CAN WE REDUCE THE HAIL PROBLEM?

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ABSTRACT

The magnitude of the hail problem in New Zealand is considered. Although there is less hail damage than in some other countries, the cost is likely to increase as the area used for horticulture increases. Methods of abating hail damage by the use of protective devices are discussed. Applications of an improved hail climatology are considered.

Two methods of suppressing hail that have been widely used overseas are reviewed.

One method involves the seeding of cloud with silver iodide, or other substances, that are intended to promote freezing of supercooled water at temperatures higher than those at which cloud water freezes naturally. It is shown that carefully designed scientific experiments have not demonstrated any reduction of hail resulting from cloud seeding. However there is evidence that many hail suppression operations in various parts of the world appear to have reduced hail damage.

Hail cannon, which are now being introduced to New Zealand, belong to a class of attempted hail suppression methods based on explosives. Possible mechanisms for their claimed success are reviewed. The lack of firm scientific evidence for their efficacy is demonstrated.

INTRODUCTION

Hail is defined as precipitation in the form of small balls or pieces of ice with a diameter of at least 5 mm falling either separately or agglomerated into irregular lumps (World Meteorological Organization, 1956).

Hail is formed in tall convective clouds, usually cumulonimbus. Ice growth takes place on initial ice particles by the accretion of supercooled liquid water droplets which freeze on impact. The resulting hailstone embryo is of low density as it includes air-filled gaps. Should such objects fall to the surface they readily crush. Under appropriate conditions of temperature and of accretion rate in cloud, the gaps in these objects are filled, giving rise to the formation of ice pellets a few millimetres across. Ice pellets may also form by the freezing of raindrops or snowflakes that have largely melted. Additional accretion on ice pellets results in an increase of volume to form a hail stone. The physics of hail formation is discussed further in Mason (1971), English (1973) and Rogers (1979). The distinction between true hail and other forms of frozen or partially frozen precipitation is not always strictly followed and can lead to difficulties in interpreting hail statistics.

Hailstones grow while they are maintained in cloud having a temperature of 0°C or less by a near balance between their fall speed (which increases with hailstone size) and the cloud updraught. Eventually, hailstones may grow to a size such that they fall relative to the updraught, or they may be displaced laterally from the updraught, or the updraught may weaken. The hailstones can then descend to levels with temperatures above 0°C where melting takes place. The larger hailstones fall to the ground without melting completely.

HAIL DAMAGE

The high energy of large hailstones when they impact crops or other sensitive surfaces is a principal cause of hail damage. Additional damage to buildings can arise from the combined effects of hail impact, water damage and wind, from hail weight on structures or through hail blocking drainage. The annual cost of damage by
Hail has been estimated as amounting to billions of dollars.\(^1\)

It is difficult to compare agricultural hail losses between countries and periods because of varying crop values and exchange rates. However, some estimates from countries where horticulture is a major industry are noteworthy. In Italy, annual crop losses to 1973 amounted to $NZ120m dollars or $NZ388 per square kilometre (Morgan, 1973). The annual hail loss in an 80 000 square kilometre area in the southwest of France was reported by Dessens (1986a) as $NZ82 000 000 or $NZ1025 per square kilometre.\(^2\)

Urban hail damage losses can also be very high. A devastating hailstorm in Munich in 1984 caused an insured loss of over $US500m, with the total loss possibly twice as much (Munich Reinsurance Company, 1984). Vehicle damage was a substantial part of the insured loss. A hailstorm in Denver caused losses of $US350m in June 1984 (Blanchard and Howard, 1986). Hailstorms in Australian cities have caused large losses. The greatest losses occurred from a storm in Sydney in 1976 with insurance claims exceeding $A40m (Morgan, 1979).

Some horticultural damage estimates are available for recent New Zealand hailstorms. A storm in the Bay of Plenty in January 1987 was reported (“Evening Post”, 2 February 1987) as having caused a loss of $6 000 000 to kiwifruit growers. The combined cost of hail and wind damage, mainly horticultural, from the November 1984 storm in west Auckland was $4 000 000 (McGill, 1987). The October 1986 hailstorm in Hawkes Bay is estimated to have caused 30 percent damage to 959 hectares of horticultural crops at a cost of about $4 000 000. When the losses from lesser or less publicised storms are added, the total may already amount to more than ten million dollars per annum. Between 1981 and 1986 the area used for horticulture increased by 55 percent. If this expansion of the area used for producing valuable but vulnerable crops continues, horticultural losses caused by hail can be expected to increase.

It is therefore timely to examine the hail problem in New Zealand. This paper examines the possibility of reducing hail damage. A second paper (Steiner, 1988) examines the climatology and characteristics of New Zealand hailstorms. The principal results of that study are summarised below.

Analysis of reports of hail at climatological stations reveals that the incidence of hail generally increases from north to south and from east to west. The analysis suggests that the hail frequency is highest in winter or in spring in most parts of New Zealand. Analysis of the reporting of hail in hourly weather observations indicates no preferred time of day for hail occurrence.

A data set of reports of severe hail in newspapers (Neale, 1977) was extended and reanalysed. A very different seasonal and diurnal distribution is found for damaging hail. In eastern areas and in Southland more than 60 percent of all severe hail occurs in spring and summer afternoons. More than 50 percent occurs at these times in Marlborough, Nelson and the Bay of Plenty-Taupō area. In other (western and northern) areas, the seasonal and diurnal variability is less pronounced.

The different distributions above probably result from the inclusion of many small frozen particles in the climatological and hourly hail reports.

Fourteen hailstorms that had caused severe losses to the apple or wheat crops were studied. All of the hailstorms occurred in the rear of the main cold front of a depression. Most were associated with a cold and unstable troposphere but without the temperature or instability being necessarily extreme. A mesoscale or large scale circulation pattern conducive to upward motion is favourable to the occurrence of damaging hail.

**HAIL ABATEMENT**

Methods for the reduction of hail damage based on hail climatology are considered below. The international effort in hail suppression by intervention in cloud processes is reviewed subsequently. The prospects for mitigating hail damage in New Zealand are considered in the final section.

If a detailed climatology of the occurrence, quantity and size of hail is available it can be used for planning purposes. From such data the hail risk can be determined. Vento and Malossini

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1 Henderson (1987), from correspondence with Lloyds of London, quotes a 1986 estimate of at least 4 billion US dollars, or at the 1986 exchange rate, at least 8 billion New Zealand dollars.

2 The Italian and French hail losses have been converted to New Zealand currency at the exchange rate for the appropriate period.
(1982) suggest that when this information is combined with a knowledge of the damaging potential of hail to crops at various phenological stages, cost/benefit analyses can be established. These can determine the viability of particular crops in given locations.

An attempt to obtain a detailed climatology of hail in Canterbury was made by Miller (pers comm) using cards mailed to volunteer supplementary observers and requests through a radio station for additional information after known hail falls. To develop and maintain a systematic record of hail and hail damage is a major undertaking, requiring the co-operation of all land users and insurers, and the commitment of appropriate people to archive and analyse the data. In addition to its uses for planning, the availability of the data would serve both insurers in setting appropriate rates and growers in deciding if any offered insurance was worthwhile. It would also provide some guidance for evaluating any hail supression effort. Comprehensive high resolution hail archives have been developed in Alberta (Wojiw, 1975) and France (Dessens, 1986a).

A further possibility for reducing hail damage is to use protective screens above the crop. Vento and Malossini (1982) suggest these may be appropriate for particularly valuable crops. The hail climatology, microclimatic effects of the cover and its lasting properties would all need to be considered in evaluating the merit of such screening.

Towery et al (1976) demonstrate that trees can markedly reduce hail damage in their immediate vicinity when hail is associated with strong winds. The trees have three effects. Some hail is intercepted directly by the trees protecting crops immediately downwind. The trees also create a change in the air flow so that the area in the lee of them is partially sheltered with hail deflected laterally. Wind speeds will also be less in the lee of the shelter so the total hail kinetic energy, which results both from the vertical fall speed of the hail and the wind speed, will be less. The impact of a clump of trees on the hail damage to an otherwise open field of soybeans is shown in Fig. 1. If there is a preferred wind direction with hail then shelter belts can be planted perpendicular to this

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**Fig. 1. Distribution of damage (as measured by the percentage of the yield lost) in a soybean field in Illinois, USA in 1975. The area was generally flat and open but there was a clump of trees (shown) in the northwest corner. (From Towery et al, 1976).**
direction to reduce crop damage (Vento and Malossini, 1982). The wind direction and estimated speed during hailstorms are additional items that should be included in developing local hail climatologies.

**HAIL SUPPRESSION**

Most forms of weather modification do not cause changes that are so direct and immediate that the change can irrefutably be ascribed to the technique employed. Thus, the evaluation of a weather modification experiment requires that it have both physical and statistical plausibility (World Meteorological Organization, 1986). The first criterion requires that there is a demonstrable linkage — by established physical principles, by calculation, or simulation, or preferably by measurements — between the modification action taken and the sequence of ensuing events. The second criterion implies that a trial of the technique is undertaken involving some randomization. A series of periods are divided on a random basis into those in which the technique is employed and those when it is not and the results of the two sets are compared.

Two techniques for hail suppression have been widely employed: seeding of clouds with silver iodide or other materials, which induce freezing to occur at warmer temperatures than otherwise, and the use of cannons or explosive devices.

(a) CLOUD SEEDING

There are two ways in which seeding is postulated to reduce hail severity. The most commonly pursued is the beneficial competition approach (Iribarne and Pena, 1962). Seeding is intended to cause a vast increase in hail embryos, none of which grows to large hail because of competition for the available liquid water. Another approach, premature rainout, involves seeding of cloud elements at an early stage, so that particles which might otherwise become hail embryos fall out of the cloud as rain from lower levels rather than ascend to the higher levels where hail formation takes place (Ludlam, 1959).

The most systematic test of hail suppression by cloud seeding was undertaken in Switzerland from 1977 to 1981 (Federer et al., 1986). A beneficial competition methodology that was developed in the Soviet Union was employed; it involves the discharge of large amounts of silver iodide into a particular zone of the cloud using rockets (e.g., Sulakvelidze et al., 1974). In this experiment, the hail kinetic energy, as measured from a network of hailpads, was compared with the energy that could have been expected from the atmospheric measurements prior to the hail event. This statistic was compared for seeded and unseeded storms, the decision to seed or not seed having been made randomly. No significant reduction of hail kinetic energy was found. An earlier experiment in Colorado, USA also failed to demonstrate the effectiveness of the Soviet technique (Crow et al., 1979). A randomised experiment in Argentina, using ground based generators of silver iodide, was also inconclusive but there was some evidence that there was a decrease of damage to crops in frontal situations, but an increase in other situations (Iribarne and Grandoso, 1965).

In addition to such scientific experiments, seeding is or has been used as an operational tool in many countries. In such operational seeding no randomization is employed; all events expected to produce hail are seeded. Some evaluation can still be made by comparing hail measurements from radar, hail pads or crop losses. The comparisons may be between the target area and some supposedly unaffected nearby area — the control — or between the period of seeding and some other period, usually the hail seasons prior to commencement of the seeding operation. Evaluations may also employ a combination of these methods by comparing the ratio of a hail parameter in the target area to that in the control area in the seeded period and an unseeded period. Difficulties in interpreting the comparisons include the possible impacts of changes in general weather patterns, in crop management practice and in loss reporting.4

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3 Pure water droplets do not freeze until the temperature reaches about -40°C. Freezing is induced at higher temperatures because of the presence in the atmosphere of impurities that act as nuclei for ice formation. However significant numbers of ice crystals are found only at temperatures below -15°C or -20°C.

4 As an illustration of the difficulties in evaluating operational weather modification consider a hypothetical hail suppression operation at Nelson over three summers. The probability of no hail (or smaller frozen particles) occurring in summer at Nelson is 79% (Steiner, 1988). Assuming that there is no relationship between hailfall in one summer and the succeeding one the probability of three summers in a row without hail is 49%. Thus if no hail at all occurred during the operational period no claim could be made for the success of the experiment since there is an almost even chance of this happening without intervention.
Hail Reduction?

A summary of seeding operations with the objective of suppressing hail of which evaluations have been reported, is shown as Table 5.

The most widespread operational seeding is carried out in the USSR where, by 1984, the 10 areas of operations extended over 80 000 square

**TABLE 1: RESULTS OF SOME HAIL SUPPRESSION OPERATIONS.**

<table>
<thead>
<tr>
<th>Programme*</th>
<th>Total Seasons</th>
<th>Release Method†</th>
<th>Type of Evaluation</th>
<th>Data‡ Source</th>
<th>Change in Hailfall</th>
<th>Change in Rainfall</th>
<th>Significance Level (hail)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AFRICA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>1 Kenya</td>
<td>8</td>
<td>A,G</td>
<td>S/N-S</td>
<td>C,R</td>
<td>-28%</td>
<td>+12%</td>
<td>0.05</td>
</tr>
<tr>
<td>(1968-1975)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 South Africa</td>
<td>4</td>
<td>AJ</td>
<td>S/N-S</td>
<td>C</td>
<td>-35%</td>
<td>n.a.</td>
<td>&lt;0.01</td>
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<tr>
<td>(1973-1977)</td>
<td></td>
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<tr>
<td>AMERICA</td>
<td></td>
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</tr>
<tr>
<td>3 Hudson Valley USA (1956-1957)</td>
<td>2</td>
<td>G</td>
<td>T-C</td>
<td>C,R</td>
<td>-35%</td>
<td>n.a.</td>
<td>not tested</td>
</tr>
<tr>
<td>4 NE Colorado USA (1959)</td>
<td>1</td>
<td>A,G</td>
<td>T-C</td>
<td>HP,R</td>
<td>-48%</td>
<td>+5%</td>
<td>0.05</td>
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<tr>
<td>5 Texas (1970-1975)</td>
<td>6</td>
<td>A</td>
<td>T-C</td>
<td>I,R</td>
<td>-31%</td>
<td>n.a.</td>
<td>not tested</td>
</tr>
<tr>
<td>6 SW of North Dakota USA (1961-1975)</td>
<td>15</td>
<td>A</td>
<td>T-C</td>
<td>I</td>
<td>-30%</td>
<td>+23%</td>
<td>various</td>
</tr>
<tr>
<td>7 W of North Dakota USA (1969-1972)</td>
<td>4</td>
<td>A</td>
<td>S/N-S</td>
<td>HP,I,R</td>
<td>-20%</td>
<td>+7%</td>
<td>not sig.</td>
</tr>
<tr>
<td>8 North Dakota, USA (1976-1985)</td>
<td>10</td>
<td>A</td>
<td>X</td>
<td>I</td>
<td>-43%</td>
<td>n.a.</td>
<td>.002</td>
</tr>
<tr>
<td>9 South Dakota USA (1972-1975)</td>
<td>4</td>
<td>A</td>
<td>T-C</td>
<td>I</td>
<td>-80%</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td>10 Utah USA (1976-1981)</td>
<td>5</td>
<td>A,G</td>
<td>T-C</td>
<td>I-R</td>
<td>-69%</td>
<td>+11%</td>
<td>.10</td>
</tr>
<tr>
<td>AUSTRALIA</td>
<td></td>
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<tr>
<td>EASTERN EUROPE</td>
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</tr>
<tr>
<td>12 Bulgaria (1972-1978)</td>
<td>8</td>
<td>R</td>
<td>S/N-S</td>
<td>C</td>
<td>-50 to</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td>13 Hungary (1976-1982)</td>
<td>7</td>
<td>R</td>
<td>X</td>
<td>I</td>
<td>-50 to</td>
<td>n.a.</td>
<td>0.05</td>
</tr>
<tr>
<td>WESTERN EUROPE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15 France (1965-1982)</td>
<td>18</td>
<td>G</td>
<td>X</td>
<td>I</td>
<td>-41%</td>
<td>n.a.</td>
<td>.01</td>
</tr>
<tr>
<td>16 Greece (1981-1985)</td>
<td>2</td>
<td>A</td>
<td>T-C</td>
<td>C,R</td>
<td>-52%</td>
<td>+6%</td>
<td>.10</td>
</tr>
<tr>
<td>17 Spain (1979-1983)</td>
<td>5</td>
<td>A</td>
<td>S/N-S</td>
<td>HP,R</td>
<td>-75%</td>
<td>+9%</td>
<td>0.03</td>
</tr>
</tbody>
</table>
| *Data sources:- 1,3,4,5,10,16 Henderson (1987), 2 Mather (1977), 6,7,9 Changnon (1977) 8 Smith et al. (1987), 11 McCarthy (1984), 12 Stantchev and Simeonov (1985), 13 Marko et al. (1985), 14 Burtsev (1985), 15 Dessens (1986b), 17 Sanchez et al. (1985).† Release method: A aircraft; AJ jet aircraft; G ground generators; R rocket.† Type of evaluation: T-C target-control area comparison; S/N-S seeded/non-seeded period comparison; X more complex comparison.‡ Measurements used: C crop damage; R radar data; I insurance data; HP hailpad data; D days of hail.□ Changes in rainfall and significance level (hail): n.a. not available, not. sig. not significant.5 There have been some attempts to augment rainfall in New Zealand by cloud seeding but seeding for the purpose of reducing hail damage has not been tried.
kilometres (Burtsev, 1985) — about 1/3 of the area of New Zealand. From Burtsev’s data, the average reduction in hail losses over the entire areas of operations in the years 1968 to 1984 is 80 percent. Using the same type of rockets, reductions of hail losses by more than half have been obtained in some eastern European countries.

Many of the other operations listed appear to have achieved significant reductions in hail. Of particular note is the long term French operation reported by Dessens (1986b). He compared hail insurance data from an area of 55 000 square kilometres in the southwest of France, in which silver iodide is released from 455 ground generators, with data for the rest of the country, without generators. A significant difference became apparent from 1965, when the silver iodide release technique was perfected. The ratio of the hail damage in the two areas was reduced by 41 percent. Unless this change can be shown as being related to changes in large scale weather patterns, or some other phenomenon, it seems reasonable to assume that it is a genuine result of the seeding. The benefit to cost ratio for this operation is stated to be about 24.

The differences in results between experiments and some operations are difficult to reconcile. Difficulties in interpreting the operations have already been noted. It must also be remembered that hailstorms can be highly variable in hail kinetic energy and in their dynamics. Not all hailstorms in a given area are similar, and it is possible that in some areas the overall statistics include cases where some hailstorms cause reduced damage through seeding, while others are unaffected or possibly cause more damage. Indeed both Burtsev (1985) and Stantchev and Simeonov (1985) comment on the occasional particularly severe storm, which is not ameliorated by seeding. Possibly in the areas where seeding appears to have been effective the storms are more uniform and amenable to control by the particular seeding methods that have been employed. The inability to accurately forecast hail and thus to initiate suppression may be a problem in some regions. A further possibility is that there is a delayed effect of silver iodide seeding, as suggested by Bigg and Turton (1985). If this was the case, then there could be large numbers of particles that act as nuclei for freezing on both seeded days and some unseeded days in the experiments.

The region of the cloud where the beneficial competition technique is considered to be effective is in the upper parts of the interior of the cloud, where there is strong upward motion. However, penetrations of this cloud region of Swiss hailstorms by an armoured and instrumented aircraft (Waldvogel et al, 1987) has demonstrated that the region already contains much ice and little supercooled water. This demonstrates that, at least in these clouds, attempts at hail suppression by beneficial competition is unlikely to be of value.

There is some experimental and modelling evidence for the success of the premature rainout approach to hailstorms in Alberta, Canada. It has been demonstrated there that hail is usually initiated in a series of “feeder” clouds which form upwind of the main cloud mass, and then merge with it. A comparison of ice particle counts obtained by aircraft flying through seeded and unseeded feeder clouds indicated that seeding could increase the ice content of feeder clouds by a factor of ten (Humphries et al, 1987). The aircraft was unable to penetrate the main cloud mass. However, numerical modelling of the processes in these storms (Farley, 1987) demonstrated that seeding leads to some increase of rainfall, with a decrease in hail.

Thus it is apparent, that at least in certain areas, some methods of seeding seem to have beneficial effects, as determined from reduced crop losses. There is also some limited physical and modelling evidence for the success of the premature rainout technique. Nevertheless, the statement of the World Meteorological Organization (1986) that “the requisite combination of physical and statistical evidence of hail suppression is lacking” remains valid.

(b) OTHER MODIFICATION METHODS

Another form of hail suppression is the use of various types of cannon, or other methods of creating loud noise or explosions. These methods have a long and colourful history (Oddie, 1965; Morgan, 1973; Changnon and Ivens, 1981; Chassany, 1982). Cannons especially made for hail suppression came to be used extensively in Austria in 1897, and their use quickly spread to neighbouring countries. The cannons appeared initially to be successful, but by about 1902 doubts emerged. It was recognized that hail has natural inter-annual variability, and that the earlier apparent success could be fortuitous. Nor was there an acceptable theory for the cannon
Hail Reduction?

effects. By about 1905 interest had waned. In France in the 1950’s, rockets were used to create explosions in cloud to reduce hail damage (Ruby, 1953); success was claimed but the method was not subject to a systematic statistical evaluation. An experiment using rockets for hail suppression was undertaken in the tea estates of Kenya from 1963 to 1967; there was an apparent reduction in crop damage (Sansom, 1968) but this method of hail suppression seems to have been abandoned there.

In recent years the use of a vertically pointing cannon which explodes acetylene at intervals of a few seconds has again found favour among fruitgrowers. A high success rate is sometimes claimed. One make of these devices is marketed in many countries and such cannon are being introduced in New Zealand.

There are a number of theories as to how such devices could modify natural cloud processes so as to reduce hail. For some of these theories an effect has been identified by laboratory experiment (Goyer and Plooster, 1968; Plooster, 1972; Favreau and Goyer, 1967) or by numerical simulation (Foster and Pflaum, 1985), but only when the pressure perturbation in the cloud is at least 100hPa.

The pressure perturbation at the ground near one type of cannon (emitting vertically) was measured by Mezeix et al. (1974). It amounted to only about 3hPa at a distance of 40 metres. A sound intensity of 96dBa was measured at a horizontal distance of 60 metres from a superficially similar cannon in New Zealand (L W Gardner, pers. comm.). This corresponds to a pressure perturbation of only 1.3 hPa. The energy level directly over the cannon may be much higher. If an additional 50 dBa is added to the New Zealand measurement to allow for the directional effect of the cannon configuration (suggested by S. Singal, pers. comm.) the magnitude of the pressure perturbation just above the cannon mouth amounts to ~400hPa. However, the intensity must become attenuated as the sound wave propagates away from the source. Assuming this pressure perturbation at a height of 1 metre above the cannon mouth, then at 1000 metres, which would typically be near cloud base in New Zealand, the pressure perturbation would only be 0.4 hPa if the energy dispersion is isotropic. Even if the dispersion is not initially isotropic because of the effect of the cannon shape, the pressure perturbation near cloud base will still only be at most a few hектopascals, and in the higher regions of the cloud where hail is formed, it will be much less. Thus pressure perturbations in cloud are at least two orders of magnitude too small to have effects on cloud physical properties. The brevity of the periods of maximum energy of the sound pulses further reduces the possibility of any effect.

Mezeix et al. (1974) also operated a hail cannon tilted to emit in a horizontal direction, and examined its effect on ice particles suspended in front of it, confirming laboratory results of List (1963). Only within 25 metres of the cannon was any motion of the particles or their supporting wires detected, but even in this range, there was no sign of any fragmentation of the ice particles. The cannon was also repeatedly fired (in the regular vertical position) at cloud on 4 occasions, with at least 150 explosions in each case. No effect was detected in the visual cloud characteristics. However it must be pointed out that the clouds were not cumulonimbus.

It is surprising that hail cannon are generally claimed to affect the area immediately surrounding them. No statistics of storm motion are available in New Zealand but overseas studies of hailstorms suggest they can move rapidly, e.g. Dessens (1986a) and Carte (1963) indicate average speeds of 15 and 13 m/s. Thus any effect from a vertically pointing cannon might be expected to be somewhere downwind.

Another possibility of hail suppression could be some modification of the electrical properties of the cumulonimbus cloud with which hail is usually associated. The makers of one type of hail cannon claim that it works through some electrolysis process. No detailed explanation is given and there is no reference to any accepted physical theory. The minimal requirement for cannon to cause hail suppression through some electrical process, would be the detection of changes in atmospheric electrical properties above the cannon. The manufacturers of hail cannon could contribute to the plausibility of these devices if they could either further explain the thory, or demonstrate an electrical effect.

Huang et al. (1981) consider that firing guns into clouds has an effect on cloud dynamics. The inherent difficulty of such a technique was pointed out a long time ago in New Zealand (Bates, 1907): the total energy of a storm is several orders of magnitude greater than that of any explosion or gun-shot that could be contemplated. If a con-
vective circulation speed of 10 m/s then the kinetic energy amounts to 0.5 TJ. Any gun fire must have several orders of magnitude less energy. Huang et al. present some evidence of changes in the radar echo following the repeated shelling of hailstorms with anti-aircraft guns. In most cases pronounced changes were reported as following the shelling, often with the appearance of holes in the echo pattern. Because changes in the radar echo can occur naturally, a careful comparison of the evolution of shelled and other events would be required, as well as an acceptable theory, before the value of shelling could be accepted.

Thus, on the basis of field, laboratory or modelling tests, a plausible theory has not been established for cannon and other hail suppression systems based on explosives or gunfire. Furthermore, there are inadequate statistics to confirm the value of such methods. The same difficulties apply to evaluation of operations, as were indicated for hail suppression by seeding; it is not enough to compare hail damage over a few years when a cannon is in use, with an earlier period before its installation.

DISCUSSION AND SUMMARY:
A HAIL PROGRAMME FOR NEW ZEALAND

Strategies for reduction of hail damage have been reviewed. Application of such strategies requires a more detailed hail climatology. It would be desirable to establish a computer archive of New Zealand hail data in as high a resolution as possible. It should not only include areas currently used for horticulture, but also other potential horticultural areas. It is considered that organizations concerned with horticulture, the insurance industry and the Meteorological Service could all be involved in this development. The cooperation of horticulturists and other land users in providing data would be essential.

Data from meteorological radars would also be valuable for developing the hail climatology. Moreover such data would be a high priority for the guidance of any attempts at weather modification.

Methods of hail suppression attempted overseas have been reviewed. In the case of cloud seeding there are scientific theories to explain the effect, and statistics showing a benefit in many cloud seeding operations. However, randomized experiments have not demonstrated a significant seeding effect.

There is no acceptable theory for the use of hail cannon or other explosive devices. Many users are convinced of the value of these devices, but this does not provide proof of their efficacy.

Decisions on undertaking weather modification activities are not necessarily made by scientists. It is important that scientists take an interest in such activities and offer advice. It would be in the interests of both those undertaking weather modification, and the wider community, if all such activities were recorded: summaries of the operations and of the results should be kept in some standard form.

There is no method capable of totally suppressing hail. Of the methods of hail suppression that appear to have some beneficial effects, none can be recommended with absolute confidence.

If it was felt that some form of hail suppression should be attempted in New Zealand, despite this lack of confidence, then the French technique of using ground based generators of silver iodide and sodium iodide (Dessens and Pham Van Dinh, 1968; Dessens, 1986b) should be adopted. It is preferred because of its apparent success over a long time period, ease of operation and high benefit to cost ratio. In the area of France where this technique has been employed, most of the damage comes from hailstorms associated with cold fronts. A study of severe New Zealand hailstorms (Steiner, 1988) suggests that they are not usually frontal. Hence the method might not yield the same results here. It should also be noted that this type of technique is intended to suppress hail over a large area rather than to protect individual properties.

There are some additional caveats associated with the introduction of any form of hail suppression. Effort needs to be put into developing high skill in forecasting potential hailstorms. The availability of weather radar would be beneficial in this regard. The possibility of a suppression technique leading to a rainfall increase, and the consequences of such an increase on horticulture and other activities, also needs to be considered. Because of the limited historic data on hail, it might be difficult to demonstrate any effect of the hail suppression attempt.

6 There is not unanimity in France on the value of this method. See Mezeix (1987).
Hail Reduction?

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