Rain Making

by
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Abstract

This thesis examines how cloud seeding works, and its economic effectiveness in Thailand. The research begins by discussing the historical development of weather modification, paying particular attention to the effort of King Bhumibol Adulyadej of Thailand in using cloud seeding to help his people. This discussion is followed by the outlining of each of the six steps involved in rain making as practiced by the Royal Rainmaking Project in Thailand. The study then proceeds to analyze the success rate and cost of cloud seeding as practiced in numerous countries. The study is especially attentive to the financial reports of the United States and Thailand and uses the information they provide to determine the cost effectiveness of cloud seeding in Thailand. The research presented in this study will be beneficial to a larger body of researchers interested in using rain making techniques for alternative purposes.

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Introduction

Rain making, cloud seeding, and artificial rain are interchangeable terms and refer to the fantastic process of weather modification (Gelt, 1992). Scientists use modification methods to increase the amount of precipitation by utilizing different kinds of chemicals. What chemical is used is dependent upon the stages of the target clouds (Royal Rainmaking Project, 2019, **ตำราฝนหลวง**). Cloud seeding has a long history dating back to the 1930s. At first, the theory was published with the purpose of increasing the chance of rain through artificial means. In 1964, the actual experiments of cloud seeding were first performed. The American chemist and meteorologist, Vincent Schaefer is the first person who conducted a cloud seeding experiment. The experiment was done in the Berkshire Mountains that are located in Massachusetts (Ley, 1961). After that experiment, many countries took advantage of the breakthrough. For example, in India, authorities use artificial rain to decrease the amount of pollution in the air (Business Today, 2018), while in the United States, the ski business uses cloud seeding to increase the amount of snow and reduce the hail damage in some parts of the country (Quinton, 2018).

Although it is called the Rain Making Project it provides additional meteorological benefits. Those benefits include increasing snow and rain in addition to reducing air pollution and hail damage. An example of cloud seeding being used to increase snow and rain is an Idaho water company that wanted to increase the amount of ice in the winter. Creating additional ice meant that as ice melts, the company can generate more water in the spring time, in order to produce more hydroelectricity (Global News, 2018). Similarly, in Thailand, the government uses rain making to produce enough

water for crops (Royal Rainmaking Project, 2019, ตำราฝนหลวง). An example of cloud seeding being used to reduce air pollution can be found in China. Here cloud seeding is being used to cause more rain; this rain binds to the pollution particles in the air, causing them to descend down to the ground. This makes the breathing air cleaner (Patranobis, 2016). An example of cloud seeding being used to reduce hail damage can be found in Argentina and Canada. In Argentina, a winery is using cloud seeding to protect their grapes (Global News, 2018). Even an unexpected business such as an insurance company has used the benefit of cloud seeding. For example, an insurance company in Alberta, Canada, is using cloud seeding to decrease the hail damage claims of their insurance clients (Global News, 2018). Both companies have reduced hail damage by using a process involving AgI. In this process, clouds are over seeded, causing extra nuclei to be in the air. The presence of these nuclei will make the water droplets spread out, making small rain particles instead of clumping together making larger hail particles.

The cloud seeding in Thailand was started by King Bhumibol Adulyadej in November 1955 (Royal Rainmaking Project, 2019, ตำราฝนหลวง). It took 15 years for him to gather all the information regarding the necessary chemicals and steps to make rain. The reason that rain making is necessary for Thailand is that Thailand is an agricultural country that relies on rain to grow crops. The king saw that there was a lack of water in many parts of the county, so he needed to help his people. He successfully discovered the effective chemicals and the government has been operating cloud seeding to help farmers ever since (Royal Rainmaking Project, 2019, ตำราฝนหลวง).

Thesis Statement and Hypotheses

This project will investigate how cloud seeding works and its economic effectiveness in Thailand. It is assumed that the cloud seeding is worth the cost because there are public and private entities that seed clouds regularly. A secondary goal is to attempt to quantify the benefit of cloud seeding in Thailand.

H_0= seeding has no effect

Studies have produced no scientific evidence that shows that cloud seeding leads to an increase in the amount of rain and snow fall, or to a reduction of hail damage.

H_1= seeding has positive effect

Studies have produced scientific evidence that proves that cloud seeding increases the amount of rain and snow fall and reduces hail damage.

H_2= seeding has negative effect

Studies have produced scientific evidence that proves that cloud seeding leaves harmful chemical traces in water, drains the government of unnecessary tax money, and produces more pollution because it requires flying on a regular basis.

My Experience as an Intern with the Thailand Royal Rainmaking Project

A significant amount of information and all pictures used in this thesis are based on my experiences as an intern at the Thailand Royal Rainmaking Project. The internship was a fantastic opportunity; it provided the first-hand experience of applying my knowledge of flying in addition to valuable information about the process of making rain.

My parents own a small cake shop in Thailand. We have a wide variety of customers, including family, college students, and popular Thai actors. This wide variety of customers is not only beneficial to build a network and good customer relations, but also leads to my internship experiences. One day there was a group of customers who came into our store, and mom noticed that a couple of them had a name tag showing that they were interns at the Royal Rainmaking Project. My mom quickly asked for more information about the internship position. One of the people from that group of customers was the meteorologist who works for the Royal Rainmaking Project, so my mom got contact information for me to apply for an internship position.

At that time, I was in grade 12 and was preparing to continue my education in the U.S. I have recently been accepted into MTSU's aerospace department, but I was not sure what concentration I should be pursuing, so my primary intention in becoming an intern at the Royal Rainmaking Project was to find out more about aviation and my passion. Then I applied and was accepted to be an intern during May and June 2017, the summer before I came to the U.S. I had heard about the Royal Rainmaking Project since I was young, but I did not have a deep understanding of how chemicals and airplanes can make rain out of the sky. My internship was a valuable learning experience for me because it

taught me so much about flying and rainmaking that I could not have learned anywhere else. I was fascinated by the rain making process, so I decided to choose it as my honors thesis topic so I could study more about rainmaking. In order to make sure that I have accurate information and a solid topic, I decided to do another short internship with the Royal Rainmaking Project in the Summer of 2019. This second internship was only a couple of days long, but it refreshed my memory and gave me a better picture of my thesis topic.

During my internship, I had a chance to experience the process of rainmaking closely *(see Figure 1)*. A typical day at the Royal Rainmaking Project begins at 8 a.m. with a meeting in which meteorologists decide the target area for cloud seeding. Then they communicate with the pilots who will be making the flight in the area of operation and chemicals are loaded into their airplane. The pilots fly to the target area, then the chemical workers release the chemicals into the clouds, after which the crew returns back to base. As an intern, I was allowed to participate in the morning meetings, attend preflight inspection, and act as an observing pilot for two rainmaking flight missions.

Those experiences flying, talking to the pilot, and observing the flight with the Royal Rainmaking Project helped me choose the concentration that I wanted to pursue at MTSU, which is Professional Pilot. I am very thankful for my experience with the Royal Rainmaking Project; it taught me so many things that I cannot find in any book. If I have a chance in the future, I would like to be a pilot for the Royal Rainmaking Project *(see Figure 2)*.

Figure 1

I closely observed the flight during the rain making mission (the figure closest to the camera is me). Photo taken by a meteorologist of the Royal Rainmaking Project.

Figure 2

I accompanied the crew during a rain making operation. Here I am standing with the pilot and the co-pilot of the mission that we just completed. Photo taken by a mechanic of the Royal Rainmaking Project.

How to Make Rain in Thailand

On their website, the Department of Royal Rainmaking and Agricultural Aviation summarizes steps to make rain (Royal Rainmaking Project, 2019, **ตำราฝนหลวง**). The purpose of the website is to make sure that the meteorologists and pilots follow the steps correctly and effectively. There are a total of six steps in the instructions *(see Table 1)*. The instructions are written out clearly to describe each specific atmospheric condition that will make cloud seeding successful, the type of chemical used in each cloud's stage, and the height of the suitable clouds (Royal Rainmaking Project, 2019, **ตำราฝนหลวง**). Before deciding to seed clouds, these factors must be considered.

Table 1. The Steps Involved in The Royal Rainmaking Project

Steps Involved in Rain Making	Definitions of Steps
Triggering	This step increases the existence of clouds.
Fattening	This step increases both the growth rate of clouds and the density of water droplets.
Sandwich Technique	This step causes the cloud base to become denser and heavier causing it to rain.
Enhancing	This step lowers the cloud base to be closer to the ground.
Attacking Cold Clouds	This step pulls small ice pellets together to create bigger ice pellets until they are heavy enough to be pulled down by gravity.
Attacking by Super Sandwich Technique	This step increases the amount and duration of rain.

There are several steps that need to be taken while considering the factors involved in the area where the rain mission will take place. The most important of these steps is determining the main industrial crop that grows in the area. The main industrial

crops grown in Thailand are rice, corn, cassava, and sugarcane. The type of crops need to be considered because different plants require different amounts of water at varying stages of growth. The second step to be considered is the current rainfall amount, because there might be flooding, making more rain unnecessary or even harmful. The third step is to check with the people who live in the area to get the report on their water situation. The last step is to check the radar to see if there is any rain in the area the night before. This can help show which area has a greater need for water.

The most misunderstood concept is that the Rain Making Project can make rain out of the clear sky by only using chemicals. However, Rain Making only works when there is at least 60% relative humidity. The atmospheric condition must be unstable with light wind for the chemical to create clouds. Once the weather condition is suitable there are six steps that must be followed to make rain. Those steps were written by the king of Thailand after his discovery and experiments. Once the decision for the target area has been made, the chemical must be picked based on the cloud stage that is visible on the weather radar. The meteorologist communicates with the chemical workers about the type of chemicals needed for the flight. Once the workers receive the order, the airplane must be loaded with the chemical and the pilots must be ready for the mission *(see Figure 3).* The chemical is loaded in the opening of the airplane fuselage *(see Figure 4).* The whole interior of the airplane must be covered with plastic or canvas to prevent the chemicals from corroding parts of the airplanes *(see Figure 3).*

Figure 3

A loaded fuselage section containing chemicals stored in small white bags. The interior of the fuselage is lined with the plastic and canvas. Photograph taken by Nakanya Rodruepid.

Figure 4

The fuselage section of the airplane where the chemicals are loaded before the mission. Photograph taken by Nakanya Rodruepid.

Once the decision has been made to seed the clouds, the first step used is called triggering. This step increases the existence of clouds. In this process, the sodium chloride (NaCl) must be used at a height of about 7,000 feet. This is categorized as a warm cloud mission; in this type of mission unpressurized airplanes can be flown *(see Figure 5)*. This NaCl acts like the nuclei in the air for water droplets to come together and create bigger and heavier water droplets. By the end of this step the cloud can develop to the height of 10,000 feet.

Figure 5

One of the airplanes that the Royal Rainmaking Project uses in the missions is the Casa C212. This type of airplane is unpressurized and is used for the warm cloud missions. Photograph taken by Nakanya Rodruepid.

The second step is called fattening. In this process calcium chloride ($CaCl_2$) must be released at a height of 8,000 feet or at least 1,000 feet above the cloud base. This step

helps to increase the growth rate of clouds and also increases the density of water droplets.

The third step is called the sandwich technique, which requires two airplanes working together. The first airplane flies at a higher altitude of up to 10,000 feet and it releases NaCl in the direction that the wind is blowing. The second airplane flies at the base of the clouds releasing Urea (CH_4N_2O), which will cause the cloud base to get denser and heavier at which point it will start to rain.

The fourth step is called enhancing. In this step, the airplane will release dry ice, a super cool substance, at 1,000 feet under the cloud base. This step will help lower the cloud base to be closer to the ground. Enhancing will decrease virga, which is rain that evaporates before reaching the surface of the ground. This step both increases rain fall and pulls the cloud into the target area.

The fifth step is called attacking cold clouds. Cold clouds are the clouds that exist above 10,000 feet and warm clouds exist below that level. Once the airplane flies higher in the altitude, the air density gets lower, which makes the procedures from the lower altitude unsafe. Above 10,000 feet the team uses a pressurized airplane to prevent hypoxia *(see Figure 6)*. Because the workers cannot open the fuselage of a pressurized airplane the chemical used has to be different. The chemical that is needed for the attacking cold clouds step is silver iodine (AgI). The AgI comes packaged as flares, which will be attached to the wings of an airplane. The meteorologist inside of the airplane is the person who fires these flares AgI once the airplane is in the target clouds. The normal operation height of attacking cold clouds is around 20,000 feet. The reason that AgI is used is because the shape of the molecule is similar to the shape of the ice

particle, so it is more likely for ice to attach to it. The AgI will pull small ice pellets together to create bigger ice pellets until it is heavy enough for the gravity to pull it down to the warm cloud level. By combining water from the cold cloud and warm cloud this process can create heavy enough water droplets to fall to the ground.

Figure 6

One of the aircraft used by the Royal Rainmaking Project is the Super King Air 350. This type of airplane is pressurized and is used for the cold cloud, weather observation missions, and hail prevention. Photograph taken by Nakanya Rodruepid.

The sixth step is called attacking by super sandwich technique. This step increases the amount and duration of rain. This step uses both pressurized and non-pressurized airplanes working together. All airplanes are working at the same time with different types of chemicals. One of the airplanes is performing the steps involved in attacking (step three), another is performing enhancing (step four), and the last airplane is performing attacking cold clouds (step five). When performed together, these steps make

the attacking by super sandwich technique, which makes it rain harder and for a longer duration.

With the exception of AgI, the chemicals that are used in making rain are heavy. Each airplane has its own weight limitation, so a mission may require a several flights per day. The chemicals that will be used depend on the stage of the cloud. For example, if the clouds are ready to rain, the meteorologist can make the decision to attack it instead of fattening it. This decision saves time and money. An airplane can carry more than one chemical at a time. This means that if the cloud is growing very well the meteorologist can attack it right after fattening it. These six steps together are the guide to make rain in Thailand. Completing all six steps are not always necessary because the cloud stage determines which steps are necessary. They can also skip steps, but whichever step they do must be done in order.

The majority of the time the flights described above consist of the following crew members: a pilot, a copilot, a mechanic, a meteorologist, and two chemical workers *(see Figures 7 and 8)*. Each position performs an essential role and by working as a team the members are able to accomplish the mission. The duty of the pilot and copilot is flying the airplane to the target area where they plan to make rain as well as returning the crew safely. The duty of the mechanic is to ensure the safety of the flight and to actively screen the checklist to make sure that the pilots are not missing any essential items. In addition, in case of any emergency, the mechanic is the person who best knows the systems of the airplane and will be able to help the pilots make safe decisions. The meteorologist is the person who identifies the correct target cloud and orders the chemical release *(see Figure*

9). Lastly, the chemical workers are the crew member who receive the order from the meteorologist to release the chemicals into the target clouds *(see Figures 8 and 10)*.

Figure 7

Several crew members seated in the cockpit. From left to right are pilot, meteorologist, and co-pilot. Photograph taken by Nakanya Rodruepid.

Figure 8

The chemical workers were opening the chemical bags to release them into the target clouds. Photograph taken by Nakanya Rodruepid.

Figure 9

The view from inside of the cockpit. After the pilots fly to the target area, the meteorologist is responsible for visually identifying target clouds. Photograph taken by Nakanya Rodruepid.

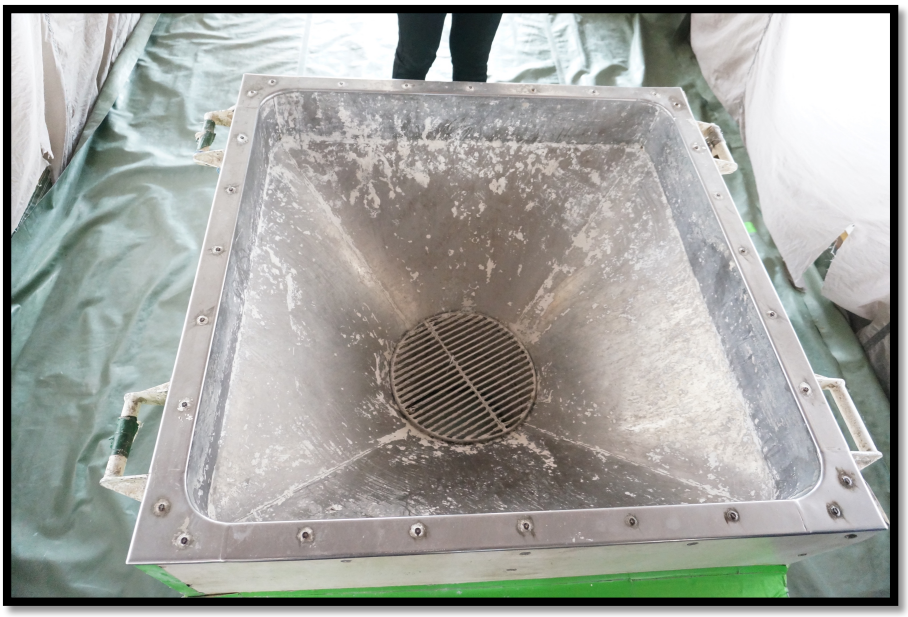

Figure 10

This is the opening through which the chemicals are released. Photograph taken by Nakanya Rodruepid.

Success Rates of Cloud Seeding

The report by Bernard A. Silverman (2008) from the Kern River Operational Cloud Seeding Program about the effectiveness of cloud seeding from 1977 to 2006 shows a significant increase in the streamflow. The research was conducted in the three target areas where they seeded the clouds. The streamflow of the river increased from 8.4% to 12.2% in the Kern River Basin. The conclusion of the report supports the idea of the cost effectiveness of rain making by stating that, "there is strong statistical evidence in support of the hypothesis that cloud seeding in the watersheds of the Southern Sierra Nevada Mountains is a cost-effective technology for increasing streamflow by significant and societally important quantities" (Silverman, 2008, p.7).

The study "Modeled streamflow response under cloud seeding in the North Platte River watershed" was conducted by Acharya, Piechota, Stephen, & Tootle over the Platte River in 2011. The periods of the study were from 1950-80 and 1981-2000. Both periods of study were conducted in the state of Wyoming. The result of the first period of the study found that cloud seeding increased the annual streamflow by 0.3-1.5%. The second period of the study was conducted throughout the watershed, and the result was an increase in precipitation by 1-5% (Acharya, Piechota, Stephen, & Tootle, 2011).
The study "Effects of Cloud Seeding in West Texas: Additional Results and New Insights" was conducted by Rosenfeld & Woodley (1993) by dividing cloud cells into two groups, which are seeded and non-seeded. The chemical that they used was silver iodine. The results show that the clouds that were seeded increased in different aspects, which are 7% height, 43% area, 36% duration, and 130% rain volume. Those numbers

are significant and show a good indication of the effectiveness of cloud seeding (Rosenfeld & Woodley, 1993).

The study "Seeding Success" was conducted by Mercury (2010) in the Snowy Mountains, Australia. In 2014, observations indicated that there were no negative effects from cloud seeding within the area surrounding the seeded area. The study also shows that the success rate of the seeding process averages about a 14% increase in precipitation. The precipitation that was tested was snow. They planned to use the same method of increasing snow to increase the chance of rain to help with drought in the country (Seeding Success, 2010).

The study "Explained: How Successful is Cloud Seeding Technology" was conducted by Indian Institute of Tropical Meteorology (2019). The Indian Institute of Tropical Meteorology has conducted a study of cloud seeding over a period of several years. The experiment was done in the areas around Nagpur, Solapur, Hyderabad, Jodhpur, and Varanasi. The success rate of the experiment was 60-70%. The success depends on the atmospheric conditions and the amount of moisture in the air. This number is very high compared with other experiments in different parts of the world (India Institute of Tropical Meteorology, 2019)

In order to learn more about cloud seeding, CNN Business interviewed the president of Weather Modification International to understand the study that his company provided the airplanes for. The study was conducted by the Josh Aikins University of Colorado and was funded by national Science Foundation to find the success rate of cloud seeding in the Idaho mountains. The chemical used in this mission was silver iodine. The study follows the mission of Weather Modification International by using

radar and ground tracking. The radar shows the ice crystals forming after the cloud seeding in the pattern that the airplane flew. The ground tracking showed that there was snow fall after the mission. The study reported an 8-15% increase in snow, which increased the amount of water during the fall season. This amount of water would provide enough water for about 60 thousand homes. Idaho Power spent about 300 million dollars on the cloud seeding project in 2017. They got around a 300% return out of that investment, which is about 900 million dollars' worth of water (CNN Business, 2018). According to ABC News, in South Texas cloud seeding is also done in part to increase rain fall. The Texas Weather Modification Association is using radar, which is tracked by a meteorologist, to choose the most suitable cloud to seed. They fire silver iodine and calcium chloride into the bottom of the clouds, which takes about 20 minutes to see the results. The Texas program stated that cloud seeding increases annual rain fall by 12%. They also stated that the water quality is good and the chemicals used cannot be detected on the ground (ABC News, 2012).

The annual report of Thailand Royal Rain Making Project in 2018 indicates that they have had the highest success rate out of any country that is making rain. Each regional station in Thailand has different success rate; those rates range from 89-100%. The average success rate of the whole country is 93%. This number was calculated by comparing the number of days on which cloud seeding was performed with the number of days that it rained per year (Royal Rainmaking Project, 2018, รายงานประจำปี)

The Cost of Cloud Seeding in the U.S.

According to Global News, hail prevention is more expensive than the process of making rain or snow. The cost of cloud seeding ranges from about two hundred thousand to one million dollars per year. Cloud seeding is estimated to produce an extra 1.5-4.5 meters of snow in the mountains and 50-125mm of rain in the summer (Global News, 2018).

The North Dakota Cloud Modification Project (Langerud, 2009) reports a significant increase in the amount of dollars earned by agriculture through the process of cloud seeding. The North Dakota Cloud Modification Project is funded by both state and private companies. The cloud seeding in this study increased the amount of rain by 5-10% in the summer. With this level of rain increase, they calculated that the monetary impact on the average per planted acre is between $3.58 and $6.84. Once this process is applied to a large area of agriculture, this amount can make a really big impact on the revenue for farmers, as demonstrated by the statewide statistics from the same study. For the statewide section of the study, Langerud also observed how the scenario of increasing rain by 5-10% could increase agricultural production from $42.1 million to $81.3 million over the period of ten years (Langerud, 2009).

The Cost of Cloud Seeding in Thailand

The annual report of Thailand Royal Rain Making Project in 2018 shows that the most expensive cost of making rain in Thailand is the workers' salary. These workers include meteorologists, pilots, and chemical workers (Royal Rainmaking Project, 2018, ผลการดำเนินงาน). The total cost per year of making rain is approximately $40 million (Royal Rainmaking Project, 2018, ผลการดำเนินงาน). This number was calculated by using the exchange rate of about 30 baht to $1. The cost for a warm cloud mission, which includes pilots, meteorologists, chemical workers, fuel, and airplanes is estimated to be about $3,300 per two planes to complete all three steps, which are triggering, fattening, and attacking (Royal Rainmaking Project, 2018, ผลการดำเนินงาน).

There is no complete data for how much the Royal Rainmaking Project spends per year to make rain per each acre. However, the calculation of a rough estimate is possible. The data provided on the website by the Royal Rainmaking Project is very limited, but it provides just enough information to calculate the cost of making rain in Thailand. On the website of the Royal Rainmaking Project there are monthly reports of the cost of making rain, including every aspect such as payment for the pilots, chemicals, workers, and data collectors. The monthly cost is partially dependent upon the weather condition and season. The rainy season in Thailand is the season that cloud seeding has been perform the most. Rainy season starts in May and ends in October. The expenses during those periods are higher because the cloud seeding project is more active during those months. The reason for this increase in activity is because there is a lot of moisture in the air during the rainy season, so there is more chance to make rain. Oftentimes there are rain clouds during this season, but the rain does not reach the ground or does not rain

as much as the farmer's need, so seeding the clouds in rainy season helps produce a sufficient amount of water.

Table 2 explains and shows how calculation was done to find the rough estimate on how much the Royal Rainmaking Project spends on rain making per year per acre. The website of the Royal Rainmaking Project only reported the cost from February 2018 until August 2018, which is listed in the first column (Royal Rainmaking Project, 2018, **ผลการดำเนินงาน).** The second column shows the cost of making rain in each month in the Thai currency, baht. The third column shows the conversion rate from baht to U.S. dollars. One U.S. dollar is about 30 baht. The fourth column shows the area in which the Royal Rainmaking Project cloud seeded successfully. The unit that is used to measure large areas in Thailand is Rai, which is converted to acres in the fifth column (Royal Rainmaking Project, 2018, **ผลการดำเนินงาน).** One rai is about 0.4 acres. The U.S. dollars spent per acre can be found by dividing the monthly cost (U.S. dollar) by the successfully cloud seeded area (acre) as shown in column six. After the average cost for these 7 months was found, the yearly cost of rain making was calculated by adding together all the U.S. dollars spent per Acre, dividing that number by 7, and then multiplying the result by 12. This resulted in about $4.5 per acre to make rain each year.

Table 2. The Cost of Making Rain per Year by the Royal Rainmaking Project

Monthly Cost (Baht)	Monthly Cost (U.S. dollar)	Successfully Cloud Seeded Area (Rai)	Successfully Cloud Seeded Area (Acre)	U.S. Dollars Spent per Acre
453,048,988	15,101,632.93	218,000,000	86,166,007.91	0.17526207
581,138,013	19,371,267.1	217,880,000	86,118,577.08	0.224937148
686,788,306	22,892,943.53	217,880,000	86,118,577.08	0.26583049
740,269,785	24,675,659.5	210,380,000	83,154,150.2	0.296745976
803,230,322	26,774,344.07	190,440,000	75,272,727.27	0.355697808
1,079,958,276	35,998,609.2	163,560,000	64,648,221.34	0.556838355
1,215,266,627	40,508,887.57	140,630,000	55,584,980.24	0.728773985
	30 Baht = $1		1 Rai = 0.395256916996 Acre	

Monthly Average of U.S. dollars spent per Acre	0.372012262
Yearly Cost per Acre (U.S. Dollars)	4.46414714

Conclusion

Cloud seeding is a very popular method to increase precipitation in the air. There are a lot of countries that are using the benefit of cloud seeding for reasons other than making rain, such as reduction of hail damage and pollution. This paper explored in detail how cloud seeding works in Thailand, including steps, chemical use, cost, and the success rate. There are six steps to seed clouds and four different types of chemicals used in Thailand. Other countries such as the U.S. only use silver iodine to seed the clouds. The chemical types that each country uses depend upon the type of airplane and altitude of operation.

There is much evidence from different countries that have conducted cloud seeding studies that shows that cloud seeding is successful. Three main examples of the successful cloud seeding include first, a study by Bernard A. Silverman in 2008, which shows streamflow of the river increased from 8.4% to 12.2% in the Kern River Basin. The next study was done by CNN Business in an Idaho mountain range, which reported an 8-15% increase in snow. Another important piece of evidence is the 2018 annual report by the Thailand Royal Rainmaking Project, which shows the average success rate of the whole country is 93%.

Even though there are studies from multiple countries, it is impossible to compare the success rate between each country to draw a conclusion regarding which country has the highest success rate in cloud seeding. The reason is because the moisture content in the air affects the success of cloud seeding and moisture varies between the locations. For example, Thailand is located in southeast Asia, which has tropical weather and thus a lot of moisture in the air. By comparison, Idaho is located in the northwest of the U.S.,

which has forests and is also located far from the sea. This difference in location could be the reason why the success rate of cloud seeding in Thailand is a lot higher than the cloud seeding that is done in Idaho.

The calculation from Table 2 provided the yearly cost per acre of cloud seeding of about $4.5, which leads to the next calculation about the effectiveness of rain making to the farmers in Thailand, which shows on Table 3. The four main industrial crops that are grown in Thailand are rice, corn, cassava, and sugarcane, which appear in the first column. Those crops will be the main crops that are used for the calculation of the economic effectiveness of the rain making. A rough estimate for the profit per rai for each crop is shown in the second column (numbers were taken from the following sources; Technology Chaoban, Matichon Online, Thai Publica, and Rakbankerd). The next step involved converting profit per rai to profit per acre, which shows on the third column. The fourth column shows the cost to make rain per acre in U.S. dollars. In order to find economic effectiveness, the cost to make rain must be subtracted from the crops' profits; the remaining profit is shown in the sixth column. The calculation clearly showed that the Royal Rainmaking Project is very economically effective, as the sixth column shows that all main industrial crops benefit from rain making.

Table 3. The Economic Benefits of Rain Making Calculated per Year

Main Industrial Crops Grown in Thailand	Profit per Rai per Year (Baht)	Profit per Acre per Year (Baht)	Profit per Acre per Year (U.S. Dollars)	Cost to Make Rain per Acre (U.S. Dollars)	Benefits per Acre (U.S. Dollars)
rice	8,040	3,177.9	105.9	4.5	101.4
corn	10,200	4,031.6	134.4	4.5	129.9
cassava	3,500	1,383.4	46.1	4.5	41.6
sugarcane	10,000	3,952.6	131.8	4.5	127.3
		1 Rai = 0.395257 Acre	30 Baht = $1		

As shown in column six, the cost of making rain was subtracted from the profit of the farmer and the remainder is still significant. Thus, Table 3 provides data that demonstrates that the cloud seeding that was done by the Royal Rainmaking Project is economically effective.

This table, when considered with the other research presented in this thesis, supports the H_1 hypothesis, which stated that seeding has positive effects. Among these positive effects are increasing rain and snow as well as decreasing hail and pollution, all of which contribute to the economic effectiveness of cloud seeding at local and national levels. By gathering all of these studies together, this thesis has effectively demonstrated the usefulness and positive effects of cloud seeding.

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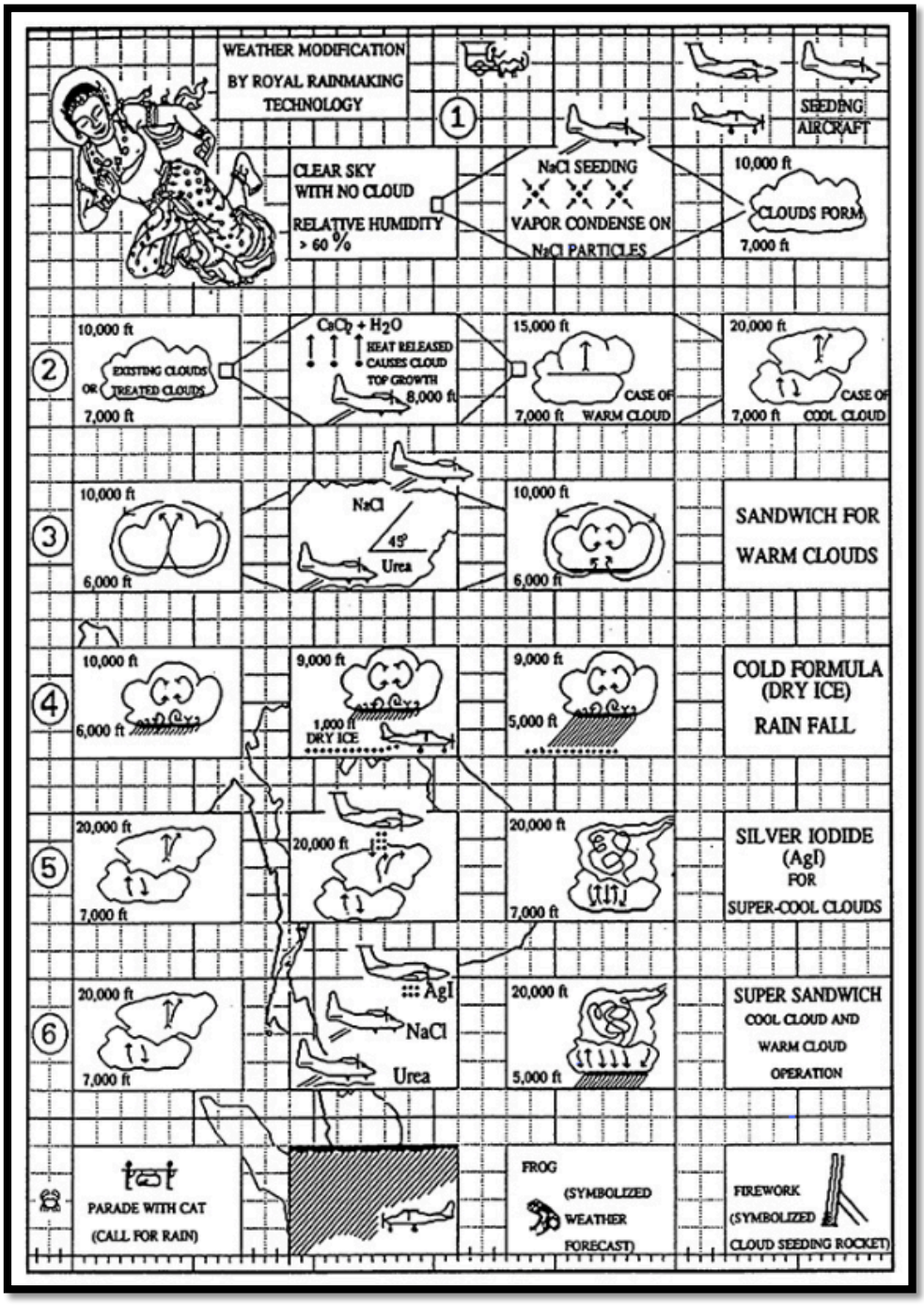
Appendix: Royal Rainmaking Project Cloud Seeding Steps



This chart visualizes the steps and techniques for cloud seeding that are used by the Royal Rainmaking Project. These steps were written by King Bhumibol Adulyadej of Thailand.