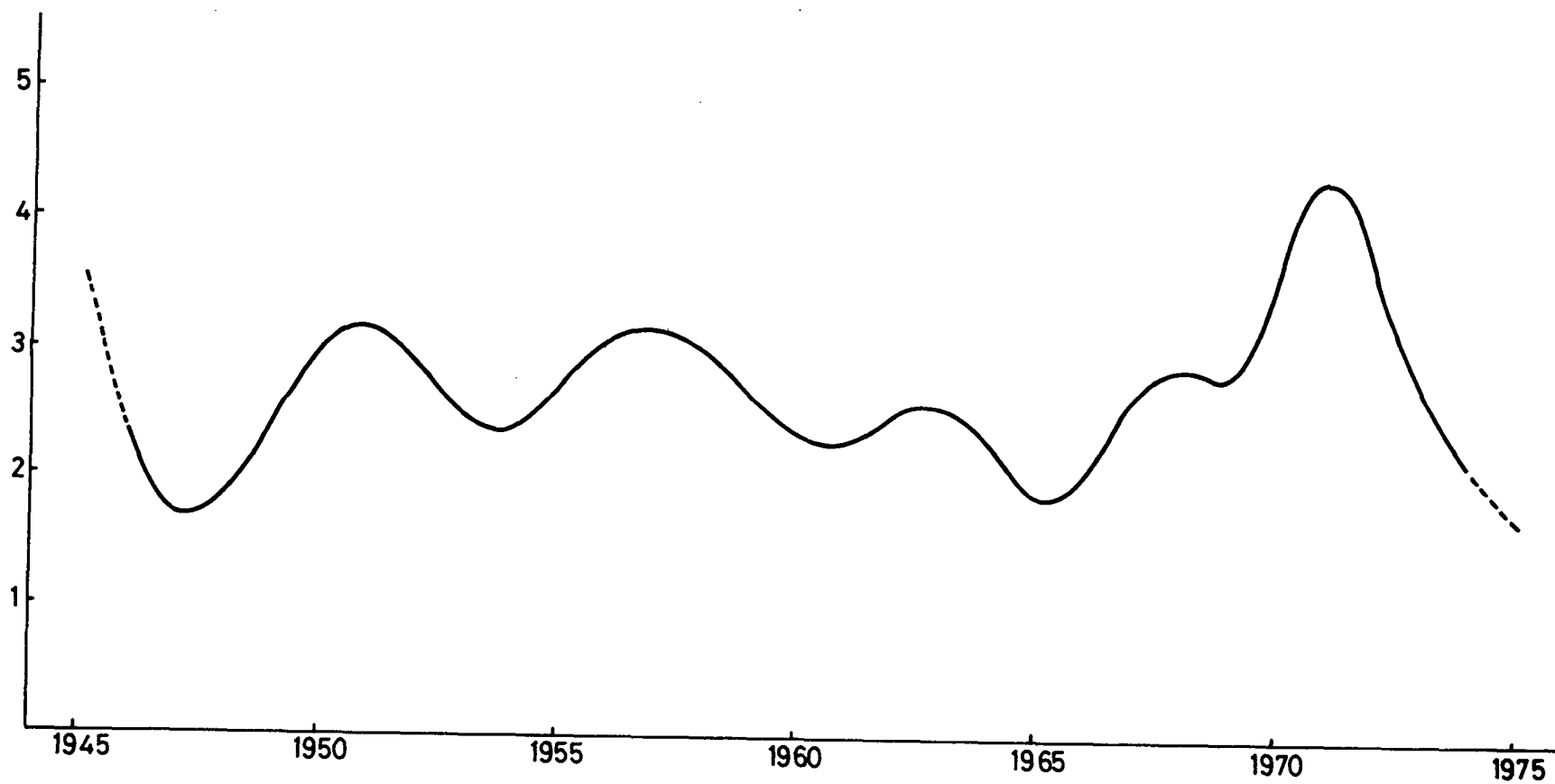


FIGURE 2.

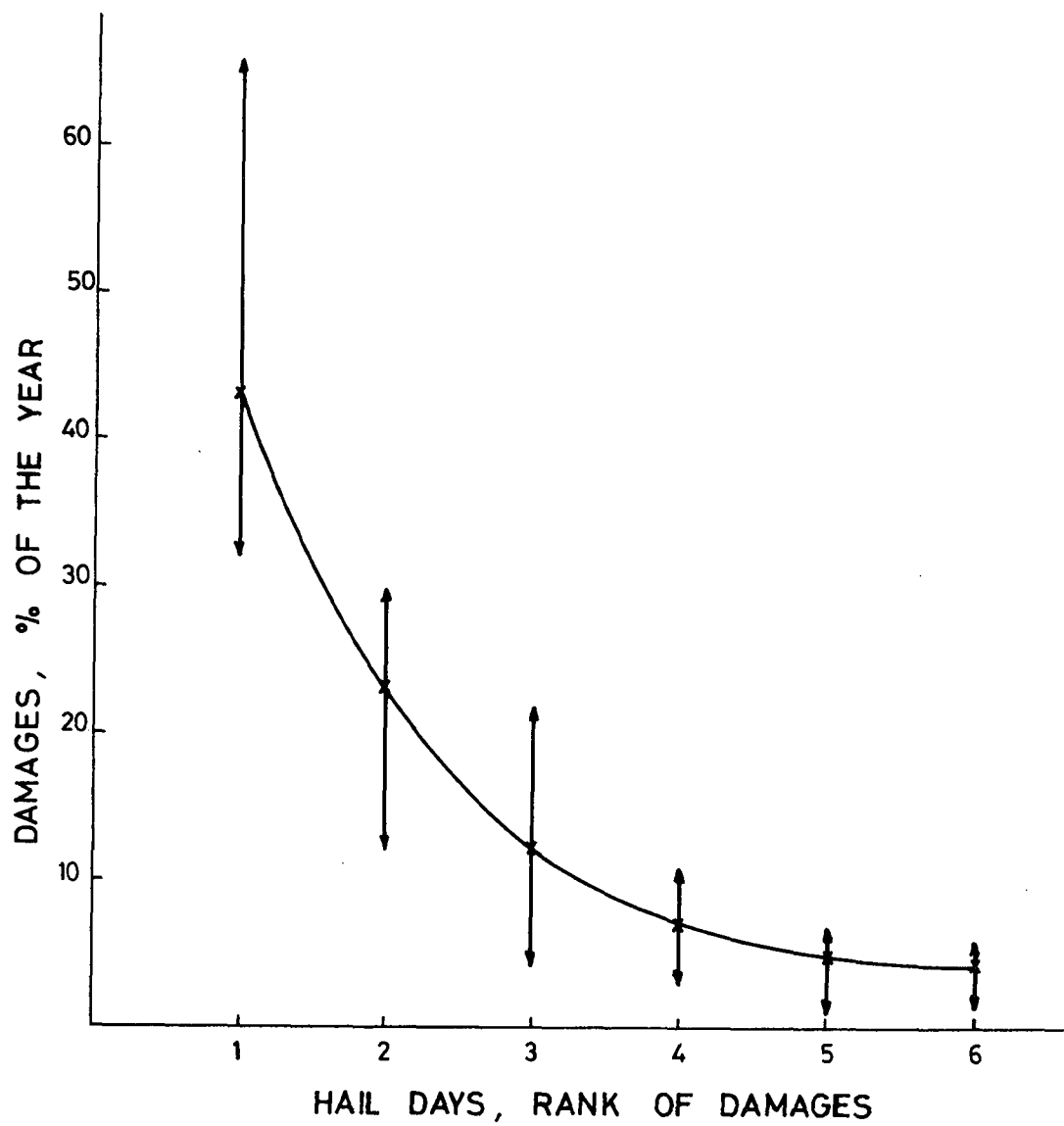


FIGURE 3.

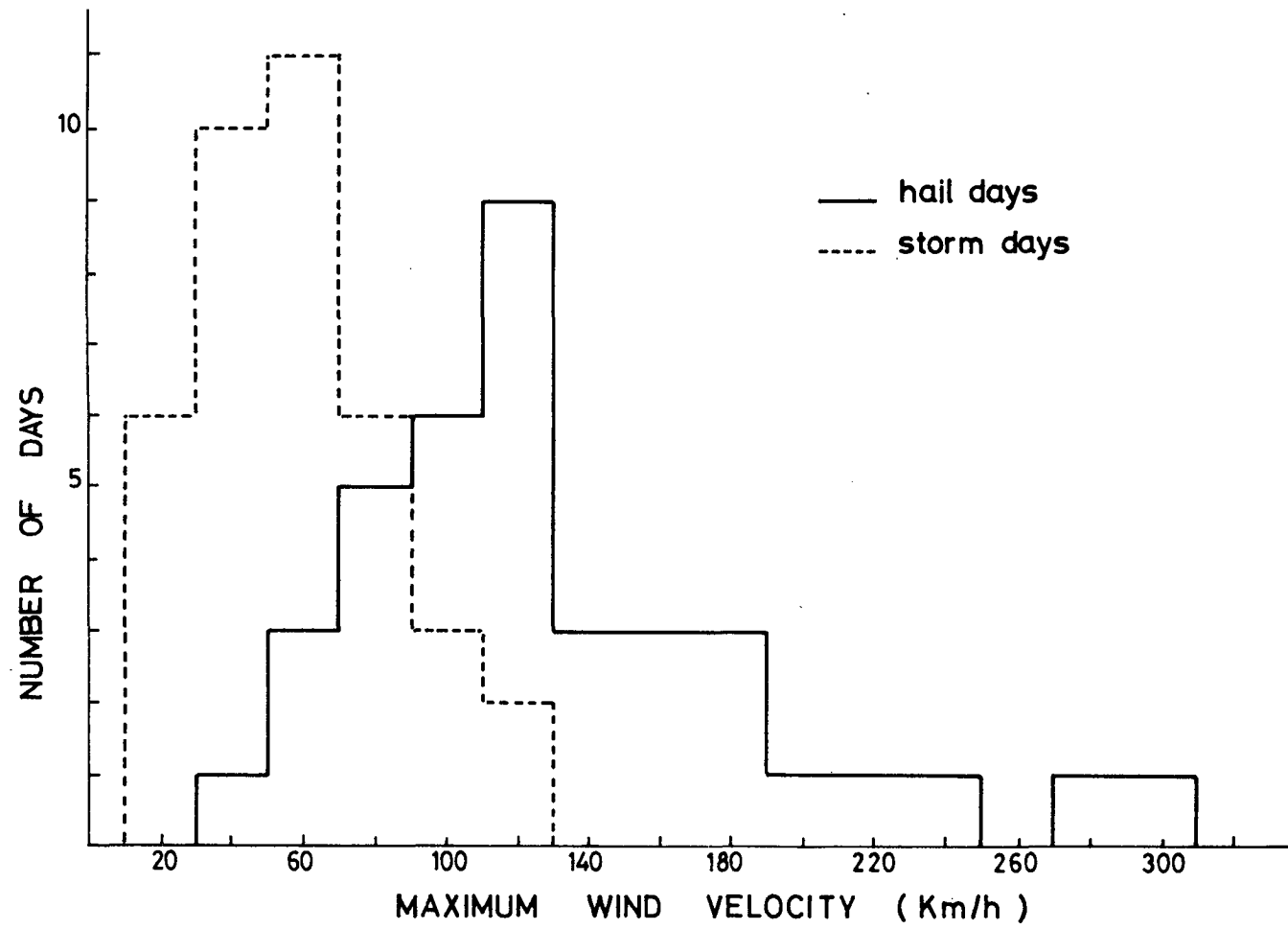


FIGURE 4.

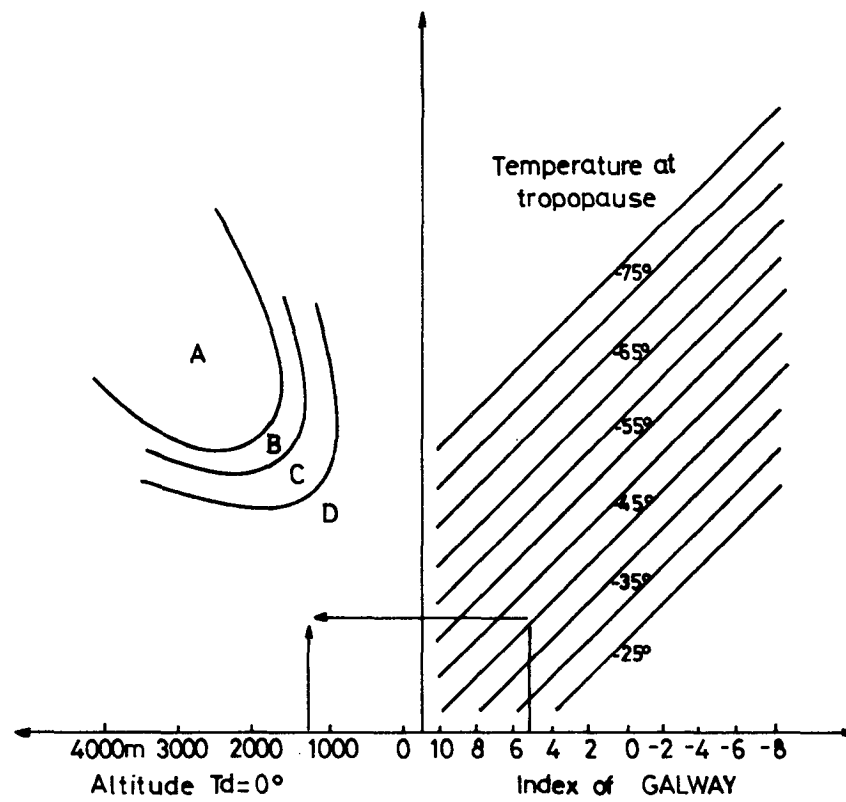


FIGURE 5.

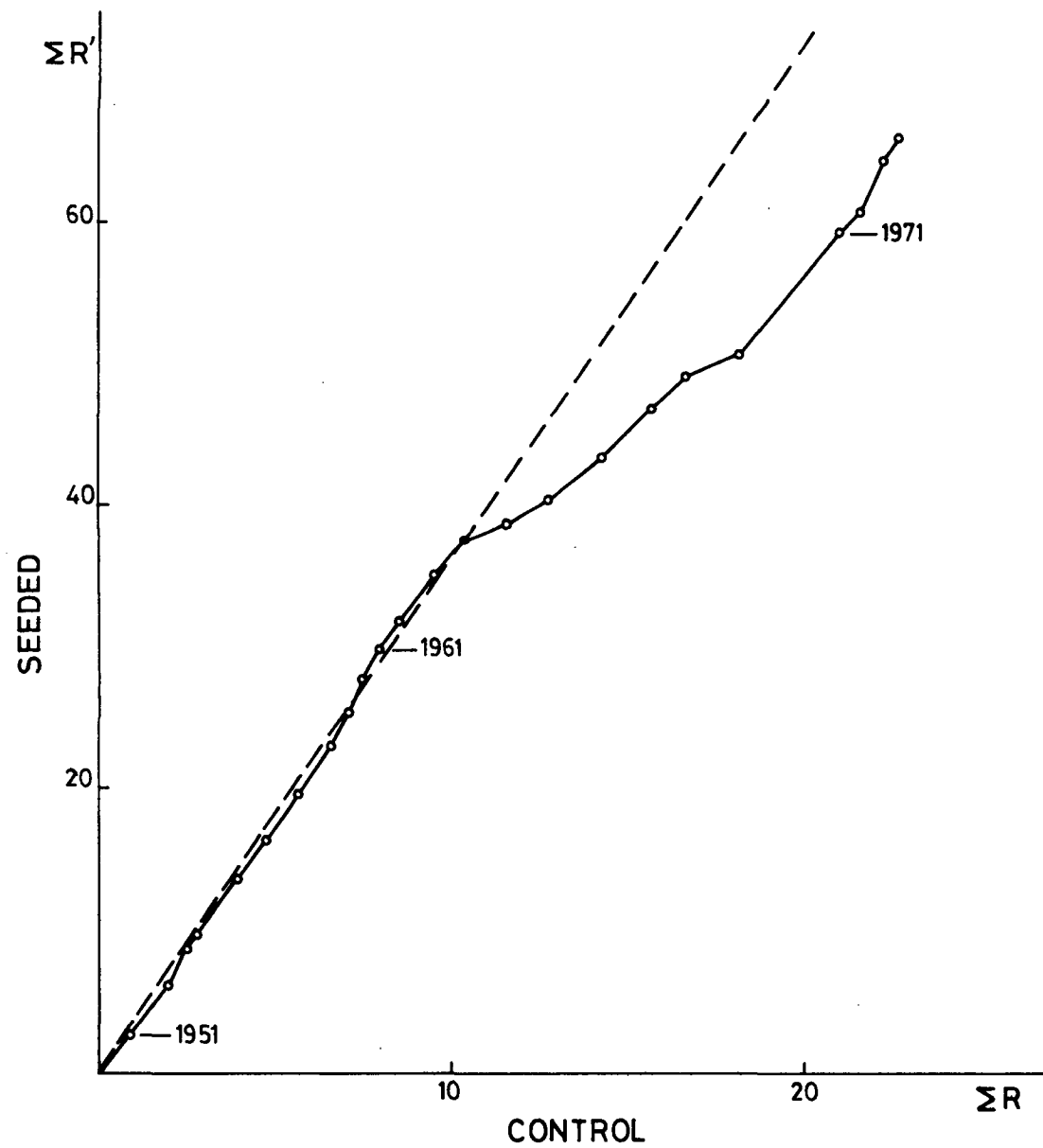


FIGURE 6.