THE KENYA HAIL SUPPRESSION PROGRAM

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ABSTRACT

Beginning in October 1967, an operational hail suppression program was initiated in an area located some 130 miles northwest of Nairobi, Kenya, East Africa. The project was supported by private companies which have approximately 45,000 acres of select tea in production. Within the operational area, average precipitation is about 71 inches and hail on the ground is experienced on more than 200 days per year. During the period October 1967 through January 1975, silver iodide was applied by aircraft at cloud base in the inflow area identified to be relevant to that volume of cloud which gives birth to, and allows growth of, hailstones. Program design included a rate of silver iodide application sufficient to produce ice nuclei concentrations of 100 - 1,000 per liter effective at -15°C within this important hail producing volume of cloud. A total of 1,382 operational days and 2,910 seeding flight hours have been logged. More than 5,700 individual cumulus cells have been seeded. In comparisons of hail damage from seeded and non-seeded cumulus developments, the average damage to tea has apparently been reduced by approximately 40%.

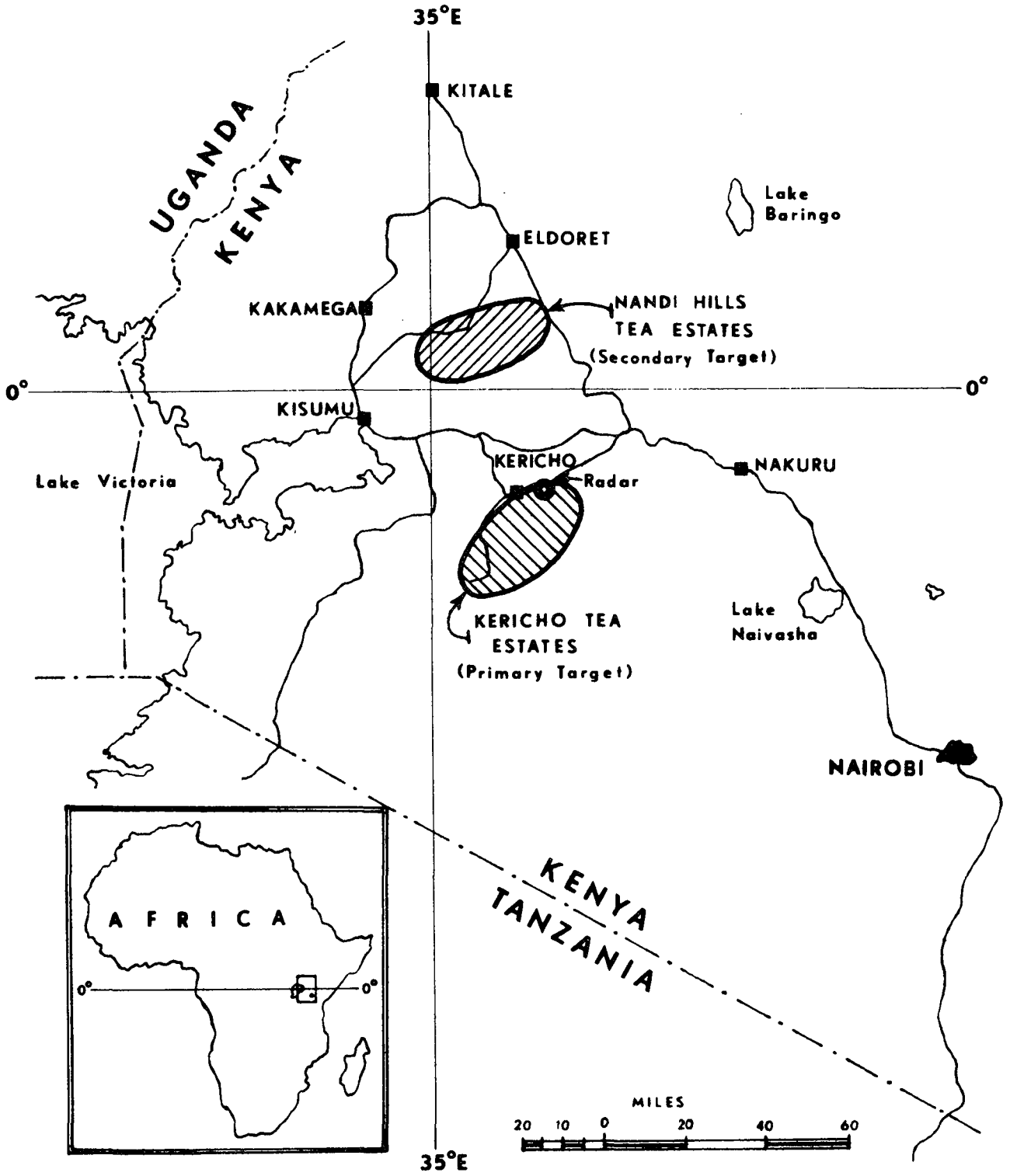
I GENERAL BACKGROUND

The Kericho-Nandi Hills area of Kenya, East Africa, is located some 130 miles northwest of Nairobi. Approximately 45,000 acres of select tea are in production throughout this area. The estates lie at elevations between 6,500 and 7,000 ft. msl, but eastward the land rises quickly to elevations above 10,000 ft. The peaks of Mau (10,002 ft.) and Mililí (10,165 ft.) are along the Mau escarpment some 50 miles southeast of the main tea growing area. For some 35 miles westerly from the Kericho-Nandi Hills area the land slopes away to the shore of Kavironda Bay, an arm of Lake Victoria. Here, along the shoreline at Kisumu, the elevation is only 3,720 ft. above sea level. A general location map of the area is shown in Figure 1.

The African Highlands Produce Company (James Finlay Co., Ltd.) and the Kenya Tea Company (Brooke Bond) represent the largest portion of total acreage in this area. About 20 other smaller groups, including those within the Kenya Tea Development Authority, also have tea acreage in production. With the exception of pruning periods and excessive hail damage, tea is plucked every 10-15 days each month of the year. Kenya is one of the only places in the world where the tea plant does not go completely dormant during some portion of each year.

FIGURE 1

KENYA HAIL SUPPRESSION
PROGRAM



In July, 1963, the African Highlands Produce Company initiated an experimental hail suppression program on a single tea estate of about 1,000 acres in the Kericho area. This program utilized Italian anti-hail rockets fired from 13 positions on the Kitumbe Estates. These rockets were fitted with an explosive head containing about 800 grams of TNT. No silver iodide or other ice nuclei material was added to the mixture. In early 1967, a cost assessment was applied to the rocket anti-hail program. It was noted that an extension of this program to include all tea estates of the area would not be economically feasible. Accordingly, Atmospherics Incorporated of Fresno, California, was asked to design, operate and evaluate a hail suppression program based on past experience in the United States and the current technology available throughout the world. On 1 Oct. 1967, utilizing aircraft application of pyrotechnic generated silver iodide, this newly designed program began operations in the Kericho-Nandi Hills area. The program operated continuously through January 1975.

II CLIMATOLOGY

The Kericho area of Kenya may possess the highest hail incidence of any location in the world. On the average, thunderstorms occur on more than 200 days per year. Hail reports from numerous stations on the ground, as well as pilot reports and observations from seeding flights, indicate that more than 90% of the individual thunderstorms contain hail during some period of their life cycles.

The daily weather pattern is repetitious with mostly clear mornings and only a light flow of air at the surface. On most days, small cumuli are noted over the high country before noon and these often exhibit a vigorous development by 1400. As vertical development proceeds to upper levels, the cumulus cells begin to move westward away from the mountains out across the tea estates and forest land. Activity over the tea area subsides by late afternoon and nocturnal thunderstorms are noted over Lake Victoria. By daybreak, clear skies are again established and the cycle repeats.

This rather persistent weather pattern produces an average annual rainfall of about 71 inches in the Kericho-Nandi Hills area. There are extreme spatial variations during any single storm day as well as wide monthly and seasonal variations in total amounts. In the valley area between Kericho and Nairobi, the average annual rainfall drops to less than 20 inches. Only a few localized areas in East Africa have annual averages above 80 inches and these are confined to mountain areas such as Mt. Kilimanjaro, Mt. Kenya, the Abadare Range, the Usanbara Range and South Nyanza. The single exception to this high mountain--high rainfall relationship is the area over Lake Victoria where annual totals also average more than 80 inches.

Freezing temperatures near Kericho are occasionally recorded but average monthly minimum temperatures are near 55°F throughout the year. Average monthly maximum temperatures are about 74°F but days have been recorded where temperatures climbed well above 80°F. On the whole, it is pleasant weather with no apparent change in seasons other than the high rain periods of April-May and October-November, about a month following the times when the sun is approximately overhead.

The number of annual hail occurrences at any one point in this area may vary from a single instance to more than 25. Records have shown this wide variation to occur over short distances within the tea estates. For example, many years are noted when a hail occurrence is logged somewhere within a single 1,000 acre estate and the adjoining estate of the same size may have recorded as many as 20 hail instances during the same period. There is evidence that areas within the total tea estates may be favored for excessive hail during a single year, but there is no evidence of area favoritism from year to year. The limited hail records indicate a preference for hail during the periods February-March and August-September, but hail does fall every month of the year and single high intensity storms can occur at any time.

The single most important feature which differentiates the Kericho-Nandi Hills area from other hail areas of the world is the fantastic number of hail days which persists every year.

III PROGRAM DESIGN

It is extremely important to note that the design of this operational program was produced from data obtained during a number of field programs conducted in the United States during the 1956-60 period and from information obtained in the field while a part of the hail suppression research projects conducted by Colorado State University in Northeast Colorado during the period 1961-65. Observations and measurements made during these formative years produced a reasonable understanding of the thunderstorm models and their related common denominators necessary for the proper design of such an applications program. Without these initial efforts, sponsored by the private sector in the early period and largely by the National Science Foundation during more recent years, it would have been impossible to design and operate this meaningful field program.

The design of this Kericho-Nandi Hills program involves the aerial application of silver iodide ice nuclei to the inflow areas at cloud base identified as being important to that particular volume of cloud which gives birth to hailstones within each thunderstorm cell. The remaining and much larger volume of cloud, which does not support the birth and growth of hailstones, is left untreated. Attempts have been made to apply material at a rate sufficient to produce ice nuclei concentrations of 100-1,000 per liter effective at -15C within this important hail producing volume. Pyrotechnic generated silver iodide has been used exclusively during the 1967-70 period. In more recent years liquid fuel airborne generators using ammonium iodide-silver iodide solution have been used to supplement the pyrotechnic capability.

During the period 1 October 1967 through 31 December 1968, aerial application of silver iodide was accomplished by a single aircraft. On 1 January 1969, a second aircraft was added to the program. Beginning on 1 October 1970, a third aircraft was added for purposes of seeding more of the total numbers of thunderstorm cells noted on any given day. Inasmuch as the total tea growing area is large, and storms are often too numerous for total coverage by three aircraft, many of the individual cells are left un-

seeded. However, a priority is established in which the most intense cells, as noted by radar, are seeded first and subsequent cells are seeded in order of decreasing intensity.

IV OPERATIONS

During the past few years in the Kericho-Nandi Hills area, there appears to be an increase in total days in which hailstorms are present. Of greater importance is the fact that each hail day is producing greater numbers of thunderstorm cells per day. A flight summary of operational days, seeding flights, and other flights during the 88-month period, October 1967 through January 1975 is shown in Table 1.

Of particular interest might be the numbers of seeding events and numbers of individual hailstorm cells seeded during this 1967-75 period. This summary is shown in Table 2. Note that during the first three-year period the numbers of seeding events did not equal the total seeding flights for any individual year. In those years, a single seeding flight may have conducted seeding operations in both the Kericho and Nandi Hills area. When this occurred, two seeding events were logged for each seeding flight.

V EVALUATION

Almost all evaluations of weather modification programs eventually direct their attention to a single primary question: "What would the particular weather event have produced if no weather modification effort had been attempted?" If a realistic answer to that question is possible, then the data obtained from a treated situation can be compared to the extrapolated values and the differences attributed to the modification effects.

The production of a hailstone is complex and the storm which produces it does not easily lend itself to a meaningful project design or subsequent evaluation procedure. However, the considerable knowledge gained from applied research and operational projects conducted during the past years has enhanced one's ability to understand thunderstorms and related hail mechanisms. The area of Kericho-Nandi Hills has provided a unique test bed for the design of a modern hail suppression program and the direct application of current cloud seeding technology.

One of the most powerful "indicators" which can give us a reasonable estimate of effects from seeding is an assessment of hail damage to tea. Inasmuch as tea is plucked from each bush every 10-15 days, growth and production curves related to each estate provide a means of estimating loss in the field after each hail instance. This estimate is subsequently compared to the actual amount of finished tea obtained from that particular plucking round and, if necessary, adjustments made in the original estimate damage figures. The tea estate managers seldom know if any particular hail producing cumulus cell has been treated, so there is little chance the damage figures can be manipulated prior to the submission of each data tabulation. Consequently, the tea bushes act as nearly infinite

hail indicators with each leaf responding in some way to the individual hailfall.

While a strict randomized design was not applied at the outset, the choice of which potential hailstorm cell to seed in the case of more than one cell in either of the target areas, is based solely on severity. The actual storm severity is expressed in terms of greatest growth rates, highest inflow velocity, and strength of precipitation echo from the radar site. This intentional choice from the most severe cell may allow some bias to creep into any comparisons of damage from seeded and unseeded storms, but the bias would more than likely penalize any indication of hail damage reduction. In any case, many of the individual cumulus cells are necessarily left unseeded. Much of the time there is no physical connection between the individual cells because of target area dimensions. It is further unlikely that any dynamic interaction exists which would play an important role in evaluations dealing with seeded and unseeded cumulus cells.

During the 88-month period from October 1967 through January 1975, there have been 5,705 seeded storm cells and 3,569 have produced a reported hail instance. A total of 2,195 instances have been reported from cells that have not been seeded. Average damage per hail instance for this 88-month perod is 3,082 Kg from seeded cells and 4,280 Kg from non-seeded cells. The hail damage summary for seeded and non-seeded cells is shown in Table 3.

To compute the possible reduction in damage in terms of finished tea, let us first consider the 1,269 seeded cells which produced a hail instance and assume they would have produced damage equal to the non-seeded instances if they had not been treated. The difference of 1,198 Kg per hail instance when multiplied by 1,269 is equal to a reduction in damage in this category of about 1,520,262 Kg of made tea.

There now remains the possible hail damage reduction from the cells which did not produce a hail instance. Assume that only half of these would have produced a hail instance if not seeded and the damage only half the average noted from non-seeded cells. With these conservative estimates in view, the reduction in hail damage from seeded cells which produced no hail instances is approximately 2,285,520 Kg of finished tea.

For the 88-month period of operations since October 1967, it now appears the program has produced an apparent reduction in hail damage amounting to approximately 3,805,782 Kg of finished tea.

TABLE 1.

- FLIGHT OPERATIONS SUMMARY -

Oct-Sept Periods	Operational Days with one or more seeding flights	Total seeding flights	Seeding flight hours	Observation and other flights	Flight hours in this category
1967-68	184	282	310.0	135	86
1968-69	210	431	383.0	200	91
1969-70	200	400	304.5	197	91
1970-71	232	741	640.1	320	145
1971-72	222	636	616.4	456	267
1972-73	185	391	367.3	413	235
1973-74	126	249	241.4	209	142
1974-75 (Oct-Jan)	23	43	45.2	50	33
TOTALS	1,382	3,173	2,907.9	1,980	1,090

TABLE 2.

- FLIGHT AND SEEDED CELL DISTRIBUTION -

Oct-Sept Periods	Seeding Flights		Hailstorm Cells Seeded		
	Kericho	Nandi	Kericho	Nandi	Total
1967-68	197	85	515	155	670
1968-69	320	111	209	61	270
1969-70	314	86	426	112	538
1970-71	492	249	1001	487	1488
1971-72	462	174	1173	322	1495
1972-73	265	126	556	213	769
1973-74	136	113	210	193	403
1974-75 (Oct-Jan)	24	19	49	29	78
	2,210	963	4,133	1,572	5,705

TABLE 3.

HAIL DAMAGE SUMMARY

(Includes nil-damage reports)

Oct-Sep Periods	Seeded		Non-seeded	
	Instances	Damage per instance (Kg)	Instances	Damage per instance (Kg)
1967-68	112	2629	299	3315
1968-69	169	1245	276	3029
1969-70	181	3414	356	3651
1970-71	237	1264	344	3257
1971-72	149	2016	334	5352
1972-73	182	5024	296	6557
1973-74	212	4953	265	4846
1974-75 (Oct-Jan)	27	8302	25	5370
TOTALS	1,269		2,195	
AVERAGE		3,082 Kg		4,280 Kg

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