ECONOMIC FEASIBILITY OF USING WEATHER-ALTERING TECHNOLOGY ON APPLE ORCHARDS IN VIRGINIA

by

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INTRODUCTION

Statement of Problem

In recent years, new weather-altering technologies have been developed that are capable of increasing yields in years of adverse weather conditions.

Poor yields in years of adverse weather conditions cause losses in net revenue to orchard producers. Obviously, low yields will decrease gross revenues. And, since orchards must be kept in a healthy state to support production of good quality apples, production costs except for harvest costs in poor weather years are relatively the same as in years of normal or good weather; thus, net revenues are decreased.

To date, no research has been conducted to determine under what conditions it is economically feasible for orchard producers to adapt new weather-altering technology. This study makes an economic comparison of alternative weather-altering technology for apple producers in Virginia.

The approximately 700 orchardists in Virginia could expect to produce approximately 12 million bushels of apples annually with good weather conditions. Extremes of production since 1970 have ranged from 11,900,000 bushels in 1972 to about 4,000,000 bushels in 1976. With the prices that have prevailed since 1970 and with the fact that Virginia prices are primarily affected by U. S. rather than Virginia production, the loss in revenue from weather related factors have averaged over $7,000,000 annually in the six years, without significant reductions in non-harvest expenses. Such losses can be important in determining the future viability of the apple industry in Virginia.

Factors causing reduced yields are categorized as those over which producers have no control and those over which producers have some control. Weather factors dominate the first category. Historically, producers have had little control over weather conditions. However, technological developments now have made systems available which producers may use to partially protect their orchards against the adverse effects of temperature and rainfall extremes which affect apple sets and development. These technologies are wind machines, which can be used to protect against freeze damage, and overhead sprinkler systems, which can be used for freeze protection and irrigation.

Even with the new technologies, procedures still can not control excessively high or excessively low temperatures to the degree that damage to crops can be completely eliminated. Also, if weather conditions are such during the pollination period that bees cannot fly, no number of hives per acre will provide adequate pollinization.

Physiological factors dominate the second category. However, many management practices have been developed to control adverse conditions in these factors. Management practices such as orchard establishment, pruning and training, thinning, fertilization, insect and disease control, rodent and other animal control, weed control, and pollinization are examples of how producers can control certain adverse factors. In the analysis that follows, producers are assumed to follow good management practices from year to year and these management practices do not vary with the system analyzed. However, for completeness, Appendix A discusses the management practices involved in apple production.

This study will concentrate on the effects that weather conditions have on yields, and under what conditions weather-altering technology is economically feasible for use in Virginia apple orchards.

Objectives

Given that poor yields caused by weather factors decrease net revenue for apple producers, and that technology is available to alter these weather factors, the objective of this study is to determine whether weather-altering systems are economically feasible for use in apple production.

The following steps are necessary in meeting this objective. First, the weather factors significantly affecting production must be identified and these effects measured. Second, it must be determined what effect the weather-altering systems can have on these factors. Then, using costs and returns with economic criteria, it will be determined which, if any, of these technological systems are economically feasible to use in the production process.

Content of the Following Chapters

The remainder to the dissertation is organized in the following manner:

Chapter II explains the effect of weather factors on production, the mechanics of overhead sprinkler systems and wind machines, and reviews research that has been reported on the effect of weather factors on production and the effectiveness of the adaptable technology on altering weather factors.

Chapter III provides the economic foundation used to develop the decision criteria to determine under what conditions the adaptable technology is economically feasible.

Chapter IV explains the regression model used to predict yields and determine the weather factors which affect production. The different steps used in the simulation model to determine if the adaptable technology is economically feasible is also outlined in this chapter.

Chapter V presents the results from the regression model and explains the calculations and results in the simulation model. This chapter then explains the economic implications of the study and what further research could be undertaken.

Chapter VI is the summary and conclusions chapter.

CHAPTER II

A DISCUSSION OF WEATHER EFFECTS ON PRODUCTION AND A REVIEW OF RESEARCH RESULTS USEFUL TO THE STUDY

This chapter discusses the effects of weather on production and reviews research on the effectiveness of technological systems which will be used in this study.

Weather Effects on Production

Weather factors can be divided into six conditions, each having particular effects on production. These can be listed as:

1. Freezes
2. Moisture level during critical periods
3. Rainfall
4. Sunlight during the production season
5. Temperatures during the late stages of production
6. Hail

Freeze is probably the most important weather condition affecting production in Virginia. There are two basic types of weather conditions under which freezing temperatures can occur. The most frequent cause of freezing temperatures in Virginia during the non-producing period, although not necessarily the most destructive, is the transport of cold air masses southeastward from Canada over the United States. These air masses have originated over the snow covered polar and artic regions in Canada, where the process of radiational cooling during the long nights and days of little sunshine causes the air to become progressively colder. As the air mass migrates southeastward into the United States, its temperatures, which are below freezing at the surface, get colder with increased elevation. This type of freeze condition is called advective freeze. It occurs mostly during non-producing periods; but, when it occurs in critical periods such as early spring or early fall, there is virtually nothing that the producer can do to protect the crop. Heat applied to an orchard during this type of freeze is quickly radiated away.

The second type of weather condition that causes freezing temperatures is called a radiational freeze, which is the one that most frequently freezes the buds or early fruit during the spring season. This type of freeze occurs when a relatively cool but very dry air mass moves into an area. This air also originates over Canada where its surface temperatures were below freezing; however, as it moves southward it begins to get warmer during the daylight hours and most times will reach temperatures in the sixties. The air mass at the surface will stay above freezing during the daytime hours, but, after sunset, radiational cooling on the earth's surface causes temperatures in the lowest layers of the atmosphere to fall below freezing, while temperatures at the levels just a few hundred feet higher remain constant, thus forming an inversion. In a situation where there is an inversion and the warm air is at low enough levels, most crops can be at least partly saved with the use of adaptable technology.

During radiational freezes and advective freezes, production can be affected by damage to either the trees or the fruit. Freeze damage occurs when it is cold enough to freeze the sap in a tree. The ice crystals don't generally form inside the living cells; but, rather the sap from the cell moves to spaces between the cells where the ice crystals form. The more succulent the tissue and the higher the moisture content, the more prone the tissue is to injury. The expansion of the frozen moisture and the pressure it creates may split the wood and the bark and may kill other parts of the tree, especially the buds and new growth.

Freeze damage can affect production and cause permanent damage to the tree and buds. The freeze damage which permanently damages the tree can alter production for years or it may eliminate the productive capacity of an orchard. This type of freeze damage happens at any of three different periods of the year. First, it can normally occur in trees in the late fall or early winter before the tree hardens. The part of the tree most susceptible to freeze damage during this time is the collar or crown, which is located just above the ground line. This trunk area, unless protected by a snow cover, bears the brunt of frigid air, which tends to be coldest at the ground surface. Since the collar bark has not hardened, it may be destroyed by the low temperature which may cause no structural damage to other parts of the tree. In winter, during the dormant period of the tree, the roots are the most susceptible to freeze damage. Roots of apple trees will be injured if their temperatures are reduced to below -9°C. Actually, the soil does a good job of protecting the roots, but prolonged periods of sub-zero temperatures without snow cover may severely injure the roots. The last period when permanent freeze damage can harm a tree is in the spring. When the tree starts to grow in the spring, the new growth can be killed by a freeze more easily than the rest of the tree because of its high moisture content and the tenderness of the new growth.

The other type of freeze damage which does not permanently effect the trees but does effect the current year's production is the damage done to the buds or early fruit. If a large number of the buds are killed in a given season, there will be very little production. This damage usually occurs in April and May when the buds or early fruit are developing. Depending on the severity of the freeze, any percentage of that year's crop can be destroyed.

The second weather condition that influences production is that of moisture and temperature levels during the pollination period. High moisture and low temperatures adversely affect the ability of the bees to fly, and therefore, limits the area of pollination for a bee hive. This problem can be remedied, at least in part, by a manager who realizes the problem and rents more bee hives.

The amount of rainfall during the growing season is another weather condition that has a direct impact on production. Rainfall is a very important factor in Virginia apple production throughout the production season because of the tree's need of water to develop the food it requires to maintain life and grow fruit. The lack of water in the early production season in Virginia is not usually a problem because of heavy spring rains; but, during June, July, and August, it is important to have enough rainfall, since this is a critical growth period for the apples. If the trees don't get enough water during this period, the apples will be of smaller size than if they had had an adequate water supply. Because of the usual adequacy of moisture during the growing season, Virginia orchardists generally have not seen fit to provide for auxiliary irrigation, but in certain seasons and certain locations the crop is limited by drought conditions.

Sunlight has two major influences on apple production. Sunlight has a direct effect on food availability, being a major factor in the photosynthetic process which converts nutrients and water from the soil into food products for the tree to use in tree maintenance, apple development, and fruit spur development. Sunlight also affects the colorization process in the apple skin, which is a major factor in grades for fresh market. Sunlight, therefore, affects both the quantity and the quality of apples produced.

Temperature also influences photosynthesis, thus affecting apple development throughout the season. Temperature also affects the skin coloration, especially in the last periods of production. Too high temperatures can result in sunspots on the apple skin and too low temperatures will not develop good color. Cool night temperatures and warm daylight temperatures during the last month of production cause good coloration.

Hail is another weather condition that affects both volume of production and quality of apples. It not only physically damages apples, but creates points where disease organisms may gain a foothold both on the apples and on the tree itself. Diseased apples are unsalable and tree disease may affect not only the production in the current year, but may affect production for a longer period, even to the point of killing the tree. Even if the orchard is not afflicted with disease, the physical damage to the foliage may reduce photosynthetic efficiency.

These basic weather factors discussed above are not subject to management control, but may seriously affect apple orchard returns. However, by the use of adaptable technology, management can often alleviate the harmful effects of freeze, low rainfall, and low temperatures during the late stages of production in an orchard.

Review of Research Results Useful to the Study

Mechanical Systems Which Can Be Used For Freeze Control

There are three major types of freeze control systems that can be used in Virginia. These systems are conventional heating systems, wind tumbling systems, and sprinkler irrigation systems. Conventional heating systems will not be analyzed in this study.

Heat Systems Limitations

There are two justifications for leaving heating systems out of the analysis. First, heating systems must comply with the Clean Air Act of 1965, which outlawed the use of the conventional open air pots for heating. The impact of this was to increase the initial investments for cleaner burning systems. The second concern with heating systems is the increasing cost of oil. Not only has the price for fuel oil more than doubled in the last 5 years, but the uncertainty concerning both the price and availability of oil has caused the oil heating system to be impractical when considered as a long term investment. For other conventional type heating systems, LP and heating bricks are not commercially available for use in the orchard industry in Virginia. The number of firms which develop new oil and gas heaters has decreased from over twenty firms in the 60's to three firms today. [Jim Ballard] Those that have a line of commercial heaters are all doing more business in wind machines and irrigation sprinklers. The reasons for this trend are the need for using less fuel and the reduced pollution involved in using wind machines and sprinkler systems for freeze control.

Wind Machines System

The use of wind machines to control freeze is not new. The study of wind machines began in California in the 1920:s; but, not until the last 20 years, because of new technology and increased size of the systems, have they met with any success. [R. L. Reese and J. F. Gerber] The principal phenomenon that makes wind machines or helicopters effective for freeze control is the presence of an inversion, which occurs when the air temperature increases 4.4°C. to 8.75°C. from ground level to a height of 50 to 100 feet above ground level. Because of this phenomenon, it is possible to use wind machines or helicopters to tumble the warm air down through the orchard, causing the temperature in the orchard to rise as much as four degrees. The three most important factors for the successful performance of wind machines are: the presence of an inversion, the nature of the temperature composing the vertical profile, and the absence of wind. The importance of an inversion to this type of freeze control is evident. Mixing air will do absolutely no good if the temperature is no warmer at 50 feet than in the orchard. The nature of the temperature composing the vertical profile will determine how effective wind mixing will be in terms of how much of a temperature increase can be gained. If the temperature rises very quickly and if the difference in temperature from ground level to 50 feet is relatively large, then the effects of wind mixing will be much greater than in a situation where there is a smaller change in temperature from ground level to 50 feet. Wind speed or turbulence is related to the first two factors in that an increase in wind speed automatically mixes up the air, thus weakening the inversion and causing the actual difference in temperature from ground level to 50 feet to become lower. If wind speed increases to much over six to seven miles per hour, [R. L. Reese and J. F. Gerber] the inversion is relieved, thus making this system ineffective against freeze.

Sprinkler Systems

Sprinkler irrigation systems which include overhead sprinklers can aid in freeze control in two ways. The first or direct method of freeze control by overhead sprinkler systems is to spray a film of water on the apple trees. As the water film freezes, it releases its heat of fusion, which amounts to 1200 B.T.U. per gallon. [J. F. Gerber and D. S. Harrison]. The heat that is generated by the freezing process will then, under conditions of low wind and a good flow of water, keep the bloom at thirty-two degrees when the temperature in the orchard drops below the critical level. When using water for freeze control, it is very important to spray enough water on the trees to compensate for heat losses which are caused by convection, radiation, and evaporation. Heat losses due to convection and radiation are the same whether or not the tree is being sprayed by water; but, evaporation is greatly increased by increasing wind speeds, causing increased heat losses. Because of the effect of evaporation, it is very important to determine wind speeds- the stronger the wind, the more water is needed to counterbalance the evaporation cooling effect. If wind speeds are too great, it is better not to start the sprinkler system, especially if that system cannot put enough water on the trees for protection. The evaporation effect plus the cold temperatures will do more damage than that caused when the trees are unprotected. Table 1 will show the amounts of water needed, given specific wind speeds.

Most systems are set to spray .12 to .15 inch per hour, and

Table 1. Precipitation Rates in Inches Per Hour, Necessary for Freeze Protection

Temp. of Unprotected Blossom or Bud	Windspeed in m.p.h.				
	0-1	2-4	5-8	10-14	18-22
			(Inches/Acre)		
27°	0.10	0.00	0.10	0.10	0.20
26°	0.10	0.10	0.14	0.20	0.40
24°	0.10	0.16	0.30	0.40	0.80
22°	0.12	0.24	0.60	0.60	1.20
20°	0.16	0.30	0.60	0.80	1.60
18°	0.20	0.40	0.70	1.00	2.00
15°	0.26	0.50	0.90	0.30	2.60

Source: Florida Cooperative Extension Circular 348 (Technical) therefore, do not provide protection over the range of possible temperatures. When much more than .16 inch per hour is sprayed, a drainage problem exists, and with a very large system, storing enough water for more than two nights is impractical.

The second and indirect method of freeze control by overhead sprinkler systems is to delay bud development. By delaying the bud development, the probability of having a killing freeze during the critical bloom period is reduced. This method uses evaporation to cool off trees after they break rest in late winter and slows down bud development from the time the trees break rest until they reach full bloom.

This method of freeze control was first developed at Utah State University in 1971, and has since been tested in Georgia [Utah Study and Georgia Study]. There are certain principles used in developing this type of freeze control; and, to explain how these principles work, it is first necessary to explain two important concepts which will be used extensively in this model.

The first concept is a chill unit (Utah Work) which is used to determine when a tree is in rest and when the tree breaks rest. The determination of what chill units are and how they affect rest is essential to freeze control. A chill unit is equal to 6°C. (43°F.) for a duration of one hour. The chilling contribution becomes less than one as the temperature drops below or rises above this optimum value. A negative contribution to a chill unit accumulation occurs at temperatures above 15°C. (60°F.) and zero units contribution occur below 0^{o}C. (32^{o}F.). The specific temperature values and their equivalent chill unit contributions as used in this study are shown in Table 2.

Chill unit accumulation begins in late summer, when due to temperatures above 15.6^{o}C. (60^{o}F.), there is an accumulation of negative chill units. When the chill unit accumulation reaches its highest negative point, the trees start rest. At this point, the chill unit count starts over again at zero, calculating positive chill units as specified in Table 2. After the chill unit count reaches 1,234 positive units [Utah Work], apple trees break rest. When using overhead sprinklers for bloom delay, it is very important to calculate the date when trees break rest so that the sprinkler system can be used to start the delay of bloom development.

The second determination needed in the bloom delay concept is the energy unit accumulation. After the time of rest completion, any energy, in the form of temperatures above a base temperature, will result in some bud development. In general, this rate of development will increase given higher temperatures. Using past studies [Utah and Georgia Work], it was determined that the base temperature was 4.5^{o}C. (40^{o}F.). It is assumed that for each Centigrade degree above the base temperature, the energy units (Growing Degree Hours (GDH)) increase linearly. It is also assumed that under 4.5^{o}C. (40^{o}F.) there will be no bud development. When there are higher temperatures than 25^{o}C. (77^{o}F.), the process of cooling the plant will exactly equal the added energy from the

Table 2. Chill Units Related to Air Temperature

Ambient Air Temperature °C	°F	Chill Units Contributed Per Hour
1.4	34	0.0
1.5- 2.4	35-36	0.5
2.5- 9.1	37-48	1.0
9.2-12.4	49-54	0.5
12.5-15.6	55-60	0.0
16.0-18.0	61-65	-0.5
18.0	65	-1.0

Source: E. Arlo Richardson, Utah State University high temperatures. Therefore, the mathematical equation for calculation of GDH is:

$$GDH = \sum_{\imath=1}^{n} Tc - Bt \qquad (1)$$

subject to the constraint that when

$TC > 25^{o}C.$ $Tc = 25^{o}C.$

where:

GDH = Growing Degree Hours
Tc = Temperature for each hour in Centigrade
Bt = Base Temperature = 4.5°C.
ı = Hours
n = Hours to completion of full bloom

The GDH are important to predict when buds are in their different stages of bloom and also how much blooms are delayed when water is used to keep the buds at a lower temperature. Table 3 will show the different stages and the energy units needed to reach each stage.

Utilizing this information, estimates of when trees enter rest, break rest, and the occurrence of all the different stages of bud development can be made. Estimates can also be made of when these stages will occur when bloom is delayed. There are different critical freeze temperatures for each stage; therefore, it is essential to know when each of these stages occur. The critical temperatures for a 10 percent kill, 50 percent kill, and a 90 percent kill of bloom are shown in Table 4. This information provides the basis of estimating how many hours of freeze control are needed for protection in any given stage of production.

Table 3. Energy Units Required for Apple Buds to Develop to Certain Stages

Stages	Energy Units Needed
Silver Tip	2061
Green Tip	2544
Half-Inch Green	3100
Tight Cluster	3939
First Pink	4856
Full Pink	5394
First Bloom	6172
Full Bloom	6933

Source: Pheno-Clinatological Models for Various Utah Fruit Varieties; E. Arlo Richardson

Table 4. Pheno-Climatography of Red Delicious Apples-Levels of Kill to Buds at Different Stages Caused by 30-Minute Exposure to Different Critical Temperatures

Stages of Bud Development	Levels of Kill					
	10%		50%		90%	
	°C	°F	°C	°F	°C	°F
1. Silver Tip	-9.4	15	-12.8	9	-16.7	2
2. Green Tip	-7.8	18	-10.0	14	-12.2	10
3. Half-Inch Green	-5.0	23	- 7.2	19	- 9.4	15
4. Tight Cluster	-2.8	27	- 4.4	24	- 6.1	21
5. First Pink	-2.2	28	- 3.3	26	- 4.4	24
6. Full Pink	-2.2	28	- 2.8	27	- 3.9	25
7. First Bloom	-2.2	28	- 2.8	27	- 3.9	25
8. Full Bloom	-2.2	28	- 2.8	27	- 3.9	25
9. Post Bloom	-2.2	28	- 2.8	27	- 3.9	25

Source: V. J. Valli, Freeze and the Prevention of Freeze Damage in the Appalachian Fruit Region

The formuli can also be used to predict the hours a sprinkler system will be used for bloom delay and how many days the bloom would be delayed.

Multiple Uses for Overhead Sprinklers

Wind machines can be used for no other purpose than frost control, but overhead sprinkler systems can be used to alter other weather effects. In addition to bloom delay and freeze control, an overhead sprinkler system can be used for irrigation purposes. Using a ground moisture sensor to determine the need for water, the overhead sprinkler system can be used for irrigation during periods of insufficient rainfall. Another use of an overhead sprinkler system is to cool the fruit during hot days late in the production season. This may reduce sunspots, which discolor the apple skin and hence cause the fruit to be of lower quality and value.

CHAPTER III

THEORY OF INVESTMENT OF THE FIRM

The purpose of this chapter is to develop a theoretical basis for making economic decisions as to whether to make a capital investment; and, if so, which of a choice of investments would be better. Different investment situations will be considered and decision rules determined. This chapter will also explain what decision tools can be used when risk and uncertainty are introduced into the analysis.

Profit maximization is the behavioral assumption that is the key to the neoclassical study of the theory of the firm. When time is entered into the analysis with attendant capital funds and interest cost considerations, more than one criterion can be used for maximization and there has been little agreement as to which criterion is best [Lutz] There are four such criteria which could logically be used for maximization in this situation. Before these criteria are explained, it is important to develop the concept of quasi rent which is used in all of the criteria. Quasi rent is used to show the short run gross considered as an investment alternative [Lutz] [Stigler]. Therefore, there will be a quasi rent for each short run production period for the lifetime of the durable production instrument (technology). Figure 1 shows the quasi rent for a production period using the traditional short-run cost curves of the firm.

Quasi rent is then equal to the area BDEG and will be represented as V for the rest of this section. The cost of use of this production instrument is the area BCFG and will be represented as C for the rest of this section. Both V (Quasi Rent) and C (cost of operating the production instrument) will be used in the four decision criteria.

The four decision criteria are as follows:

1. Maximize the difference (V-C) in present value of the future quasi rents and cost streams.

2. Maximize the present value of the quasi rents divided by the costs (V/C).

3. Maximize the internal rate of return. [1/]

4. Maximize the return on the owner's capital to be invested.

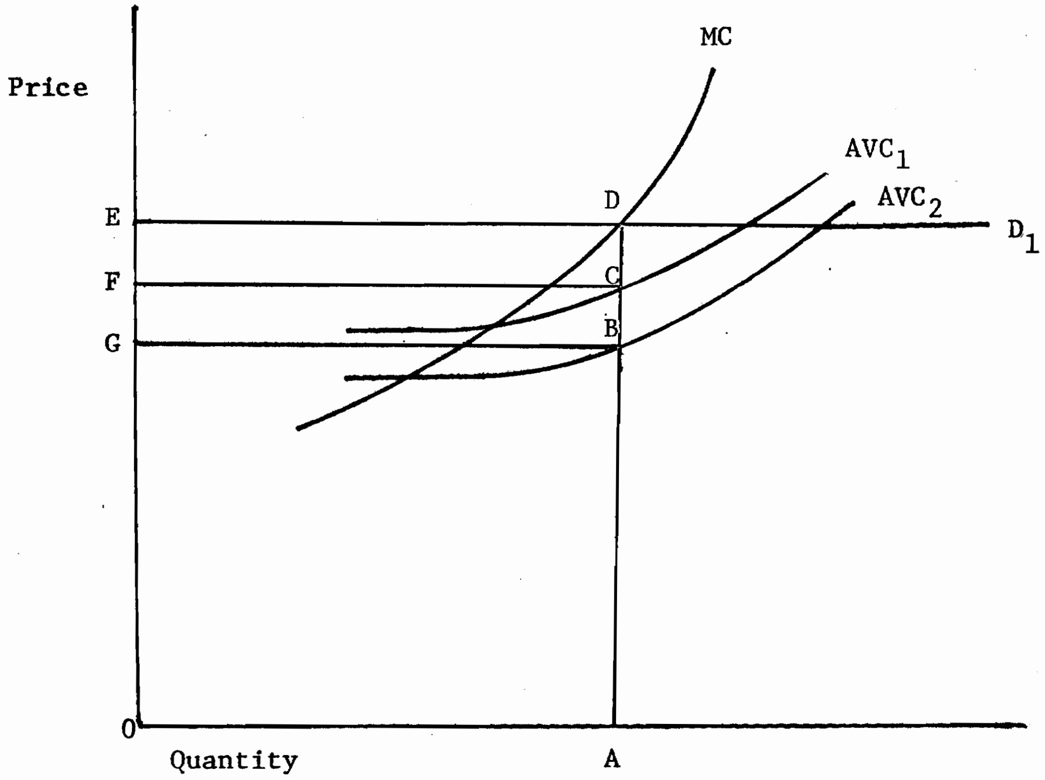
[1/] The internal rate of return on investment (average internal rate of return on investment) is computed by following the standard capitalization formula of:

$$I = \sum_{t=1}^{T} \frac{V-C}{(1+r)^t} \qquad (2)$$

where:

I = level of investment
T = life of capital invested
V = gross returns
C = variable costs
*r = rate of return to be determined

*The average internal rate of return on investment is the r which satisfies the equation.



where:

MC = the marginal cost curve
AVC1 = the average cost curve
AVC2 = the average cost curve minus the costs of operating the durable production instrument
D = the demand curve that an individual firm faces

Figure 1. Illustration of Quasi Rent for a Given Production Period.

These four decision criteria are then evaluated under the different investment situations.

Investment Case Where Investment Decisions Can Be Made at Continuous Levels of Investments

In the first case, there is assumed to be a very simple functional relationship between revenue and capital investment. This assumes that revenue varies solely with the size of investment and that investment can be accrued in a continuous manner. It is also assumed that capital is invested at one point (point in), that all revenues are received at one period (point out) in the planning horizon, and that the period of production for that investment is technically given. It assumes that at first, output increases at an increasing rate, then at a decreasing rate, and then output decreases. This is due to the effects of economies and diseconomies of scale. It is further assumed that the rate of interest is constant with respect to the volume of funds borrowed and that the firm can borrow as much capital as is needed.

Given the above investment situation, what would happen when each of the four criteria mentioned above is maximized? Two terms must first be clarified. The first is the marginal internal rate of return [2/], which is used to discount the marginal income generated

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[2/] The marginal internal rate of return on capital is:

$$\rho_m = \frac{\Delta V - \Delta C}{\Delta I} - 1 \qquad (3)$$

where:

ρ_m = marginal internal rate of return on capital
V = gross discounted returns
I = investment
C = gross discounted operating costs

by additional investment units to present value. It is the rate that will make present value unity (V-C=0). The second term is the average internal rate of return. This is the rate of discount which equates the present value of the future income stream and investment.

In the above situation the condition for maximizing (V-C) is when the discounted marginal revenue resulting from an additional unit of investment is equal to 1. (V-C) is also maximized when the marginal internal rate of return is equal to the market rate of interest. This is demonstrated in the following set of equations:

Quasi rent is a function of the level of capital invested,

$$V = f(C) \qquad (4)$$

Thus, the present value is

$$V = f(C)e^{rt} \qquad (5)$$

where:

t = the useful life of the investment
r = the discount rate (which in this case is equal to the market rate of interest)

The criterion is to find the conditions for maximizing (V-C).

Call this G.

$$G = F(C)e^{-rt} - C \qquad (6)$$

The conditions for maximization are:

$$\frac{\partial G}{\partial C} = 0 \qquad (7)$$

$$\frac{\partial G}{\partial C} = f'(C)e^{-rt} - 1 = 0 \qquad (8)$$

or

$$f'(C)e^{-rt} = 1 \qquad (9)$$

which states that the discounted marginal revenue is equal to unity.

let ρ_a = average internal rate of return

let ρ_m = marginal internal rate of return

One can write:

$$C = f(C)e^{-\rho_a t} \qquad (10)$$

and

$$1 = f'(C)e^{-\rho_m t} \qquad (11)$$

Solving for ρ_a and ρ_m:

$$\rho_a = \frac{1}{t} \log \left(\frac{f(C)}{C}\right) \qquad (12)$$

and

$$\rho_m = \frac{1}{t} \log f'(C) \qquad (13)$$

It follows from equations 9 and 11 that (V-C) is maximized when the marginal internal rate of return is equal to the market rate of interest.

$$f'(C)e^{-rt} = f'(C)e^{-\rho_m t} \qquad (14)$$

$$r = \rho_m \qquad (15)$$

The second criterion, maximizing V/C, requires that the percentage rate of increase in quasi rent should be equal to the percentage increase in costs. Thus, the object is to:

$$\text{Max } \frac{V}{C} = \frac{f(C)e^{-rt}}{C} \qquad (16)$$

Differentiating with respect to C and setting the equation equal to zero obtains

$$\frac{d\left(\frac{V}{C}\right)}{d(C)} = f(C)e^{-rt} - C(f'(C)e^{-rt} = 0 \qquad (17)$$

and simplifies to

$$f'(C) = \frac{f(C)}{(C)} \qquad (18)$$

Take log of both sides and multiply by $\frac{1}{t}$:

$$\frac{1}{t} \log \left(\frac{f(C)}{C}\right) = \frac{1}{t} \log f'(C) \qquad (19)$$

Using equations 12 and 13 shows that V/C will be maximized when the marginal internal rate of return is equal to the average internal rate of return.

The third criterion is to maximize the internal rate of return.

Given that:

$$e^{\rho_a t} = \frac{f(C)}{C} \text{ and } e^{\rho_a t} = f'(C) \qquad (20), (21)$$

One wants to maximize ρ_a:

e and t are constant so maximization of $e^{\rho_a t}$ = maximization ρ_a

and differentiate with respect to C:

$$\frac{d(e^{\rho_a t})}{dC} = \frac{d\left(\frac{f(C)}{C}\right)}{dC} = \frac{Cf'(C) - f(C)}{C2} = 0 \qquad (22), (23)$$

this simplifies to

$$Cf'(C) - f(C) = 0 \qquad (24)$$

or

$$f'(C) = \frac{f(C)}{C} \qquad (25)$$

which shows that the internal rate of return is maximized when it is equal to the marginal internal rate of return, which is the exact same solution as when V/C is maximized.

The fourth and last criterion considered is maximization of the entrepreneur's rate of return on his own capital.

Maximize k-rate of return on own capital

Let:

C = total capital
K = own capital
$(C-K)$ = borrowed funds if $C>K$
$(C-K)$ = loan funds if $C<K$
r = market rate of interest
e^{kt} = rate of return on own capital
e^{rt} = rate of return on borrowed or loan funds
$f(C)$ = total returns
k = rate of return on own capital

Thus:

$$Ke^{kt} = f(C) - (c-K)e^{rt} \qquad (26)$$

Since K, e, and k are constant, maximizing k is the same as maximizing of Ke^{kt}. So, differentiate Ke^{kt} with respect to C and set equal to zero.

$$\frac{d(Ke^{kt})}{dC} = f'(C) - e^{rt} = 0 \qquad (27)$$

or

$$f'(C) = e^{rt} \qquad (28)$$

or

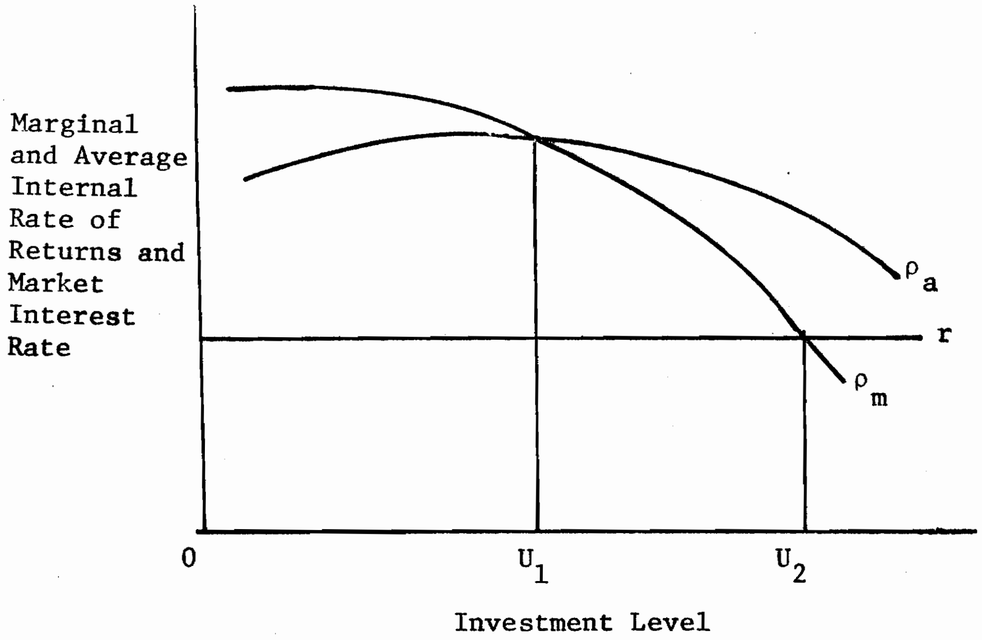
$$f'(C)e^{-rt} = 1 \qquad (29)$$

which is the same solution as when (V-C) was maximized. In other words, criterion four is maximized when marginal internal rate of return equals the market rate of interest.

A comparison of the four criteria in regard to the first investment situation is represented diagramatically in Figure 2. The investment level which maximizes (V/C) and the internal rate of return is OU_1 units of investment. It can be shown also that a change in the interest rate will not change the maximum solution for internal rate of return and (V/C). It is also true that between OU_1 and OU_2 levels of investment the marginal rate of investment is higher than the market interest rate. Therefore, it would increase the present value (V-C) to use borrowed capital to increase investment up to the point that the marginal internal rate of investment equals the market rate of interest. Thus, the rule that would be followed in decision making in this situation would be to maximize (V-C). This would occur at the point where the marginal internal rate of return on investment equals the market rate of interest (OU_2).

Maximizing present value is the only method discussed in the rest of this section for evaluating investments. In later chapters, the other criteria will be considered only to show what value each of them have when present value is maximized.

In the long run, if the investment is profitable all firms will want to invest, which increases the demand for money. The increase in demand for money then increases the interest rate until only a normal return is received from the investment. This point would be where marginal internal rate of return equals the average internal rate of return, and would be the long run equilibrium for investment in the production instrument. And, at



where:

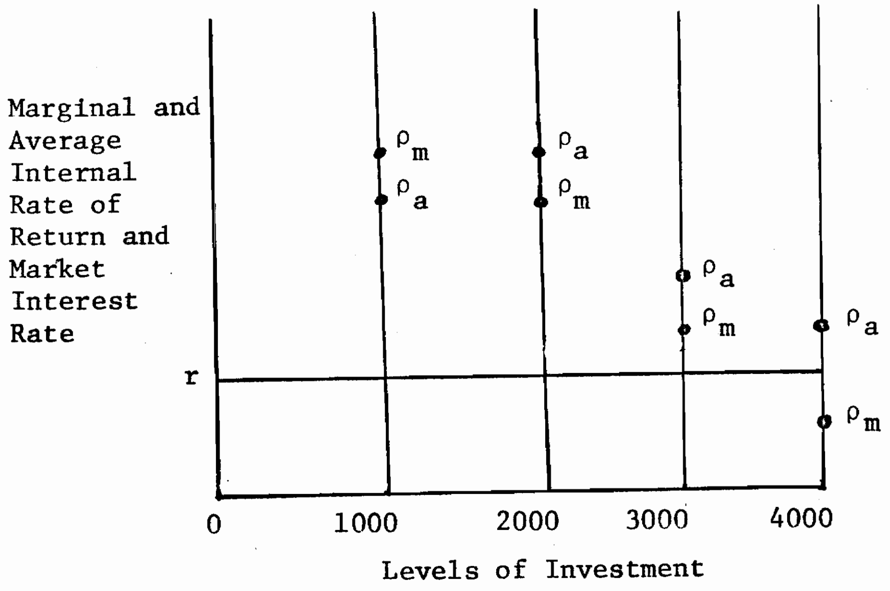
ρ_a = average internal rate of return
ρ_m = marginal internal rate of return
r = market rate of interest

Figure 2. Marginal and Average Internal Rate of Returns Depending on the Level of Investment

the long run equilibrium, all four of the economic criteria have the same solution point and would be OU_1 in Figure 2.

The Discrete Investment Case

The discrete investment case explains how investment decisions are made when capital can be invested only in discrete increments, which is most usually the case. Using all of the assumptions from the continuous investment case except that there are no continuous curves, the following example illustrates how decisions are made with the discrete investment increments. For example, a firm is deciding on the number of tractors it should invest in, but they must invest in whole tractors. Instead of smooth curves, as in the first case, the decision possibilities are now the different levels of investment, or specific points. Figure 3 represents a graphic example of a firm with the choice of investing in 1,000 dollar increments. As in the first case, maximizing present value is the criterion that a firm would use. In Figure 3 the point of maximizing present value would be the last decision point where marginal internal rate of return (ρ_m) is above the market rate of interest. This point is where the level of investment is 3,000 dollars. The following example will also show that at that level present value is maximized.



where:

ρ_m = marginal internal rate of return of investment
ρ_a = average internal rate of return of investment
r = market rate of interest

Figure 3. Marginal and Average Internal Rates of Returns Given Levels of Investment

Given certain revenues for each level of investment solving for ρ_m using Equation 3, we have:

Investment Levels	Returns	Marginal Internal Rate of Return
0	0	0.00
1,000	1,500	0.50
2,000	3,250	0.25
3,000	4,350	0.10
4,000	5,400	0.05

Assuming the market rate of interest is 8 percent, the firm would choose the level of investment to be 3,000 dollars. At that point, present value is maximized. If the firm invests 4,000 dollars, it pays 1,000 more dollars and receives only a 5 percent increase in returns on money for which it is paying 8 percent. Therefore, the firm would lose 30 dollars on that additional investment. Thus, present value is maximized at the last investment point where marginal rate of return is above or equal to the market rate of interest.

Investment Decision for Mutually Exclusive Investments

There are situations where more than one type of investment can be used for the same purpose in the production process, although, due to the nature of the investments, they can not be used together. In this situation, the investments are mutually exclusive. The decision rule in this case would be to first determine what the maximum present value would be for each of the investments. Then the investment with the highest present value would become the investment that is used in the production process.

Investment Decisions Under Uncertainty

In the three cases shown before, it was assumed that the firm knew with certainty what the returns would be for each system; but, in the real world situation, especially when time enters the analysis, that assumption is not very realistic. In most, if not all cases, there is uncertainty in determining the returns for each investment. These uncertainties rise from unknown prices received for goods produced, input prices, and changes in other factors which affect production. Therefore, to make a more realistic investment decision, one should account for uncertainty in the analysis. This can be accomplished in several ways.

One of the best ways to account for uncertainty is to use expected value. Expected value can be calculated in a number of different ways. First, it can be included in the discount rate of the present value formula. This is done by adding or subtracting an adjustment for uncertainty to the discount rate for different income levels. This uncertainty adjuster is added or subtracted to the discount factor depending on whether the firm is a risk adverter or a risk taker. A risk adverter prefers to avoid risk; therefore, he would increase the discount rate which would decrease the present value of the investment. A risk taker, who prefers more risk to less risk, would decrease the discount rate and increase the present value of the investment.

A second and more popularly used way to calculate expected value is to calculate the present value of an investment under different economic and physical circumstances. Then, a probability of occurrence can be assigned to each of the present values. For each investment, the probabilities for different present values must add to one. These probabilities are again determined differently depending upon whether a firm is a risk taker or a risk adverter. After the probabilities are determined, they are multiplied times the present value and these products are then added to get the expected present value for that system. The following example will show the procedure for calculating expected present value for an investment with four income possibilities.

Present Value Under Four Different Outcomes of the Same Investment	Probability of This Occurrence of Present Value
$700.00	0.1
500.00	0.3
400.00	0.4
300.00	0.2

and using the expected present value formula,

$$E(PV) = \sum_{\imath=1}^{n} PV_{\imath} P_{\imath} \qquad (30)$$

where:

E = expected value
PV = present value
P = probability of occurrence
$\imath$ = each outcome
n = total outcomes

$$E(PV) = \$700 \times .1 + \$500 \times .3 + \$400 \times .4 + \$300 \times .2$$

$$E(PV) = \$440$$

The expected present value is 440 dollars. This 440 dollars is the present value which would then be used in the investment decision.

Other ways can be used to account for risk and uncertainty. Briefly they are: maximizing minimum present value criterion, minimizing maximum present value criterion, and the Hurwicz α Index criterion. After the firm uses these procedures, it would then make its investment decision on the selected present value of each investment.

Another factor which firms like to use when making decisions on investment is the payback period. Firms like to know how long money (borrowed or owned) will be tied up in the investment. Firms must look at their cashflow situation. The longer the investment takes to pay off, the longer their money is tied up and the more problems they might have in handling short or intermediate debt situations. Also, the longer the payback period, the more uncertainty there would be in the investment. The payback period can be calculated by obtaining the present value for the investment, then using the annuity formula to determine what the average yearly income would be, then divide the investment cost by yearly income to find the payback period.

These methods determined from profit maximizing behavior provide the basic framework for the economic analysis of investments.

CHAPTER IV

PROCEDURES

This chapter explains the procedures used in developing and explaining the models which evaluate whether either the overhead sprinklers or wind machines are economically feasible for use in Virginia. The two models explained in this chapter are the regression and simulation models. The regression model is used to predict yields and determine the factors which affect production. The simulation model is used to derive the values of investment decision criteria explained in Chapter III.

The decision rule for evaluating these mutually exclusive investments, as shown in Chapter III, would be the present value approach. Therefore, to choose among alternatives the economic feasibility of these two systems, the present value or expected present value must be derived.

To derive the present value, the first procedure must be to develop a yield response equation which predicts yields, given data on weather variables.

The yield response equation then will be used in a simulation model to derive production and return estimates for the different weather altering technologies in different years.

Development of the Production Function

The first step in developing the yield response equation was to determine the factors that significantly affect production. The large number of factors that affect the production of apples and the fact that these factors affect not only this year's production, but may affect production for several years to follow, causes problems in estimating the production function. These problems, although they cannot be completely eliminated, can be lessened by first assuming that all factors except weather factors are held constant. Another assumption made to simplify the analysis was to assume that weather factors which affect production are independent from one year to the next (assuming the year starts at the end of fall harvest and ends at the end of the next harvest). This assumption is justifiable for two reasons. First, especially in Virginia, there have been no recorded extremes in weather conditions, extreme low temperatures, or extensive periods of drought years, which have done permanent damage to many trees. Second, adverse weather which does effect crop production in one year, causing side affects which could alter the next year's crop, can be corrected in most cases by good management practices.

Given the two assumptions stated above, the analysis can then be focused on how weather factors affect production.

Holding the other variables constant, the yield response equation used in the analysis would now show in equation form as:

$$q = f(X_{11} \ldots\ldots X_{nt}) \qquad (31)$$

where:

q = apples produced
x = inputs into the production process
n = number of inputs
t = periods

The Regression Model

Regression models are used in two segments of this study. First, in determining which of the weather factors have a significant effect on production and second, in predicting estimated yields in the simulation model.

The first step is to select the model and the variables which will be used in the study. The model must meet two criteria. First of all, they must be a realistic representation of apple production. Second, they must be usable in the simulation model. This second criterion is important because the freeze and rainfall variables in the systems that have weather altering technology must be stated in such a way that they can be modified in the simulation model.

The model and variables were selected in two different procedures. The first procedure was to manually select models and the variables in these models which theoretically and horticulturally seemed to realistically state the production process. These models are used to test the interaction among the variables and slope, and intercept shifters. Then, by eliminating the insignificant variables, a model is developed to depict a realistic production situation.

The second method used to develop the different regression models is a procedure which is included in the SAS computer system as a stepwise regression procedure. Five different stepwise techniques were used to develop the models, first specifying all variables which would be applicable to the study.

After all the models which are to be developed from the two procedures were prepared, a decision was made as to which models to use in the study. This decision will be made on the basis of three criteria, all of which should be met. The first creterion is the size of the Multiple Correlation Coefficient (R^2), the second is the mean square error, and the third is that the factor values determined in the regression model be consistent in the four weather-altering systems when modified in the simulation model.

Therefore, a regression model will be selected that has a relatively high R^2, a relatively low mean square error term, and one in which the factors can be used in the simulation model.

The Simulation Model

The next and most important part of the study was to develop a simulation model to estimate apple production and monetary returns under varying weather conditions, costs, and apple prices under the four systems. These four systems were mentioned in Chapter II as:

1. No weather altering technology,

2. A wind machine used for freeze protection,

3. An overhead sprinkler system used for bloom delay and for freeze protection, and

4. An overhead sprinkler system used for bloom delay, freeze protection, and for irrigation.

Inputs and Assumptions for the Simulation Model

There are four important inputs which are used by all four systems in the simulation model.

The first input into the simulation model is the yield response equation, which predicts expected yields for each of the forty-four years for each of the four systems. This model is first used with the weather as it occurs for system one and then is successively used for each of the remaining systems with the weather conditions as altered by the various weather-altering technologies.

The second input is the weather information used to derive the weather factors which are used in the above regression model for predicting yields.

The third input into the simulation model results from the chill unit model developed at Utah State University 1/. This

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1/ This model was described in Chapter II.

model predicts the date on which trees enter into and break out of a rest period.

The fourth input is a model for determining Growing Degree Hours (described in Chapter II). This model is used for two purposes in the simulation model. First, it is used to determine the dates when tree buds will reach each of the eight critical stages when freeze damage may occur. Second, the Growing Degree Hour Model is used to predict the dates on which the eight critical stages in bud development will occur when different weather altering systems are used to delay bud development and to predict the amount of freeze damage that will occur when the weather altering technologies are used to alter weather conditions during these critical stages.

The final input used in the simulation model for all four systems is the harvest cost. Harvest costs are the only costs considered because all other costs are assumed to be practically constant at yields above 300 bushels per acre; and, only slightly reduced at lower yields because of the need to keep the orchard in condition for future production. Harvest costs, which include picker compensation, ladder costs, picking bag costs, and bin costs as well as tractors, trailers, and picker supervision costs incurred in servicing the pickers, are estimated to amount to $1.26 per bushel. This cost will be assumed as applicable to each of the four systems.

Procedures and Assumptions Used in All Three Systems Using Weather-Altering Technologies

Some attempt is made in all three weather-altering technology systems to directly alter low temperatures to reduce freeze damage. The method used for altering low temperatures depended upon the system used. The following discussion depicts the inputs and assumptions made in the methods used to alter low temperatures.

Wind Machines

Wind machines use a tumbling action of mixing the warmer upper strata of air with the cooler lower strata air when an inversion is present. The effectiveness of the tumbling action in raising the lower level temperatures is dependent on the presence of an inversion, the difference in temperatures in the different strata, and the wind speeds in the lower strata. With wind speeds of 0-4 miles per hour, the wind machine may raise lower strata air temperature by from 2^o to 4^oF. If wind speeds are from 5 to 8 miles per hour, temperatures may be increased by from 0^o to 2^oF. If winds are above 8 miles per hour, the wind has already mixed up any inversion that might have been present and the wind machines are completely ineffective.
In the simulation model, the effectiveness of the wind machine is dependent upon the probability of different wind speeds being in effect.

Overhead Sprinklers

Overhead sprinklers use the natural process of energy release when water freezes to keep low temperatures from killing buds or bloom. This process is also affected by wind speeds. At higher wind speeds, evaporation rates increase, lowering the temperature of the buds or bloom. The effectiveness of the overhead sprinkler system in reducing bud kill is shown in Chapter II, Table 1. A problem with using the information in Table 1 as constraints in the simulation model is that the data on wind speed could not be broken down into small enough increments. Therefore, the 0-4 miles per hour, 5-8 miles per hour and over 8 miles per hour categories of wind speed had to be utilized. The effectiveness of the sprinkler systems with the different wind speeds were assumed to be the same as with the wind machines; 2^o to 4^oF., 0^o to 2^oF., and no effect for the three categories respectively. It was assumed in the simulation model that the overhead sprinkler systems would have different levels of freeze protection given certain probabilities of wind speed.

Because it was necessary to get some estimate of probability of wind speed for use in the simulation model, windspeed data was obtained from the airport at Weyers Cave, Virginia, the closest source of data to the production area. Hourly windspeed data was available from this source from 1961 to 1976. Probabilities of the occurrence of the three different categories of wind speed were calculated from these data for the months of March and April and for May 1-10. These probabilities are shown in Table 5.

The total probabilities for the occurrence of different wind speeds from Table 5 were used in the simulation model.

Table 5. Probability of Windspeeds, Total and by Months During Bloom Development and Early Fruiting

Windspeeds	March	April	May 1-10	Total
0-4	.523	.552	.5567	.540
5-8	.201	.190	.2369	.200
Over 8	.276	.258	.2064	.260

Source: Derived from the airport at Weyers Cave, Virginia.

Steps in the Procedure for Modifying Temperatures

The first step in the procedure to modify temperatures is to obtain from the GDH (Growing Degree Hours) model the dates on which the critical stages of bud development or early fruiting occurs. For the wind machine system this information is obtained directly from the GDH model. For the overhead sprinkler systems this information comes from modifications in the GDH model due to bloom delay (this will be explained later in this chapter). The simulation model must be run separately for each of the systems because of the probability that the critical periods being identical for all systems for all years is zero. The procedure from this point to the end of the modification steps is identical, so the following steps need be explained only once for both of the overhead sprinkler systems and the wind machine system.

It must be remembered that each step has to be repeated for each year and for each critical temperature.

The second step is to use the dates on which the different stages of bud development occurred and determine whether temperatures were low enough on that date to result in freeze damage; and, if so, what level of kill would result (10%, 50%, 90% kill of the bloom). This critical temperature is then used in the next step to determine what the modified temperature might be with the different systems and what the new level of kill might be.

The steps for determining the modified temperatures are as follows:

1. The critical temperature in step two above is sent through the modification procedure.

2. The low temperatures are sent, one at a time, through the modification procedure.

3. The modification variable is set equal to zero (MV = 0).

4. Steps five through seven are repeated 100 times.

5. A random number generator, RANDU (provided in the Scientific Subrountine Package supplied by the V.P.I. and S.U. Computing Center) is used to randomly select a number between 0 and 1.0 using a uniform distribution. The number generated is then used to determine the wind speed. If the number is less than 0.54, the windspeed is assumed to be between 0 and 4 miles per hour. If the random number is between 0.54 and 0.74, the wind speed is assumed to be between 5 and 8 miles per hour. If the random number was greater than 0.74 the wind speed is assumed to be greater than 8 miles per hour.

6. RANDU is used again to generate another number between 0 and 1.0. This number is used to set the level of effectiveness of the systems in modifying temperatures. Because the effectiveness of the systems have a range of from 1 1/9°C. (2°F.) to 2 2/9°C. (4°F.) for wind speeds under 4 miles per hour and a range from 0°C. (0°F.) to 1 1/9°C. (0°F.) for wind speeds from 5 to 8 miles per hour, this random number is used to generate the effective temperature within that range. This random number, for explanation purposes, will be referred to as the random range number (RRN).

7. There are three sub-steps to this step:

a. If the windspeed is predicted to be 4 miles per hour or less, the following equation is used:

$$MV = MV + 1\ 1/9C + RRN \qquad (32)$$

where:

MV = the accumulated effect of the overhead sprinklers or wind machine to increase temperatures during freeze
C = Centigrade Degrees
RRN = random range number

b. If the windspeed is predicted to be between 5 and 8 miles per hour, the following equation is used:

$$MV = MV + 1/9C + RRN \qquad (33)$$

c. If the windspeed is predicted to be greater than 8 miles per hour, there is no increment to MV because neither system is effective with greater than 8 miles per hour windspeed.

8. MV is divided by 100 to determine the average expected modification (AEM).

9. The AEM is added to the low temperature, the level of kill is determined, and then is stored until all of the low temperatures at the different critical stages in bud development go through the modification process. The highest level of kill is then used in the simulation model as a variable in the yield response equation.

A flow diagram of the steps used by the temperature modification procedure is shown in Figure 4.

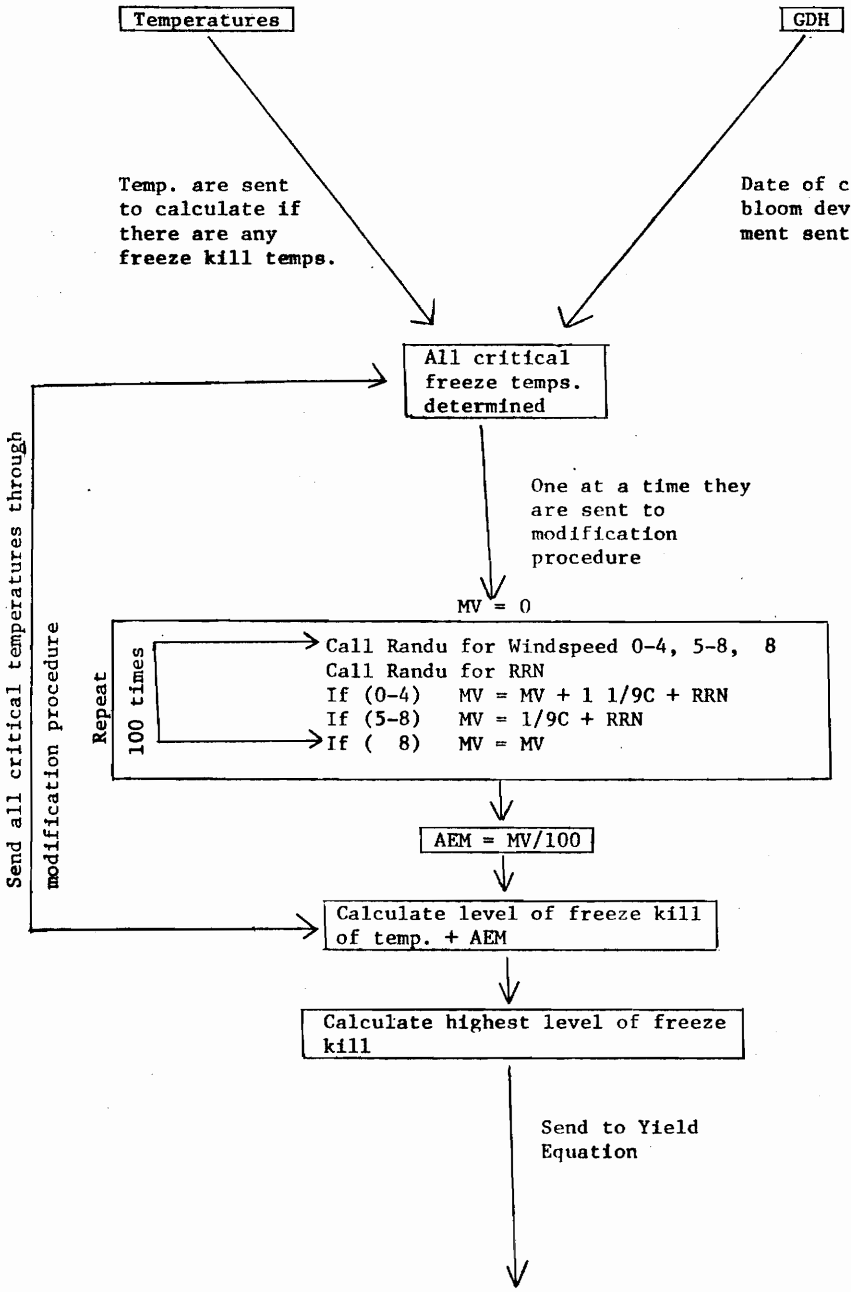

Figure 4. Flow Diagram for the Temperature Modification Procedure

Two further assumptions are needed in the procedure. First, the overhead sprinkler system is started for freeze control at 33^{0}F. and the wind machine is turned on at 32^{0}F. The early startup is to insure adequate time to initiate freeze protection. Second, the sprinkler system delivers 0.15 inches of water per area covered per hour and the water is evenly distributed over the area with a complete rotation of the sprinkler head occurring at least every minute.

The only other calculation made in this procedure is the number of hours that the system is used. The hours are calculated by determining the number of hours in which the effective temperature is below the temperature at which the system starts operating during the critical freeze periods.

Steps Used to Delay Bloom

Bloom delay can be accomplished by using an overhead sprinkler system. It is carried out to reduce the probability of freeze kill or to reduce its severity. This system of bloom delay is based on the evaporative cooling of the tree when water is sprayed on it at temperatures above 4.18^{0}C. (42^{0}F.) after the date that the tree breaks rest, which is judged to slow down speed of growth as measured by GDH units. The evaporation process decreases tree temperature from 4.4^{0}C. to 5.5^{0}C. (8^{0}F. to 10^{0}F.) [Georgia], which slows development (reduces GDH units by 4.4^{0} to 5.5^{0} per hour of sprinkling). For this step, the date that the tree breaks rest must be known so that the bloom delay process can start as soon as the trees break rest. The steps followed in the bloom delay procedure are as follows:

1. Bloom delay starts immediately after the trees break rest.

2. The sprinkler system is turned on during daylight hours when temperatures are above 4.18°C. (42°F.) during which time tree temperatures will be reduced 4.4°C. (8°F.). This is the lowest response recorded in the Utah and Georgia studies. The sprinkling system provided for 2½ minutes of spray alternating with 2½ minutes without spray, which would deliver approximately 0.07 acre inches of water per hour.

3. The resultant decrease in temperature decreases the GDH units, delaying bloom and decreasing the probability of freeze damage or reducing the level of kill.

4. The hours of use of the sprinkler system to delay bloom is calculated.

Three further assumptions are made in this procedure. They are:

1. There is no need to use bloom delay if rest is broken after March 15 because in most years, subsequent bud development will not be so fast as to jeopardize the buds.

2. No bloom delay sprays will be utilized after May 1. Again, because buds have been delayed sufficiently.

3. It is assumed that delay of bloom to this extent will have no effect on production, as none of the studies cited have mentioned production decrease as a side effect.

Steps Used in Irrigation

Irrigation is provided for only in the fourth system even though the third system is identical as far as capital investment and physical set-up is concerned. It was considered important to the study to be able to compare results of the wind machine and sprinkler system in freeze control alone.

The need for irrigation is best detected by using soil moisture sensors. However, this was impossible in this simulation model because the sensors were not installed in these orchards. Instead, the regression model was used to determine which rainfall factors were significant in affecting production and in determining what level of rainfall during that period would maximize yield. In a given year, if in the critical period rainfall is less than that optimum level, irrigation would be used. For example:

Suppose the regression model took the form of:

$$Y = -50 + .01XE + 67.2X2 - 6.1X2^2 \qquad (34)$$

where:

Y = yield
XE = Solar Energy
X^2 = July Rainfall

The optimal level of rainfall for maximizing production would be:

where: $$\frac{\partial Y}{\partial X^2} = 67.2 - 12.2X2 = 0 \qquad (35)$$

$$X^2 = \frac{-67.2}{12.2} \qquad (36)$$

$$X^2 = 5.5 \qquad (37)$$

and the second derivative is -12.2, which shows that 5.5 inches is the level of July rainfall which maximizes Y.

If in one year the rainfall in July is 2.2 inches, the simulation model would add 3.3 inches in irrigation water. Since the water is delivered at the rate of 0.15 acre-inches per hour, the simulation model would show that for system number four, the irrigation system would be used 22 hours in that year. Also, if there is no maximum point obtained for a certain model, the maximum level of irrigation will be the highest amount of rainfall observed in the data.

Investment and Operating Costs for Wind Machines

The wind machine on which costs in this study are based is typical of most of those used in Virginia and elsewhere in the United States. It has an 88 horsepower, 600 RPM motor mounted on a 35-foot platform with a 15-foot, 4-inch airplane propeller on the motor, which provides the tumbling action required to protect a ten acre area. Information relative to this particular wind machine was obtained from the Winchester Equipment Company, Winchester, Virginia and was based on 1976 prices. The unit sells for $7,733 and uses 7.5 gallons of gasoline per hour. Using these figures and adding 4% of new cost for repairs and 1% of new costs to cover taxes and insurance and assuming a 50 cent per gallon price for gasoline, the costs per acre are:

Investment = $773.30
Fixed Annual Cost for Repairs, Taxes, and Insurance = $38.67
Gasoline and Lubricant Cost per hour $0.38

These values were used as user's cost information in the simulation model.

Costs and Inputs Into the Overhead Sprinkling System

The overhead sprinkler system on which costs in this study are based is a system typical of those used with a variety of fruits and vegetables. It would be suitable for use with most dwarf and semi-dwarf orchards, but probably not suitable for mature seedling orchards because of mature tree height. Very few seedling orchards have been set in the past 15 years in Virginia.

There are two major components to the overhead sprinkler system-the sprinkler network and a source of water. The sprinkler network consists of pumps, pipes, and sprinkler heads. Using 40 acres as a basic size of orchard and assuming 100 feet elevation of the orchard above the water source, the investment in the sprinkler system would amount to $32,000. The investment estimate is taken from an unpublished draft of an article being prepared at Washington State University (Jim Ballard). The figure represents 1975 costs. The pump needed for this system would require a 300 horsepower motor which would consume 22 gallons of gasoline per hour. The costs per acre used in the simulation model for this system are:

Investment = $800.00
Annual Repair, Taxes and Insurance = $40.00
Gasoline and Lubrication (per hour) = $0.27

Water supply costs are dependent upon individual sites, defying standardization. Any one of six sources of water might be available at a given site.

1. Rivers
2. Natural lakes
3. Small streams
4. Small streams that are dammed
5. Ponds fed by springs
6. Ponds fed by run-off

For most sites, ponds fed by run-off is the prevalent alternative. Therefore, this source will be used in the simulation model. Because of variations in rainfall, irrigation requirements, evaporation, watershed area and pond leakage, no generalization on pond size and cost can be made. For this study, a given size and type of pond will be selected. People using different sources or sizes of ponds must adjust their costs to their own situation.

The pond assumed in this study will have a watershed of 150 acres with trees and medium sod cover. In a given year, there will be at least seven inches cumulative rainfall in the months of February, March, and April and a total of four inches in May and June. If these assumptions are met, there will be sufficient water available for freeze protection, irrigation, and 250 hours of spring bloom delay with a pond holding 12 acre feet of water. This can be shown by taking the most constraining use of water, bloom delay, as an example. Bloom delay might require as much as 250 hours sprinkler system use in a 55 day period (not typical). This would require 17.5 inches of water per acre (250 hours x 0.07 inches per hour). For 40 acres, 700 acre-inches would be required. If the orchard is a part of the watershed and 25% of the water applied drains back into the pond, 525 acre-inches are required. If the pond is full when the bloom delay process is initiated (probably true in most cases since no use would be made of the water in the fall and winter months up to that time), the amount of water that would need to be supplied by run-off from the watershed would need to be 381 acre-inches in the 55 day period. Using an equation for refill by ponds (Ponds for Water Supply and Recreation, Agricultural Handbook No. 387) with the type of cover assumed above, the 150 acre watershed with seven inches of rainfall would supply 543 acre-inches (150 acres x 3.62), which is more than adequate to fulfill the water requirements for bloom delay. When bloom delay is used, the probability of needing water for freeze control decreases. For the 44 years used in this study, in only six years was the overhead sprinkler system estimated to be needed for frost control when bloom delay was used. The longest period was eight hours which would use only 48 acre-inches of water. The probability of that much water being in the pond when it would be needed is very likely. The rainfall in May and June should be more than adequate to provide a water supply for irrigation purposes, which at most would require 150 acre-inches of water.

Cost information, which is highly variable depending upon site, was supplied by the Agricultural Engineering Department at

V.P.I. and S.U. It was estimated that it would cost $300 per acre-foot, or $3,600 for the 12 acre-feet, and average investment of $90 per acre of orchard.

The costs for the sprinkler system used in the simulation model including water sources were:

Investment per acre	= $890.00
Annual Costs of Repairs, Taxes, and Insurance	= $40.00
Gasoline and Lubrication per hour	= $0.27

There was an added constraint that no more than 250 hours of bloom delay could be used in any season.

Operation of the Simulation Model

The simulation model contains two major sections. In the first section, the yields for each of the four systems for each of the 44 years in which weather data are available are estimated. The second section is used to calculate the added returns to the producer from orchards in which weather-altering technology is used. The following pages explain how yields are determined for each of the systems for one year.

Steps in Determining Yields From an Orchard With No Weather-Altering Technology (System One)

1. Analyze weather data to determine the regression coefficients for significant rainfall variables.

2. Use temperatures during the different seasons in the chill unit model to determine the dates on which trees enter and break rest.

3. The dates when trees break rest are entered into the GDH model to: (1) calculate the eight critical stages in bud development and (2) to calculate the energy units for the growing season.

4. The dates for the eight critical stages in bud development and the temperatures on those dates are used to calculate what level of kill, if any, was caused due to freeze in that year.

5. The yield estimation model uses the critical rainfall variables, GDH units, and freeze kill levels in estimating yields for that season.

6. The expected yields are used to determine the harvest costs. Both the yields and harvest costs over all seasons are used in the second part of the simulation model.

A flow diagram of the steps used by System One is shown in Figure 5.

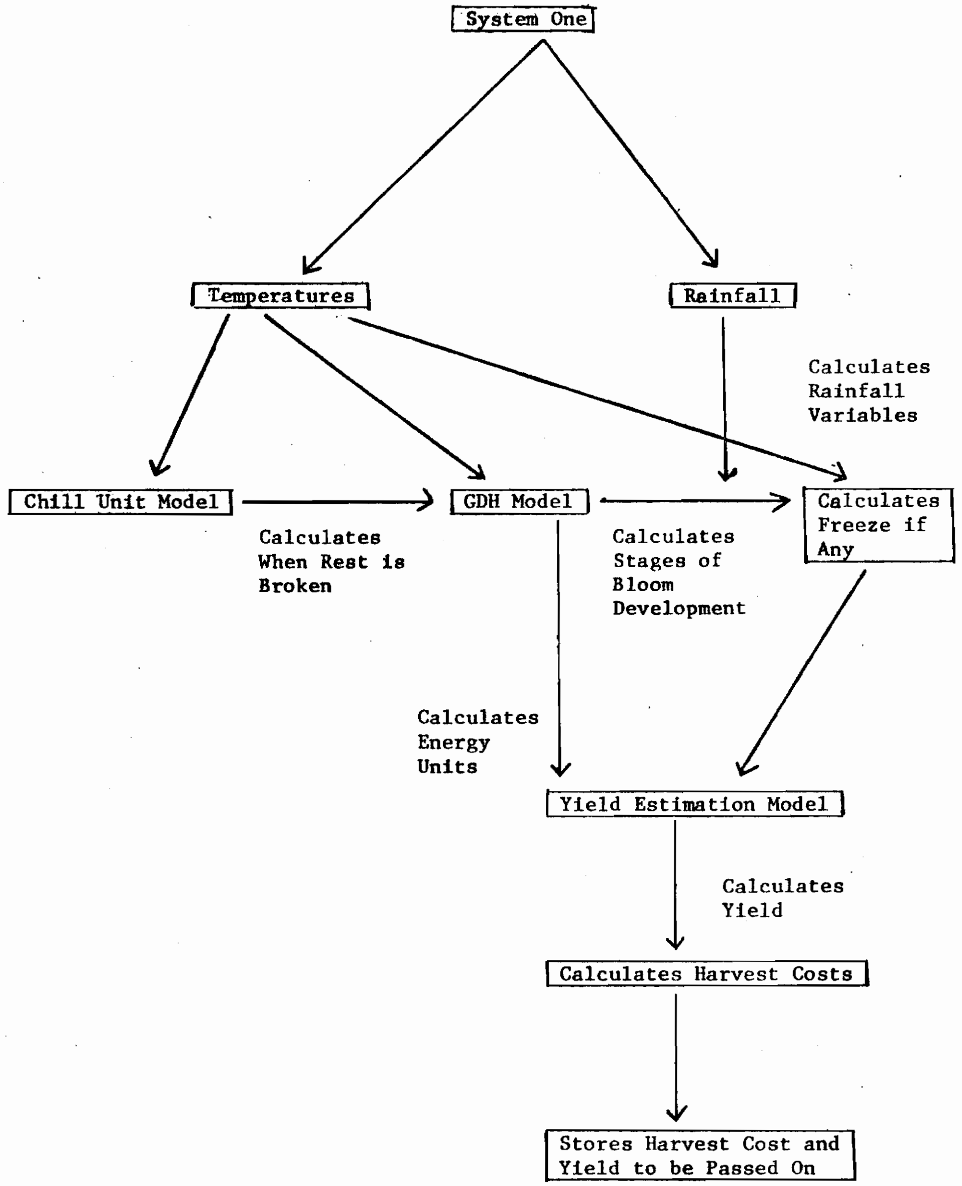

Figure 5. Flow Diagram for System One

Steps in Determining Yields From an Orchard Using a Wind Machine for Freeze Control
(System Two)

1. Same as Step 1, System One

2. Same as Step 2, System One

3. Same as Step 3, System One

4. Same as Step 4, System One

5. The information from Step 4 is used in the weather modification model to determine to what extent freeze kill can be modified. The hours of wind machine use needed to make these modifications was recorded.

6. Rainfall variables, GDH units, and the modified freeze kill variables from Step 5 are used in the yield estimation model to predict yield.

7. The yield estimates from Step 6 are used to estimate harvest costs, and these are added to wind machine costs for use in the second section of the simulation model.

A flow diagram of the steps used in System Two is shown in Figure 6.

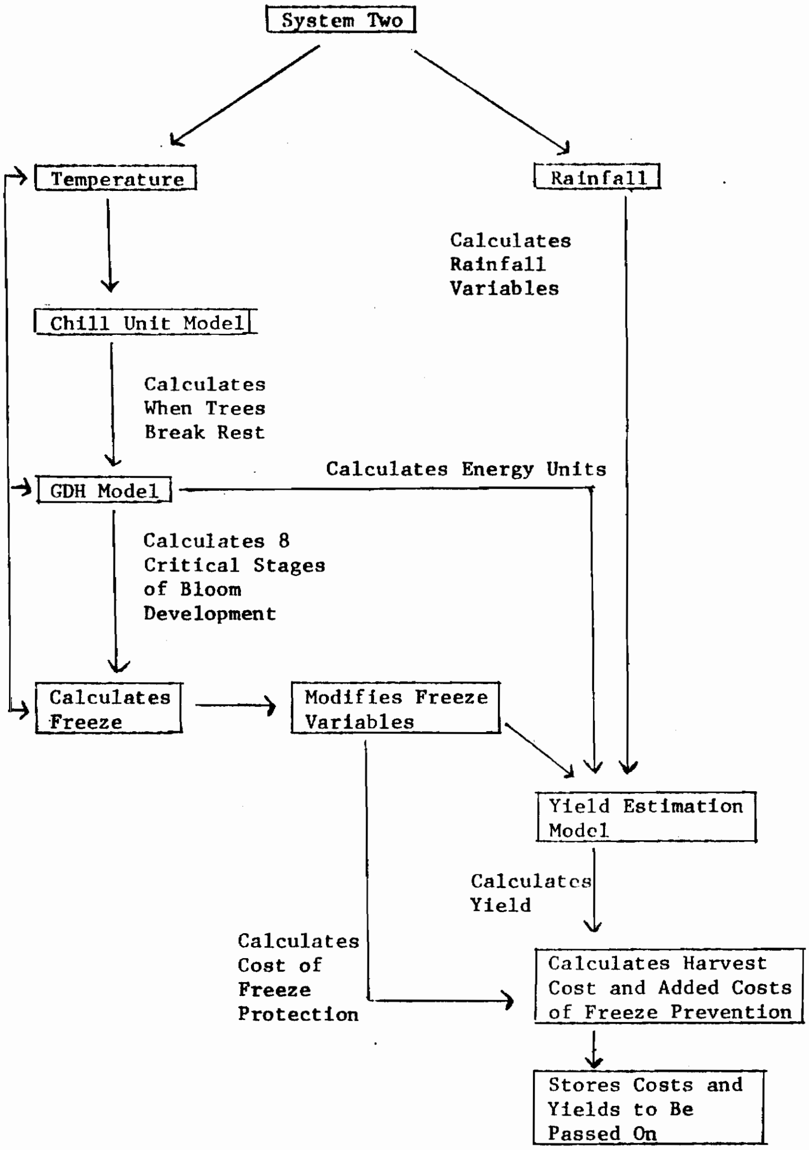

Figure 6. Flow Diagram for System Two

Steps in Determining Yields From an Orchard Using an Overhead Sprinkler System for Bloom Delay and Freeze Control Only

(System Three)

1. Same as Step 1, System One

2. Same as Step 2, System One

3. Uses the overhead sprinkler system for bloom delay, altering the temperatures used in the GDH model from which the dates for the eight critical stages of bud development are obtained. This stage also determines the costs for using the overhead sprinkler system for bloom delay.

4. The modified dates of the eight critical stages of bud development and the temperatures on those dates are used to determine freeze kill, if any, and the level of freeze kill in that year.

5. The freeze modification model takes the information from Step 4 and determines how much modification can be made in the freeze kill and calculates the hours of use of the overhead sprinkler required to bring about the modification.

6. The rainfall variables, GDH units, and the freeze levels from Step 5 are used in the yield model to predict yields.

7. The predicted yields in Step 6 are used to estimate harvest costs. These costs are added to the sprinkler operation costs. Both yields and costs are stored for use in the second section of the simulation model.

Steps Used to Determine Yields for an Apple Orchard Using an Overhead Sprinkler System for Freeze Control and Irrigation

(System Four)

The only difference between System Four and System Three is that in Step 1, System Four calculates the amount of water that is needed to optimize production in respect to rainfall. Then, in years when rainfall is less than optimal, irrigation is used to add water. Step 1 then calculates the cost of the sprinkler system to provide this water and stores this cost for use in Step 7, where it is added to the other costs. The new rainfall variable, modified by irrigation, is used in the yield estimation model in Step 6.

A flow diagram of the steps used by Systems Three and Four are shown in Figure 7.

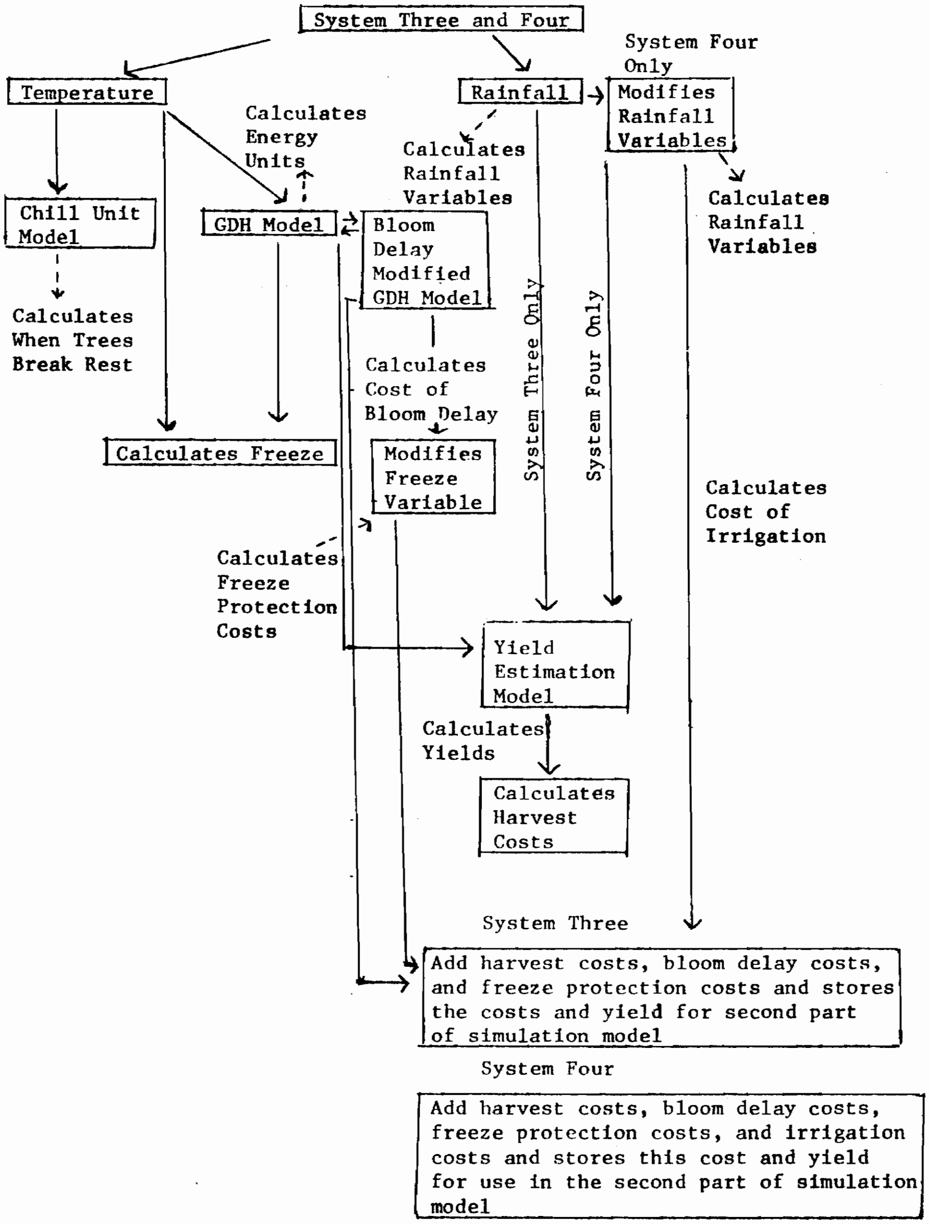

Figure 7. Flow Diagram for Systems Three and Four

The Decision Framework of The Simulation Model

One important aspect of a simulation model is that it is very versatile. In this study, temperature and rainfall patterns are of primary concern. In the first section of the model, the weather conditions that occurred during a 44-year period are used to estimate yields. Those yields are used in this section of the simulation model in different combinations of 20-year periods to determine for which patterns of weather the weather-altering technologies are economically feasible. The 20-year periods were selected for the analysis at the suggestion of the Agricultural Engineering department at V.P.I. and S.U. because a piece of machinery, if not worn out, would likely be obsolete at the end of 20 years. Seven different 20-year weather patterns were used in this analysis:

1. The 20 seasons with the lowest estimated yields from System One.
2. The 20 seasons with the highest estimated yields from System One.
3. The first through the twentieth seasons.
4. The twenty-first through the fortieth seasons.
5. The fourth through the twenty-third seasons.
6. The twenty-fourth through the forty-fourth seasons.
7. The fourteenth through the thirty-third seasons.

The worst and best twenty years of yield were selected to show the range of income that could occur. The worst twenty years of production, using System One's yields, shows the highest expected returns for the adaptable technology. The best twenty years, also using System One's yields, shows the lowest expected returns for the adaptable technology. The other five weather patterns were selected to show natural patterns of twenty seasons. These five weather patterns show the return that could have occurred during the past 44 years.

For each system, given a price for apples, a return is calculated for each of the 20 seasons. These returns are discounted back to their present value and the investments in Systems Two, Three, and Four are subtracted from the discounted value. The equation used in the above procedure is the standard capitalization formula:

$$PV_t = \frac{R_1 - C_1}{(1 + r)^1} + \frac{R_2 - C_2}{(1 + r)^2} \ldots + \frac{R_{20} - C_{20}}{(1 - r)^{20}} - I \qquad (38)$$

where:

PV_t = present value
I = Investment costs
r = Discount rate (assumed as 10%)
R = Annual returns
C = Annual costs (Systems One, Two, Three, and Four)

Present Value (PV) is calculated for all four systems. The amount that each weather-altering technology system added to the present value of the orchard is determined by subtracting the present value of System One from the present value of Systems Two, Three, and Four. The added present value for the systems with weather-altering technology would be:

Present value of the wind machine system = $PV_2 - PV_1$

Present value of the overhead sprinkler system used for bloom delay and frost control only = $PV_3 - PV_1$

Present value of the overhead sprinkler system used for bloom delay, freeze protection and irrigation = $PV_4 - PV_1$

In Chapter III, it was shown that the system with the highest PV is the best criterion for selecting the system to use. However, firms sometimes like to use other criteria as well. Other criteria calculated in this model will be the coefficient of variation in income, the internal rate of return, the expected average income, and the expected payback period.

Coefficient of Variation

The coefficient of variation is used to show the degree of disparity of income between years in each 20-year period. The coefficient of variation is calculated for each system by first calculating the means and standard deviations of the incomes minus variable costs and dividing the mean net income into the standard deviations.

$$\text{C of V} = \frac{\left[\sum_{i=1}^{20} (R_i - \bar{R})^2\right]^{1/2}}{\bar{X}} \qquad (39)$$

where:

C of V = coefficient of variation
R = annual returns minus costs

The Internal Rate of Return

The internal rate of return is used to give an estimate of how the system compares with other investments in earnings. The internal rate of return is calculated by an iterative process where progressively higher discount rates are used until the rate is found that sets the discounted returns minus costs of the weather-altering technology equal to its investment cost. The steps in finding the internal rates of return are:

1. Subtract annual returns minus the costs for System One from the returns minus the costs for each of the three weather-altering systems for each of the 20 years.

2. Set the added returns for each system equal to their investments.

3. Determine whether there is a positive or negative internal rate of return. The sign can be determined by use of a zero discount rate using the following equation:

$$X = \frac{R}{(1+r)^1} + \frac{R}{(1+r)^2} \cdots + \frac{R}{(1+r)^{20}} \qquad (40)$$

where:

X = discounted value
R = Returns-Costs for that season
r = Internal rate of return

If X is smaller than the investment costs where r is equal to zero, there is a negative internal rate of return and the iterative process is started in a negative direction and continued until the discounted present value equals the investment. If X is greater than the investment value when r = 0, the internal rate of return is positive. The iterative process is started in a positive direction and continued until the discounted present value equals the investment cost. The internal rate of return is equal to the discount rate that satisfies the following equation:

$$I = \frac{R}{(1+r)}1 + \frac{R}{(1+r)}2 + \dots \frac{R}{(1+r)}20 \qquad (41)$$

where:

I = Investment cost
R = Returns-variable cost for that year
r = Discount rate

The internal rates of return are calculated for Systems Two, Three, and Four for each of the seven 20-year periods.

Average Added Annual Net Income From the Investment

Average added annual net income from the investment measures the equivalent added annual income that is generated by the investment in the system. It is calculated by using the discounted present value of the investment in an annuity formula to determine the annual income that would be needed over the 20-year period to equal the present value of the investment:

$$PV_{\imath}\left[\frac{1}{\frac{(1+r)^{20} - 1}{r(1-r)^{20}}}\right] = \text{Expected Equivalent Annual Income From the Investment} \qquad (42)$$

where:

PV = Present Value
r = discount rate of 10 percent
ı = Systems Two, Three, and Four

Expected Payback Period

Expected payback period is the length of time it would take to pay back the investment in the system from the added returns generated by the system. It shows the firm what the minimum time would be for capital to be tied up in the system. The expected payback period is calculated by:

1. Calculating the added annual net income due to the investment.

2. Dividing the added annual net income into the investment in the system. The formula for the expected payback period is:

$$EPP_{\iota} = \frac{I_{\iota}}{\left[PV_{\iota} \frac{(1+r)^{20}-1}{r(1\ r)^{20}} \right]} \qquad (43)$$

where:

EPP_{ι} = Expected Payback Period
I = Investment Cost for System
PV = Discounted Present Value of Investment
r = Discount rate of 10 percent
ι = Systems Two, Three, and Four

CHAPTER V

EMPIRICAL ANALYSIS

Models to predict yield levels were estimated using regression analysis. Estimated yield models were then used in the simulation model.

The Regression Model

Regression models are used to determine which variables have a significant effect on production and in the simulation to predict yields.

The Statistical Analysis System (SAS) stepwise procedure, described earlier, is used to determine which of the available variables had a significant effect on production. The following variables affecting production were identified. These included:

1. Three dummy variables denoting three levels of bloom kill. Each of these variables acquired a value of 1 when they occurred and a value of 0 when they did not occur.

2. Growing Degree Hour units (GDH) for the entire growing season were used to represent solar energy, an important factor in the photosynthetic process.

3. Accumulative rainfall in each of the critical production months, May through September.

4. Hours during the period of full bloom when temperatures and moisture conditions were conducive to bee activity.

Other variables were non-significant at the 10 percent level in the regression model. This does not mean that the other variables do not affect production, it only infers that they were never a constraint on the production process.

The model selected as best in explaining the variation in yield of apples was:

$$\underset{(-1.71)}{Y = -651.07} + \underset{(2.81)^{*}}{.01556XE} + \underset{(3.12)^{**}}{67.93RJA} - \underset{(-3.69)^{**}}{5.25RJAS}$$

$$-\underset{(-3.31)^{**}}{116.32D_1} - \underset{(-5.48)^{**}}{206.5D_2} - \underset{(-6.38)^{**}}{298.32D_3}$$

where:

XE = Growing Degree Hour Units from Rest Break to September 30.
RJA = Rainfall During July and August (inches)
$RJAS$ = Rainfall During July and August Squared (inches^2)
D_1 = 10% freeze kill
D_2 = 50% freeze kill
D_3 = 90% freeze kill
* = Significant to the 2% level
** = Significant to the 1% level

Numbers in parentheses are the "t" statistic.

The multiple Regression Coefficient (R^2) was .813 and the model mean square error term was 3574.47 out of a total mean square of 43,984.49.

These variables explain 81 percent of the variance in production as well as point out the critical factors affecting production. First, rainfall in July and August is the only period in production when there was not enough rainfall to maintain a good yield, But, too much rainfall resulted in a decrease in sunlight which interfered with the photosynthetic process, which, in turn, decreased yields. Disease problems (fungus) are augmented by high moisture conditions which, in turn, limit production. These two phenomenon likely account for the negative sign and significance of the RJAS variable.

XE represents solar energy as measured by degree hours above 40^{o}F. from rest break to September 30. It has a positive relationship with production through stimulation of the photosynthetic process.

The first two dummy variables, D_1 and D_2, which represent 10 percent and 50 percent freeze kill respectively, have significant negative signs. This indicates that freeze kill even at these relatively low levels is likely to reduce yield as the kill may be total on the area of the tree or orchard affected. When there is no freeze kill and good pollinization, the orchard manager must chemically remove or hand thin from 30% to 40% of the apples set to allow the tree to produce sufficient nutrients to develop apples of adequate size. [Batjer and Billingsley]. This thinning process is spread evenly throughout the bearing surfaces of the trees. But, when a freeze kill occurs even at the 10% level, the damage is likely to be confined to certain parts of the trees or the orchard, causing total kill in those locations while the non-affected areas of the tree or orchard may still need thinning. The same can be said for the 50% level of kill.

The third dummy variable, D_3, represents 90% freeze kill, which is highly significant, with a negative sign. There are so many blooms killed that the apples from those that are left are likely to be rough and oversized because there are more than enough nutrients manufactured by the tree to produce the crop. Even with the 90% kill, there may be some bearing areas with more apples set than can be produced to advantage.

Of the variables that were found to be significantly associated with yield, only GDH units could not be altered by weather-altering technology. All of the other variables may be modified in the simulation model. The values of the significant variables used in the regression model are shown in Appendix C, Table 1.

Effectiveness of the Chill Unit Model and the Growing Degree Model

The only test of the effectiveness of the Chill Unit Model in predicting when trees enter and break rest and the effectiveness of the Growing Degree Hour Model in predicting the eight critical stages of bud development was to compare the predicted full bloom data with the observed full bloom dates. The only observed full bloom data available was recorded at the V.P.I. and S.U. Winchester Fruit Research Laboratory in Winchester, Virginia. In a linear regression of the predicted values on the observed values, R^2 was .79 and the F statistic was 154.65. These are acceptable results for two reasons. First, it is very hard to estimate when full bloom occurs using the eye-ball approach used at the Winchester laboratory. Second, the fruit laboratory is located in downtown Winchester and is not typical of the orchard sites represented in the study. The results from Utah and Georgia and the reasonably good fit in this test indicates that the models have worked with relative success and are acceptable to use in this simulation model. The observed and predicted dates of full bloom for the 44 years used in the simulation model are shown in Appendix C, Table 2.

Calculations Made By Models Within the Simulation Model

Calculations of Freeze and Energy Variables for the Simulation Model

The first calculations made in the simulation model are to determine when trees enter and break rest. These calculations are used for all four systems and are calculated by the Chill Unit Model. The predicted dates for entering and breaking rest for the forty-four years of available weather data are shown in Appendix C, Table 3.

The dates of rest completion were then utilized in the GDH model.

The GDH model was then used to calculate the number of GDH units in a season and the dates of the eight critical stages of bloom development. The GDH units for the growing seasons are shown in Appendix C, Table 4, and the number of days into the year the eight critical periods of bloom development occurred are shown in Appendix C, Table 5.

Then, these dates of the eight stages of bloom development were used to calculate the hours and level of freeze kill for the given seasonal temperatures. The level of freeze kill and time duration are shown in Appendix C, Table 6.

Next, the freeze variables are calculated for the wind machine. This section takes the calculations from Appendix C, Table 6, modifies them by the effectiveness of the wind machine, and calculates the freeze variables for that system. This section also calculates the hours that a wind machine is being used for freeze control. Appendix C, Table 7 shows how much the temperatures were modified by the wind machine and the expected hours that the wind machine is to be operated.

After calculating the freeze variables for wind machines, the next step is to calculate the freeze variables for the overhead sprinkler system. The first step in the calculation of freeze variables is to use the bloom delay model and growing degree hour model to determine how many days the blooms were delayed, and the dates of the eight stages of bloom development modified by bloom delay. This section also calculates the number of hours that the overhead sprinkler system was used for bloom delay. Appendix C, Table 8, shows the days into the year when the eight stages of bloom development occur. Appendix C, Table 9, will show the number of days that bloom was delayed compared to not using bloom delay, the expected date of full bloom, and the number of hours the overhead sprinkler system for bloom delay was used for each season.

Taken from Appendix C, Table 9, the average full bloom delay for seasons where bloom delay was practiced was 9.25 days and the range was from 4 to 14 days. This average full bloom delay of 9.25 days was less than the 17 and 14 days, respectively, shown in the Utah and Georgia studies. This only points out that the overhead sprinkler system is probably capable of delaying full bloom longer than is reported in this study. And, it also substantiates the using of these results in the study as they are very easily within the realm of reality for bloom delay in Virginia apple orchards.

Using the dates for the different stages of bloom development resulting from using bloom delay, the critical freeze, duration, and level of kill were calculated. The year, level, and duration of freezes are shown in Appendix C, Table 17.

Using Appendix C, Table 10, which shows the amount of freeze kill that occurred when overhead sprinklers were used for bloom delay, and Appendix C, Table 6, when bloom delay was not available, it can easily be seen that the number of freezes are decreased. When bloom delay was used, there were only six seasons out of 44 with freeze kills, while systems not using bloom delay had 20 seasons out of 44 with some level of freeze kill.

Since the overhead sprinkler system also has the capability of being used directly for freeze control, the next calculation made is the modification of those six seasons of freeze kill of bloom by the overhead sprinkler system. This is accomplished by using the effectiveness of the overhead sprinkler system, the freeze kill temperatures and the critical temperature for each stage of bloom and level of kill to calculate the new freeze variables.

This section is also used to calculate the number of hours the overhead sprinkler systems are used when they are used directly for freeze control. Appendix C, Table 11 shows the modification of the freeze kill of blooms and Appendix C, Table 12, shows the hours that overhead sprinkler systems are used directly for freeze control.

From Appendix C, Table 11, the results of using an overhead sprinkler system for freeze control using both bloom delay and direct freeze controls show that in only two seasons out of forty-four is there any freeze damage to apples. This compares with the effectiveness of wind machines taken from Appendix C, Table 7, where in 12 years out of 44, there was some level of freeze damage. Appendix C, Table 12 shows the number of hours the overhead sprinkler system was used in direct freeze control in the different seasons.

The reason that there are some seasons in Appendix C, Table 11 where there are no critical temperatures which cause freeze damage and, yet there are hours of direct freeze protection by the overhead sprinkler system is that the system is turned on at .55^{o}C. (33^{o}F.). The justification for turning the system on at that temperature is to maintain the buds at -.27^{o}C. (31.5^{o}F.). If, for example, the temperature drops below the critical temperature of freeze kill, it is almost impossible at that point to spray enough water on the trees to bring the bud temperature back up above the killing temperature. Therefore, management starts the systems at around .55^{o}C. (33^{o}F.) to insure that the temperature is above the critical freeze kill temperature and that there has been enough water sprayed to maintain that temperature. This procedure of turning the system on at .55°C. (33°F.) is because the cost of running the system is minimal compared to the loss of revenue resulting from freeze damage.

These freeze variables for the four systems and the energy variables are then passed to the yield response equation. They are then used, along with the rainfall variables, which are calculated next, to estimate the expected yield.

Calculation of Rainfall Variables

Rainfall variables for July and August are calculated directly from the weather information gathered at the Woodstock weather station for the first three types of orchard systems. This rainfall information, which is used in the yield response equation, is shown in Appendix C, Table 13.

The remaining system, System Four, also uses the overhead sprinkler system for irrigation purposes. This section then is used to calculate the amount of irrigation water which is sprayed onto the orchard in July and August, and to calculate the hours it takes to spray the needed amount of water onto the orchard. To calculate the amount of irrigation needed, the first step is to determine the amount of water needed to maximize yield (for the yield response model, the level of rainfall which maximized production would be 6.5 inches for July and August). In every season where rainfall in July and August fell under 6.5 inches, irrigation water was added to bring the total of rainfall plus irrigation water up to 6.5 inches. Appendix C, Table 14 shows the seasons when irrigation water was needed to supplement rainfall, the amount of irrigation water that was added, and the hours the overhead sprinkler system was used for irrigation purposes.

Irrigation was added in thirteen out of forty-four years. This indicates that rainfall in July and August has been less than desired in 30 percent of the years.

After the amount of irrigation water applied by System Four has been calculated, all of the rainfall variables are recalculated for each of the orchard systems and are then ready to be used in the yield response equation.

Calculating Expected Yields

Three sets of inputs are needed in each of the four systems to determine expected yields: (1) the energy units (GDH Units), (2) the freeze kill level, and (3) the July and August rainfall.

The GDH units (energy units), calculated by the GDH model, are the same for all four systems.

The freeze kill levels were calculated and modified in three different ways to determine their level for the yield response equation. System One uses the freeze kill levels directly as they are calculated from the freeze kill model. System Two takes the same freeze kill levels as used in System One and modifies them. System Three and System Four obtain their freeze kill levels by modifying the GDH units in System One using bloom delay and then further modifying the kill levels by freeze control procedures.

The rainfall variables are all derived directly from weather information except in System Four, which uses this weather information and supplements it by using irrigation when appropriate.

These variables for the four systems are then fed into the yield response equation to predict yields. The yield response equation is the same as the regression model explained earlier in this chapter. Table 6 shows the expected yields for the four systems.

Table 6 shows that increases in production from 13 percent to 20 percent were obtained in the orchards that were protected from freeze kill over the production in orchards without freeze protection. To determine whether these increases are sufficient to be economically feasible, the yields in Table 6 must be used in the second part of the simulation model to develop the economic criteria upon which decisions are based.

Calculating the Values of The Decision Criteria

Inputs and Cost Used in Calculating The Values of the Decision Criteria

The major input into this section of the model is the expected yields calculated in the last section. Yields are used for two purposes: (1) to calculate gross revenue, and (2) to calculate harvest costs for each system.

The costs used in this section for each system are:

1. For System One, there are no more additional costs.
2. For System Two, there are the additional costs of operating

Table 6. Expected Yields Determined for the Four Systems

Season	System One 1/	System Two 2/	System Three 3/	System Four 4/	Season	System One 1/	System Two 2/	System Three 3/	System Four 4/
1	270.011	496.731	496.731	496.731	23	494.311	569.327	610.258	672.362
2	567.082	567.078	567.078	567.078	24	619.261	619.258	619.258	619.258
3	195.597	419.334	419.334	419.334	25	247.818	465.590	546.137	546.137
4	384.658	519.571	519.571	519.571	26	430.895	503.847	547.215	547.215
5	557.057	557.055	557.055	558.156	27	387.807	513.770	594.316	648.719
6	404.483	465.044	520.801	558.766	28	342.982	342.980	342.980	342.980
7	470.856	470.855	470.855	470.855	29	454.599	592.493	661.105	665.254
8	389.085	535.930	595.594	595.594	30	487.770	550.397	550.397	550.397
9	225.622	327.717	432.129	432.129	31	267.020	487.776	565.340	569.031
10	465.013	465.012	465.012	465.012	32	589.570	589.570	589.570	589.570
11	567.214	567.211	567.211	567.211	33	359.639	506.484	566.148	597.637
12	307.964	307.961	307.961	-307.961	34	489.291	489.289	489.289	576.219
13	255.117	457.972	553.434	611.621	35	602.901	602.898	602.898	602.898
14	577.534	577.531	577.531	626.660	36	350.156	470.151	470.151	496.471
15	407.988	468.548	468.548	468.548	37	498.478	498.477	498.477	498.477
16	566.472	566.469	566.469	566.469	38	615.042	615.039	615.039	615.039
17	586.032	586.031	586.031	588.973	39	531.518	531.516	531.516	531.516
18	586.908	589.906	589.906	589.906	40	507.094	507.094	507.094	507.094
19	567.770	567.770	567.770	567.770	41	537.011	537.008	537.008	537.008
20	419.545	492.496	535.863	552.855	42	416.905	473.334	533.223	533.223
21	572.433	572.430	572.430	572.430	43	430.426	589.202	636.934	636.934
22	592.926	592.926	592.926	592.926	44	543.523	543.520	543.520	559.215

Means	System One-457.825	System Two-517.512	System Three-538.373	System Four-548.617
% Increase		System Two-13%	System Three-17.6%	System Four-20%

1/ System One had no weather altering technology.
2/ System Two used a wind machine for freeze protection.
3/ System Three used an overhead sprinkler system for bloom delay and freeze control.
4/ System Four used an overhead sprinkler system for bloom delay, freeze control, and irrigation.

Source: Calculation from yield response equation the wind machine, plus the investment and annual costs.

3. For System Three, there are the added costs of using the overhead sprinkler systems for bloom delay and direct freeze protection, plus the investment and annual costs.

4. For System Four, there are the added costs of using the overhead sprinkler systems for bloom delay, direct freeze protection and irrigation, plus investment and annual costs.

5. For all systems, two levels of apple prices will be used, one at a time, to generate expected revenue. These two levels of prices are used to demonstrate the sensitivity of the decision criteria to price change. The prices used were \$3.00 per bushel and \$3.50 per bushel. Three dollars per bushel is approximately the average farm price during the 1973-1975 crop season in Virginia as reported by the Virginia Crop Reporting Service, while the 1973-1974 farm price was slightly in excess of \$3.50 per bushel.

The above information is used to calculate the present value, the internal rate of return, the expected annual income, and the expected payback period for Systems Two, Three, and Four. It is also used to calculate the coefficient of variation in income for each of the four systems. These five decision criteria are then calculated for the seven different 20 season periods of yield patterns. Tables 7 and 8, show the values for each of the decision criteria under the seven yield patterns and two different prices for apples.

Table 7, which uses \$3.00 per bushel for the price of apples, shows System Four with the highest average present value. System

Table 7. Values of the Decision Criteria Using Three Dollars Per Bushel Prices and Added Income Received From Weather-Altering Technology

	Seasons of Production							Average of All Seven Patterns
Item	Worst Twenty 5/	Best Twenty 6/	First Twenty	Second Twenty	4th-23rd	24th-43rd	14th-33rd	
Added Present Value (dollars)								
System Two	940.98	- 770.91	406.74	110.64	- 38.95	335.23	-202.34	122.27
System Three	1,269.58	-1,045.47	355.64	178.30	32.54	485.30	-250.72	160.21
System Four	1,546.91	- 937.74	513.39	510.52	269.11	748.52	35.64	191.57
Income Coefficient of Variation (decimal part)								
System One 1/	0.23	0.06	0.30	0.24	0.75	0.24	0.24	0.25
System Two 2/	0.17	0.06	0.16	0.13	0.16	0.13	0.12	0.14
System Three 3/	0.19	0.06	0.15	0.13	0.15	0.13	0.12	0.13
System Four 4/	0.21	0.08	0.17	0.14	0.17	0.14	0.14	0.15
Internal Rate of Return								
System Two	0.32	-0.09	0.22	0.12	0.09	0.17	0.80	0.14
System Three	0.34	-0.14	0.18	0.13	0.11	0.20	0.09	0.14
System Four	0.38	-0.07	0.20	0.17	0.15	0.23	0.11	0.17
Estimated Payback Period (years)								
System Two	3.80	n/a	5.58	7.45	8.97	5.94	11.53	7.78
System Three	3.20	n/a	5.47	6.38	7.38	4.95	10.65	6.70
System Four	2.80	n/a	4.85	4.86	5.68	4.16	7.36	5.42
Yearly Expected Average Income (dollars)								
System Two	110.53	- 90.55	47.78	13.00	- 4.58	39.37	-23.77	14.36
System Three	149.12	-122.80	41.77	20.94	3.82	57.00	-29.45	18.82
System Four	181.70	-110.12	60.30	59.97	31.61	87.92	4.19	22.50

1/ System One is an orchard using no weather-altering technology
2/ System Two is an orchard using a wind machine for freeze control
3/ System Three is an orchard using overhead sprinklers for freeze control
4/ System Four is an orchard using overhead sprinklers for freeze control and irrigation
5/ Worst twenty seasons based on the twenty lowest yields using System One's yields
6/ Best twenty seasons based on the twenty highest yields using System One's yields

Table 8. Values of the Decision Criteria Using $3.50 Dollars Per Bushel Prices and Added Income Received From Weather-Altering Technology

	Seasons of Production							Average of the
Item	Worst Twenty 5/	Best Twenty 6/	First Twenty	Second Twenty	4th-23rd	24th-43rd	14th-33rd	Five Natural Patterns
Added Present Value (dollars)	1,546.29	- 765.36	754.95	373.66	118.07	664.22	- 30.34	376.11
System Two	2,069.03	-1,036.82	552.70	552.54	347.28	984.70	- 11.02	485.04
System Three	2,394.69	- 910.28	957.95	941.31	625.04	1,257.71	325.20	821.44
System Four								
Income Coefficient of Variation (decimal part)								
System One 1/	0.23	0.06	0.30	0.24	0.25	0.24	0.24	0.25
System Two 2/	0.17	0.06	0.16	0.13	0.16	0.13	0.12	0.14
System Three 3/	0.19	0.06	0.15	0.13	0.15	0.13	0.12	0.13
System Four 4/	0.20	0.08	0.17	0.14	0.17	0.14	0.14	0.15
Internal Rate of Return								
System Two	0.45	-0.08	0.32	0.16	0.14	0.24	0.10	0.19
System Three	0.49	-0.11	0.27	0.17	0.17	0.28	0.10	0.20
System Four	0.52	-0.05	0.29	0.22	0.22	0.31	0.13	0.24
Estimated Payback Period (years)								
System Two	2.84	n/a	4.31	5.74	6.90	4.58	8.86	6.08
System Three	2.30	n/a	4.10	4.73	5.51	3.70	7.75	5.16
System Four	2.07	n/a	3.67	3.72	4.50	3.71	5.60	4.24
Yearly Expected Average Income (dollars)								
System Two	181.63	- 89.90	88.68	43.89	21.27	78.02	- 3.56	44.18
System Three	243.03	-121.79	90.76	64.78	40.79	111.44	- 1.29	56.97
System Four	281.28	-106.92	112.52	110.57	73.42	147.73	38.20	96.47

1/ System One is an orchard using no weather-altering technology
2/ System Two is an orchard using a wind machine for freeze control
3/ System Three is an orchard using overhead sprinklers for freeze control
4/ System Four is an orchard using overhead sprinklers for freeze control and irrigation
5/ Worst twenty seasons based on the twenty lowest yields using System One's yields
6/ Best twenty seasons based on the twenty highest yields using System One's yields

Four had a negative present value in only one of the 7 different periods, and had the highest present value in each of the other 6 periods. System Four also had the highest internal rate of return, the highest expected annual income, and the lowest expected payback period. The only criterion which was not as good for the other two systems was the coefficient of variation in income. This was due to the fact that the range in levels of production was greater for System Four than for the other two systems. In years when there was no need for irrigation, but other variables which could not be altered by any of the systems caused the yields to be low, the yields for Systems Two, Three, and Four were the same. In another year, when all the weather variables are favorable except rainfall, Systems Two or Three did not increase yields, but System Four, using irrigation, increased production significantly.

System Three, which is exactly the same as System Four except that it was not used for irrigation because there was a need for a comparison of the economic returns between Systems Two and Three when they were used for freeze control, showed a higher average present value than did System Two. System Three had negative present values in two of the seven periods, while System Two had three negative present values. Both System Two and Three had the same internal rate of return and coefficient of variation in income. If, somehow, the best twenty year periods could have been included in the average expected payback period, System Three would have been almost identical to System Two in respect to payback period.

With the price of apples set at $3.00 per bushel, there is little that can be said about which system is more effective in increasing returns by altering freezes. But, at $3.50 a bushel for apples, the difference becomes greater. This occurs because System Three has a greater yield than System Two, and since the cost of operating the two systems remains constant, the increased yield and higher prices caused by System Three is more profitable.

Since there are no increased costs from using the systems, when prices go from $3.00 to $3.50 per bushel, it is obvious that the price increase makes all of the systems more profitable; but, the increases are greater with systems that increase production by a greater percentage.

Also, comparing Tables 9 and 10, the value of an overhead sprinkler system for irrigation and freeze control can be separated. Since System Three is only used for freeze control, it has the direct present value for freeze control, which is $146.45 at $3.00 price and $525.36 at $3.50 price. If these values are subtracted from the present value of System Four, the value remaining should be the present value added to an orchard by using overhead sprinkler systems for irrigation. These values are $77.41 and $273.44 for the two prices.

Using the decision rule on investment from Chapter III to choose the system for investment that has the highest present value in this study, there is no question that at the prices used for apples, System Four, the overhead sprinkler system used for both irrigation and freeze control, is the system to be chosen. But, at prices for apples from $3.00 and up, all of the systems analyzed were economically feasible.

Economic Implications

Wind Machines

The results of the analysis show that the wind machines were the second best investment. Using the criterion of present value, overhead sprinkler systems were shown to have a higher present value; therefore, it would be the system to acquire to alter weather conditions. But, in two situations, the wind machine would be preferred. The two situations are:

(1) In orchards where there is a problem with freeze damage and not sufficient available water source to satisfy the capacity needed to run an overhead sprinkler system, the only available technology to alter freeze damage is a wind machine.

(2) In orchards planted in the middle fifties with seedling type rootstock trees that have a problem with freeze damage, the only adaptable technology to alter freeze damage is a wind machine. The two reasons why an overhead sprinkler system can not be used are (1) it would be virtually impossible to install a sprinkler system because of the size and placements of the roots and (2) the increased surface of the trees makes even distribution of water needed for freeze protection virtually impossible.

Given the investment is being made when the production situations are similar to the two above, and under similar production situations which were used in the study, the wind machine would be a feasible investment to alter freeze damage, assuming the firm making the investment decision was satisfied with an average internal rate of return of fourteen percent and an average payback period of 7.78 years.

In production situations different from those used in the study, the analysis would have to be altered to determine if the wind machines are economically feasible for use in freeze protection.

Overhead Sprinkler Systems

The results from the study showed that overhead sprinklers were the better investment. This came in part because they can be used both to alter freeze damage and for irrigation in July and August. This system, on some orchards, could not be used for two reasons. First, if adequate water sources are not found, they can not be used. Second, they can not practically be used with seedling trees due to the problem mentioned earlier. But, in situations where water is available, the overhead sprinkler systems are the systems which add the highest added present value to the orchard. Not only can they be used for the two purposes mentioned above, but they can be used for the following:

1. For irrigation purposes other than July and August, if necessary.

2. For fertilization

3. To cool the fruit during high temperature periods in July and August, which causes the fruit to have better color. This, in

turn, increases the quality of apples produced and also increases the price received for the apples.

Also, in recent years the trend has been to plant high density orchards in areas with heavier soil in order to increase production. In this case, the overhead sprinkler system becomes increasingly important for both freeze prevention and irrigation for two reasons. First, these areas are usually bottom land, which is more prone to have freeze damage, and also, using bloom delay would decrease the probability of freeze damage. Second, these orchards would need more water and an irrigation system could provide needed water.

Because of the ability of overhead sprinkler systems to provide all of the services mentioned above, the overhead sprinkler system, where adaptable water is available, is the system to invest in to alter weather factors.

Continuation of Further Research

A possible sequel to this study would be to gather specific information about specific orchard sites. The information needed at these sites are weather data, yield data, and some type of classification of the site. This information could then be used to predict which type of site is more prone to freeze damage. From this analysis, two important criteria can be determined. First, from the analysis, one should be able to determine the value of a good site location. Second, one should be able to predict which type of site needs freeze protection and the value the adaptable technology would add to that site.

Another sequel to the study would be to determine the effect irrigation has on production. This could be accomplished using the standard type of experiment of having a control orchard without irrigation effects and an experimental orchard using irrigation. Then, using a standard type of statistical analysis, a determination of the effect of irrigation on production and incorporation of these effects into the simulation model can be made. This procedure would be a much more efficient procedure than one using the effect of rainfall on production because rainfall has more decreasing effects on production than does irrigation. For example, cloudiness causes loss of solar energy, which decreases the photosynthetic process and extended periods with high moisture can cause disease problems.

Both the continuations of study mentioned above would increase the accuracy of the simulation model. But, since the information to run an analysis is needed over a period of years, the process of gathering the information would be very expensive and time consuming, and it would be questionable if Virginia apple production is high enough to warrant a study of this magnitude.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Apple producers in Virginia are effected by adverse weather factors, which cause poor or lower than normal yields. These weather factors, such as freeze kill of bloom and lack of rainfall, cause decreases in production and, therefore, cause decreases in revenues received by apple producers. These weather factors, although they can not be completely controlled, can be altered by wind machines and overhead sprinkler systems. Therefore, the major purpose of the study was to determine if these types of weather-altering technologies could be economically feasible for use in Virginia.

The first segment of the study was to determine what weather variables could be altered by wind machines and overhead sprinkler systems and how effective the systems were in the alteration process. Since there have been no studies made in Virginia to test these systems, sources and studies outside of the state had to be drawn on. From research done in Florida, California, and Washington State, it was determined that the wind machine could be used to alter freezes and would increase the temperatures as much as 2.2^{o}C. (4^{o}F.) with wind speeds under 4 miles per hour and 1.1^{o}C. (2^{o}F.) with wind speeds between 5 and 8 miles per hour. From research done in Florida, Utah, and Washington State, it was concluded that the overhead sprinkler systems were equally as effective in altering freeze damage as the wind machine. And, from further research from Utah and Georgia, it was shown that the overhead sprinkler system also could be used to delay bloom development, which would decrease the probability of freeze damage. Also, the overhead sprinkler system could be used for irrigation.

The next step was to decide what economic criterion would be used to determine if the systems were economically feasible. Using economic theory, the criterion chosen was the present value criterion. If the present value (present value being the discounted returns minus the discounted cost minus the investment), was greater than zero, then the systems were deemed economically feasible. And, the system with the highest present value would be the best system to invest in.

The next step was to acquire data to be used in the analysis. The production data was gathered from seven orchard producers in the Northern Shenandoah area. And the weather data was acquired from the U.S. Geological Survey and National Weather Service tapes of weather at the Woodstock, Virginia station. The above sets of data were then used to develop weather variables which could affect production.

These weather variables were then used in regression models to determine which of the variables significantly affected production. These variables were:

1. Three levels of bloom kill by freeze
2. Solar energy

3. Rainfall in July and August

Of these variables, 1 and 3 were alterable by weather-altering systems.

The significant variables, the regression model, and the effectiveness of the systems were then used in a simulation model which did two things. First, it calculated yield for four systems, which were:

1. No weather altering technology
2. Wind machine
3. Overhead sprinkler system used for freeze protection and bloom delay
4. Overhead sprinkler system used for freeze protection, bloom delay, and irrigation

The yield for the first system was calculated using the regression model without modifying the weather variables. The yields for the last three systems were calculated by the effectiveness of the three systems. Second, the simulation model used these expected yields, hours the systems were used, the cost per hour of use, and the investment cost to determine the present value of each of these systems added to the orchard. Then, from these present values, the following conclusions were drawn:

First, with apples priced at $3.00 per bushel, both System Two and Three were economically feasible for freeze control and neither system seemed much better than the other. But, as prices increase, System Three's present value increases faster than

System Two's, making System Three more economically feasible as prices received for apples increased. Furthermore, System Four showed the highest present value of the systems using weather-altering technology because System Four could be used for more than one purpose. It can be used for irrigation as well as freeze control.

Therefore, it is shown that both wind machines and overhead sprinkler systems can be economically used in Virginia. But, because the overhead sprinkler system can be used for multiple purposes, they will yield a much greater return than the wind machine, which can only be used for freeze control.

Therefore, from the analysis, it is concluded that, given normal production situations, an overhead sprinkler system would be the best investment for orchard producers who want to acquire a system which alters weather factors affecting orchard production.

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APPENDIX A

APPENDIX A

FACTORS WHICH AFFECT PRODUCTION LEVELS

These are factors which affect production, but were not used in this study. They are briefly explained for anyone who wants more information about factors involved in the production of apples.

The factors are grouped into 3 major categories and are called:

1. Orchard Establishment
2. Orchard Care (Management Practices)
3. Natural Tendency of Apples Toward Biennial Bearing

Decisions made in orchard establishment affect production in that orchard throughout its life and also affect management decisions on orchard care and the effect of weather on variability in production. Site location and tree setting are two important sub-considerations in orchard establishment. Site location selection is based on five criteria. First, the site should be at a relatively higher altitude, gently sloping away to the surrounding land area. This helps in giving the orchard a better chance of surviving freeze conditions since cold air tends to run down the slope to settle in the lower areas. Gentle vs. sharp slopes enables machinery to operate more efficiently, thus facilitating orchard care and harvest. The second criterion is that the site provides for good surface and internal water drainage. Poor drainage will result in poor root development and root disease problems. Good air drainage is a third criterion which has been mentioned previously in relation to elevation, but also includes impediments to air drainage such as wooded areas across the slope. The fourth criterion is that of the directional exposure to the sun's rays in the spring of the year. A north, north-eastern or north-western slope will receive a minimum of direct rays from the sun and will be held back in development so that late spring frosts will be less likely to cause damage than in an orchard with a south-eastern, southern, or south-western slope. The fifth criterion is the soil depth, internal drainage, supply of nutrients, and type. A good orchard soil should be deep to allow good range of the root system, good internal drainage combined with water holding capacity and be heavy enough to anchor the trees against heavy winds. Tree setting is also important to orchard productivity. Spacing of rows to allow air drainage, sun penetration, and movement of orchard equipment and spacing of trees in the row to take up the available space at maturity without crowding is ideal. A knowledge of tree-type growth characteristics with soil conditions of the site is essential and few general recommendations can be made.

Orchard care or management practices is the second general group of factors that affect production. It is broken into seven sub-groups which affect production potential, variability of production and tree vigor. These practices are:

1. Pruning and Training
2. Thinning
3. Fertilization

4. Pollinization
5. Rodent and Other Animal Controls
6. Weed Control
7. Insect and Disease Control

Training, especially in the early years, is important throughout the life of the orchard. It determines the general configuration of the bearing area of the mature tree. Strong limb angles, scaffold branches that do not overlap, but will provide adequate bearing surface, are determined early in the life of the tree. As the trees mature, pruning becomes a matter of removing weak wood such as down growing branches, sap wood, and thinning cuts to allow sunlight penetration. This allows the available nutrients to be used by productive parts of the tree, promotes photosynthetic activity, and promotes color development in the apples.

Thinning may be done either chemically or by hand or by a combination of the two methods. It is done to eliminate a part of the apple crop before nutrients are utilized in developing the fruits. Ideally, apples should be borne one in a place spaced throughout the tree. Clusters of two or more apples are hard to protect against insect damage such as leaf roller, and the apples may be damaged by rubbing and hitting against each other while still on the tree. Thinning not only promotes better size of apples in the current crop, but it also promotes development of fruiting spurs for next year's crop, combating the tendency in some varieties toward biennial bearing.

Fertilization provides necessary nutrients for the maintenance of tree vigor, apple development, and sod maintenance. While it is necessary to maintain fertility, care must be taken not to over fertilize, especially with nitrogen, which may promote excessive vegetative growth, shading of apples, thus reducing color formation, and development of soft fruit with low storage life. It will cause increased pruning costs and fewer fruit spurs.

Pollinization is important for development of fruit. Some pollinization must occur for an apple to mature. Partial pollinization may result in poorly shaped and slowly developing fruit. To promote proper pollinization, the orchard should have been established with enough varietal mix to provide cross pollination and sufficient bees be provided to carry out the pollinization process. More bees may be needed in periods of wet or cold weather during the bloom period than when it is fair and warm.

Rodents (mice, voles, ground hogs) and other animals such as rabbits and deer may damage the roots or even kill trees if they are not controlled.

Weeds growing uncontrolled in an orchard can compete with the trees for nutrients, provide cover for rodents, and interfere with other orchard operations. While a good sod is needed for providing protection against erosion and for movement of machinery through the orchard, the area between trees in the row and beneath the trees should be kept as free of weeds and other vegetation as possible.

The last orchard care practice is that of controlling insects and diseases that attack the tree and the fruit. The tree must be protected to promote photosynthetic activity and the fruit must be protected to give an acceptable product for sale. Special sprays may also be used to promote or delay ripening to suit harvest schedules, to promote color development, or to control vegetative growth.

All of these seven orchard care and management practices affect the quality and yield for the year they are executed, and they also are related to the ability of the orchard to produce high quality yields for the years thereafter.

Biennial bearing is the last of the production factors to be discussed. It is highly related to variety. Biennial bearing varieties tend to produce large crops one year likely to be of small size and small crops of large apples the next year, usually with heavy vegetative growth. With the large crops there are not sufficient nutrients for the development of the next year's fruit spurs. Higher costs are incurred under biennial bearing because of the greater costs of pruning incurred in the off year and the quality of the large crop is likely to be impaired both by reduced size of fruit and greater disease and insect defects, thus reducing the price of the fruit from the large crop. Total production in a biennial bearing orchard is about twenty-five percent less than in steadily producing orchards. biennial production is a serious problem, but can be controlled somewhat by good management practices, especially thinning practices.

APPENDIX B

APPENDIX B

PRODUCTION AND WEATHER DATA USED IN THE STUDY

Production data used in the regression model were gathered from seven producers in an area extending from New Market to Winchester, Virginia, all of whom were relatively large commercial orchardists. The data were supplied in confidence that information obtained would be published only in aggregate with producers' identity concealed. The information was gathered on a block basis (a block being a contiguous area of orchard that was treated by the orchardist as a unit of production). The information used in the study obtained for each block was:

1. Total bushels produced
2. Number of acres
3. Age of trees
4. Type of trees (dwarf, semi-dwarf, seedling)

The age information was usually updated as the producer prepared information for the Virginia orchard survey which is taken once every five years. This information was obtained, where available, from 1951 to 1974. More complete information was available from 1961 to 1974. Table B-1 shows a summary of the data obtained from the producers and transformations that were made in this data to prepare it for use in the study.

The estimated average mature production in Table B-1 was calculated

Table B-1. Orchard Block Yield Data, Index of Mature Production, and Estimated Mature Production, 1951-1974

Year	Acres Represented In Blocks	Average Production/Acre	Index of Mature Production*	Estimated Average Mature Production
	Acres	Bushels	Index	Bushels
1951	851	377.00	.70	538.58
1952	851	460.19	.80	575.59
1953	910	386.19	.75	514.92
1954	910	495.20	.80	619.80
1955	956	155.65	.75	207.53
1956	982	351.77	.78	450.99
1957	982	289.97	.82	353.64
1958	1,034	241.66	.68	355.88
1959	1,052	327.25	.72	454.52
1960	1,121	306.39	.75	488.52
1961	1,653	199.80	.65	307.00
1962	1,627	382.80	.68	562.95
1963	1,627	309.84	.73	424.44
1964	1,676	382.74	.77	497.07
1965	1,692	493.31	.75	657.57
1966	1,750	168.71	.72	234.32
1967	1,723	316.70	.75	422.26
1968	1,765	416.06	.72	577.86
1969	1,823	377.10	.76	496.19
1970	1,818	419.33	.78	537.61
1971	1,829	459.02	.74	620.30
1972	1,801	345.90	.76	455.14
1973	1,793	412.46	.80	515.57
1974	1,793	474.95	.82	579.21

*Decimal fraction of production that would be expected when trees reached maturity based on Table by determining the average age of trees in the individual blocks, weighting these ages by the number of acres in each block and dividing the sum by the total number of acres. The result is then divided by the index of mature production for that age of tree as shown in Table B-2.

All of the trees in blocks from which data were obtained in the 1950's had seedling rootstock. In the early 1960's, most of the new trees were with semi-dwarf rootstock and late in the 1960's and early 1970's a few acres of dwarf trees were included in the blocks. No distinction was made between levels of production per acre for different types of trees or varieties because of the uncertainties as to types and varieties in the collected data.

Weather Data

The weather data used in the regression model came from U. S. Geological Survey and National Weather Service tapes of information from Virginia weather stations by courtesy of the Water Resources Center at V.P.I. and S.U. Weather data from the Woodstock, Virginia station, which is located near the center of the geographical area in which the producers were distributed, was chosen as representative of the weather under which production in these blocks occurred. The weather information used included: (1) daily minimum and maximum temperatures and daily and monthly rainfall information. This weather information was obtained for January 1, 1931 through December 31, 1974.

Table B-2. Estimated Index of Mature Production by Type and Age of Tree

Age	Seedling	Semi-Dwarf	Dwarf
1	0.0	0.000	0.000
2	0.0	0.000	0.000
3	0.0	0.000	0.000
4	0.0	0.200	0.200
5	0.0	0.333	0.466
6	0.0	0.466	0.733
7	0.2	0.600	1.000
8	0.3	0.733	1.000
9	0.4	0.866	1.000
10	0.5	1.000	1.000
11	0.6	1.000	1.000
12	0.7	1.000	1.000
13	0.8	1.000	1.000
14	0.9	1.000	1.000
15	1.0	1.000	1.000

Source: Estimates of decimal fraction of full bearing made by horticulturalists at V.P.I. and S.U.

APPENDIX C

CALCULATIONS AND INPUT USED IN CHAPTER V

Table C-1. Values of the Significant Variables Used in the Regression Model

Year	Production	Rainfall July and August	Rainfall July and August (Squared)	GDH Units	10% kill of bloom	50% kill of bloom	90% kill of bloom
	(Y)	(RJA)	(RJAS)	XE	D_1	D_2	D_3
1951	538.58	6.63	43.96	64,542	0	0	0
1952	575.59	8.54	72.93	67,298	0	0	0
1953	514.92	3.04	9.24	70,958	1	0	0
1954	619.80	6.53	42.64	67,545	0	0	0
1955	207.53	11.37	129.27	70,949	0	0	1
1956	450.99	7.30	53.29	63,145	1	0	0
1957	353.64	3.25	10.56	69,438	0	1	0
1958	355.38	13.09	171.34	64,577	0	0	0
1959	454.52	5.58	31.14	70,501	0	1	0
1960	408.52	7.11	50.55	66,707	1	0	0
1961	307.00	5.53	31.70	64,315	0	0	1
1962	562.95	6.68	44.62	65,650	0	0	0
1963	424.44	4.02	16.16	66,154	0	1	0
1964	497.07	2.40	5.76	64,777	0	0	0
1965	657.57	6.68	44.62	66,507	0	0	0
1966	234.32	4.23	17.89	65,212	0	1	0
1967	422.26	8.86	78.50	61,708	0	0	0
1968	577.86	7.24	52.42	67,473	0	0	0
1969	496.19	10.42	108.58	67,171	0	0	0
1970	537.61	11.04	121.88	67,384	0	0	0
1971	620.30	9.35	87.42	65,057	0	0	0
1972	455.14	8.55	73.27	63,488	1	0	0
1973	515.57	7.12	50.69	68,823	0	1	0
1974	579.21	8.11	65.77	63,684	0	0	0

Source: Y=Actual Orchard Production Data
RAJ and RAJS=Rainfall Data Received from National Weather Service
D_1, D_2, D_3=Calculated from Critical Freeze Temperatures, Chill Unit Model, GDH Model, and Temperatures from National Weather Service

Table C-2. Observed Predicted Full Bloom Data

Year	Actual Date Full Bloom	Predicted Date Full Bloom	Day of Actual Full Bloom	Day of Predicted Full Bloom
1931	May 4	April 28	124	118
1932*	May 2	May 1	122	121
1933	May 1	April 26	121	116
1934	May 4	May 1	124	121
1935	April 28	May 1	118	121
1936*	May 1	May 1	122	122
1937	May 4	May 1	124	122
1938	April 18	April 17	108	107
1939	April 26	April 25	116	115
1940*	May 9	May 6	130	127
1941	April 22	April 23	112	113
1942	April 25	April 18	115	117
1943	April 29	April 29	119	119
1944*	May 1	April 29	122	120
1945	April 1	April 5	91	95
1946	April 18	April 23	108	113
1947	May 1	April 27	121	117
1948*	April 16	April 19	117	110
1949	April 22	April 18	112	108
1950	May 5	May 2	125	122
1951	April 21	April 27	111	117
1952*	May 1	April 26	121	117
1953	April 25	April 20	115	110
1954	April 22	April 23	112	113
1955	April 21	April 15	111	105
1956*	April 29	April 29	120	120
1957	April 27	April 25	117	115
1958	May 1	May 1	121	121
1959	April 26	April 22	116	112
1960*	April 25	April 24	116	115
1961	April 25	April 25	115	115
1962	April 29	April 29	119	119
1963	April 21	April 19	111	109
1964*	May 2	May 4	123	125
1965	May 4	May 1	124	121
1966	May 2	April 25	122	115
1967	April 22	April 22	112	112
1968*	April 19	April 18	110	109
1969	April 27	April 26	117	116
1970	May 2	May 2	122	122
1971	May 2	April 30	122	120
1972*	April 30	May 1	121	122
1973	April 23	April 18	113	108
1974	April 29	April 29	119	119

* Leap Year

Source: Observed Data were received from V.P.I. and S.U. Fruit Lab at Winchester, Virginia.
Predicted Data were determined by using the Chill Unit Model and the Growing Degree Hour Model with temperature data from the National Weather Service.

Table C-3. Dates When Trees Enter and Break Rest

Season	Enters Rest	Breaks Rest	Season	Enters Rest	Breaks Rest
1	October 17	February 24	23	October 2	February 11
2	October 9	March 13	24	November 4	March 11
3	October 5	February 26	25	October 15	February 20
4	October 2	March 17	26	October 19	March 9
5	October 23	March 18	27	October 24	March 6
6	November 6	March 11	28	September 28	February 25
7	October 23	February 27	29	October 18	March 10
8	October 7	March 2	30	October 12	February 6
9	October 1	March 1	31	October 20	March 25
10	October 11	March 9	32	November 6	March 17
11	October 15	February 23	33	October 17	March 9
12	October 23	March 6	34	October 28	March 20
13	October 23	March 15	35	October 4	March 4
14	October 16	March 12	36	October 2	February 23
15	October 9	March 8	37	October 10	March 12
16	October 2	March 20	38	October 6	February 16
17	November 5	March 23	39	October 20	March 9
18	October 28	March 19	40	October 14	March 13
19	October 3	February 10	41	October 16	March 7
20	October 23	February 25	42	November 4	March 17
21	November 4	March 25	43	October 9	January 27
22	October 28	March 10	44	October 16	March 15

Source: These values were calculated using the Chill Unit Model

Table C-4. GDH Units for Each Season

Season	GDH Unit	Season	GDH Unit	Season	GDH Unit	Season	GDH Unit	Season	GDH Unit
1	67,449	10	61,835	19	68,114	28	64,577	37	61,708
2	64,355	11	67,077	20	63,275	29	70,501	38	67,473
3	67,232	12	69,082	21	64,542	30	66,707	39	67,171
4	66,419	13	67,053	22	67,298	31	64,315	40	65,057
5	63,616	14	68,020	23	70,958	32	65,650	41	63,488
6	63,655	15	69,381	24	67,545	33	66,154	42	68,823
7	62,956	16	64,194	25	70,949	34	64,777	43	63,684
8	66,576	17	65,597	26	63,145	35	66,507	44	
9	63,260	18	66,715	27	69,438	36	65,212		

Source: GDH Units were calculated from the GDH Model

Table C-5. Days Into the Year That the Eight Stages of Bloom Development Occur.

Season	1 1/	2 2/	3 3/	4 4/	5 5/	6 6/	7 7/	8 8/
1	94	99	101	104	108	110	113	118
2	94	96	99	108	113	115	118	121
3	90	92	96	99	104	107	112	116
4	96	98	100	106	109	113	116	121
5	88	92	101	109	114	116	118	121
6	89	92	101	108	113	115	119	122
7	89	93	97	106	110	113	118	107
8	79	81	83	89	94	101	104	115
9	84	85	87	95	102	108	113	127
10	94	96	100	107	111	117	123	113
11	94	99	102	104	107	108	110	108
12	80	84	92	95	98	99	106	119
13	87	90	93	100	109	113	116	120
14	88	95	100	103	109	112	116	95
15	78	80	83	86	89	90	93	113
16	88	92	93	98	105	107	110	117
17	97	99	101	105	108	110	114	110
18	86	88	92	96	99	101	106	108
19	70	79	87	91	94	96	103	122
20	88	93	97	107	110	114	118	117
21	94	97	101	107	111	113	115	118
22	91	93	96	105	111	114	116	105
23	78	81	85	91	98	101	100	113
24	93	97	99	103	106	109	111	105
25	69	71	75	88	94	97	101	120
26	92	94	100	106	114	115	101	115
27	86	93	97	105	109	111	117	121
28	101	105	107	110	112	114	113	115
29	90	92	95	98	102	106	118	121
30	93	97	103	106	108	109	109	112

Table C-5. (Continued)

Season	1 1/	2 2/	3 3/	4 4/	5 5/	6 6/	7 7/	8 8/
31	93	97	102	106	109	110	112	115
32	91	96	98	106	113	115	117	119
33	86	88	90	93	97	102	107	109
34	101	104	106	109	114	115	119	125
35	98	100	102	108	112	115	119	121
36	78	81	83	96	108	110	113	115
37	93	97	99	103	106	109	111	112
38	82	84	89	92	98	102	106	109
39	94	96	99	101	106	108	112	116
40	103	107	109	113	116	118	120	122
41	93	98	101	104	109	111	116	120
42	103	104	106	109	111	114	120	122
43	70	72	75	84	90	93	100	108
44	94	98	102	105	109	112	116	119

1/ The first stage is Silver Tip and occurs at around 2,061 GDH Units.
2/ The second stage is Green Tip and occurs at around 2,544 GDH Units.
3/ The third stage is Half-Inch Green and occurs at around 3,100 GDH Units.
4/ The fourth stage is Tight Cluster and occurs at around 3,939 GDH Units.
5/ The fifth stage is First Pink and occurs at around 4,856 GDH Units.
6/ The sixth stage is Full Pink and occurs at around 5,394 GDH Units.
7/ The seventh stage is First Bloom and occurs at around 6,172 GDH Units.
8/ The eighth stage is Full Bloom and occurs at around 6,933 GDH Units.

Source: E. Arlo Richardson and from calculations made by the GDH Model.

Table C-6. Calculated Freeze Kills for the System Without Weather-Altering Technology

Season	Stage of Bloom Development When Freeze Occurred	Hours of Freeze	Date of Freeze	% of Blooms Killed	Temperature of freeze (C°)	Critical Temperature (C°) of Freeze During That Stage
1	6	2	May 1	90%	-3.9	-3.9
2	-	0	-	-	-	-
3	6	4	April 23	90%	-5.0	-3.9
4	6	4	April 16-18	50%	-2.8	-2.8
5	-	0	-	-	-	-
6	5	2	April 24	10%	-2.8	-2.2
7	-	0	-	-	-	-
8	5	4	April 11	50%	-3.3	-3.3
9	5	4	April 13-14	50%	-3.89	-3.3
10	-	0	-	-	-	-
11	-	0	-	-	-	-
12	-	0	-	-	-	-
13	4	2	April 5	50%	-4.4	-4.4
	4	2	April 6	90%	-6.1	-6.1
14	-	0	-	-	-	-
15	6	4	April 6-7	10%	-2.2	-2.2
16	-	0	-	-	-	-
17	-	0	-	-	-	-
18	-	0	-	-	-	-
19	-	0	-	-	-	-
20	3	8	April 15	10%	-6.7	-5.0
21	-	0	-	-	-	-
22	-	0	-	-	-	-

Table C-6. (Continued)

Season	Stage of Bloom Development When Freeze Occurred	Hours of Freeze	Date of Freeze	% of Blooms Killed	Temperature of Freeze (C°)	Critical Temperature (C°) of Freeze During That Stage
23	6	4	April 10-12	10%	-2.20	-2.20
24	-	0	-	-	-	-
25	4	6	March 26-27	90%	-8.33	-6.20
	4	6	March 27-28	10%	-3.30	-2.80
26	4	2	April 26	10%	-3.30	-2.80
27	4	2	April 15	50%	-4.40	-4.40
28	-	0	-	-	-	-
29	5	2	April 12	50%	-3.89	-3.30
	5	6	April 13-14	10%	-2.78	-2.20
30	2	2	April 2	10%	-8.89	-7.80
31	6	4	May 1	90%	-3.90	-3.90
32	-	0	-	-	-	-
33	6	2	April 16	50%	-2.80	-2.80
34	-	0	-	-	-	-
35	-	0	-	-	-	-
36	3	2	March 27	10%	-5.56	-5.00
	4	2	April 1	10%	-3.30	-2.80
	6	2	March 11	50%	-2.80	-2.80
37	-	0	-	-	-	-
38	-	0	-	-	-	-
39	-	0	-	-	-	-
40	-	0	-	-	-	-
41	-	0	-	-	-	-
42	6	2	April 24	10%	-2.20	-2.20
43	6	2	April 12-15	50%	-3.30	-2.80
	6	4	-	50%	-2.78	-2.80
	6	6	-	10%	-2.20	-2.20
44	-	0	-	-	-	-

Source: Calculated using dates of stages of bloom development, temperatures and critical temperatures for the three levels of bloom kill.

Table C-7. Effectiveness of a Wind Machine in Altering Freezes and Time the Wind Machine is Used.

Season	Original Critical Temp. (C^{o}) 1/	Modified Temp. (C^{o})	Change in Temp. (C^{o})	Level of Bloom Kill Without Protection	Level of Bloom Kill With Wind Machine	Hours the Wind Machine is Operated
1	-3.90	-2.84	1.06	90%	50%	8
2	-	-	-	-	-	8
3	-5.00	-3.95	1.05	90%	90%	14
4	-2.80	-1.75	1.05	50%	0%	14
5	-	-	-	-	-	0
6	-2.80	-1.79	1.01	10%	0%	16
7	-	-	-	-	-	2
8	-3.30	-2.22	1.08	50%	10%	22
9	-3.89	-3.02	0.87	50%	50%	26
10	-	-	-	-	-	4
11	-	-	-	-	-	0
12	-	-	-	-	-	2
13	-4.40	-3.57	0.83	50%	10%	24
	-6.10	-5.27	0.83	90%	50%	
14	-	-	-	-	-	2
15	-2.20	-1.21	0.99	10%	0%	14
16	-	-	-	-	-	4
17	-	-	-	-	-	10
18	-	-	-	-	-	6
19	-	-	-	-	-	4
20	-5.56	-4.55	1.01	10%	0%	12
	-6.10	-5.09	1.01	10%	10%	
	-6.70	-5.69	1.01	10%	10%	
21	-	-	-	-	-	0
22	-	-	-	-	-	0

Table C-7. (Continued)

Season	Original Critical Temp. (C°) 1/	Modified Temp. (C°)	Change in Temp. (C°)	Level of Bloom Kill Without Protection	Level of Bloom Kill With Wind Machine	Hours the Wind Machine is Operated
23	-2.20	-1.13	1.07	10%	0%	22
24	-	-	-	-	-	0
25	-8.33	-7.35	0.98	90%	90%	28
	-3.30	-2.32	0.98	10%	0%	
26	-3.30	-2.10	1.20	10%	0%	10
27	-4.40	-3.48	0.92	50%	10%	12
28	-	-	-	-	-	0
29	-3.89	-2.95	0.98	50%	10%	28
	-2.78	-1.60	0.98	10%	-%	
30	-8.89	-7.95	0.94	10%	10%	18
31	-3.90	-2.89	1.11	50%	50%	12
32	-	-	-	-	-	8
33	-2.80	-1.75	1.05	50%	0%	24
34	-	-	-	-	-	0
35	-	-	-	-	-	0
36	-5.56	-4.56	1.00	10%	0%	18
	-3.30	-2.30	1.00	10%	0%	
	-2.80	-1.80	1.00	50%	0%	
37	-	-	-	-	-	4
38	-	-	-	-	-	20
39	-	-	-	-	-	2
40	-	-	-	-	-	2
41	-	-	-	-	-	12
42	-2.20	-1.21	0.99	10%	0%	4
43	-2.20	-1.13	1.07	10%	0%	32
	-3.30	-2.23	1.07	50%	10%	
	-2.78	-1.71	1.07	50%	0%	
	-2.20	-1.13	1.07	10%	0%	
44	-	-	-	-	-	8

1/ The wind machine was turned on at 0°C. The dashes do not denote lack of temperature information; but, rather lack of critical temperature.

Source: Calculated from the freeze modification model using effectiveness of wind machines for freeze control.

Table C-8. Days Into the Year That the Eight Stages of Bloom Development Occur When Bloom Delay is Implemented

Season	1 [1]	2 [2]	3 [3]	4 [4]	5 [5]	6 [6]	7 [7]	8 [8]
1	104	107	109	115	122	124	127	129
2	100	110	113	117	121	123	126	128
3	98	101	106	113	119	121	123	127
4*	96	98	100	106	109	113	116	121
5*	90	92	101	109	114	116	118	121
6	113	117	120	122	124	126	129	131
7	104	106	109	113	122	124	127	130
8	83	89	92	104	108	110	114	117
9	87	96	104	113	117	120	126	128
10	100	107	110	120	124	127	129	131
11	104	106	107	110	114	118	121	124
12	94	96	97	105	111	114	117	120
13	91	99	107	115	119	121	124	127
14	100	103	108	113	120	122	124	126
15	80	84	86	89	93	95	101	104
16*	88	92	93	98	105	107	110	113
17*	97	99	101	105	108	110	114	117
18*	86	88	92	96	99	101	106	110
19	85	87	89	100	106	112	116	120
20	102	109	113	118	121	124	125	127
21	94	97	101	107	111	113	115	117
22	100	105	109	112	117	120	123	126
23	84	91	96	99	111	113	116	119
24	100	103	105	109	112	114	117	120
25	75	91	94	101	106	109	112	114
26	106	114	119	121	124	127	129	132
27	102	108	110	113	115	117	119	121
28	110	111	113	118	122	123	127	131
29	95	98	99	107	111	115	118	122
30	103	105	107	110	114	116	118	121

Table C-8. (Continued)

Season	1 1/	2 2/	3 3/	4 4/	5 5/	6 6/	7 7/	8 8/
31*	93	97	102	106	109	110	112	115
32*	91	96	98	106	113	115	117	119
33	90	92	94	103	109	110	116	120
34*	101	104	106	109	114	115	119	125
35	106	110	113	119	122	123	125	127
36	82	106	110	114	120	123	126	129
37	99	101	106	100	116	118	122	124
38	91	93	96	103	108	112	115	118
39	99	101	106	109	116	118	122	124
40	111	113	116	119	122	123	126	129
41	103	106	110	115	122	125	128	131
42*	103	104	106	109	111	114	120	122
43	76	89	93	107	110	112	115	121
44	103	105	109	113	119	120	122	127

1/ Stage 1, Silver Tip
2/ Stage 2, Green Tip
3/ Stage 3, Half-Inch Green
4/ Stage 4, Tight Cluster
5/ Stage 5, First Pink
6/ Stage 6, Full Pink
7/ Stage 7, First Bloom
8/ Stage 8, Full Bloom

*Seasons When Trees Broke Rest after March 15 and Bloom Delay was Not Used.

Source: E. Arlo Richardson and from calculations using bloom delay and GDH models.

Table C-9. Number of Days Full Bloom was Delayed, The Date of Modified Full Bloom, and the Total Hours Each System That the Overhead Sprinklers Were Used for Bloom Delay

Season	Number of Days Full Bloom was Delayed	Date of Modified Full Bloom	Hours Overhead Sprinkler System Used for Bloom Delay	Season	Number of Days Full Bloom was Delayed	Date of Modified Full Bloom	Hours Overhead Sprinkler System Used for Bloom Delay
1	11	May 9	205.3	23	14	May 2	245.6
2	7	May 8	164.6	24	7	April 30	167.2
3	11	May 7	206.6	25	9	April 24	220.1
4	0	May 1	0.0	26	12	May 11	162.3
5	0	May 1	0.0	27	6	May 1	192.8
6	10	May 11	178.2	28	10	May 11	178.8
7	8	May 9	195.3	29	10	May 2	173.2
8	10	April 27	214.5	30	6	April 30	155.6
9	12	May 7	199.1	31	0	April 25	0.0
10	4	May 10	152.0	32	0	April 29	0.0
11	9	May 2	197.6	33	11	April 30	192.1
12	12	April 30	213.1	34	0	May 4	0.0
13	8	May 7	160.4	35	6	May 7	174.3
14	6	May 5	165.2	36	14	May 9	203.4
15	9	April 14	148.5	37	12	May 4	212.6
16	0	April 23	0.0	38	9	April 27	191.4
17	0	April 27	0.0	39	8	May 4	171.0
18	0	April 19	0.0	40	7	May 9	142.7
19	12	April 30	248.2	41	11	May 11	181.1
20	5	May 7	185.6	42	0	May 1	0.0
21	0	May 2	0.0	43	13	May 1	248.9
22	8	May 4	177.9	44	8	May 7	167.2

Source: Calculated by the GDH Model and the Bloom Delay Model

Table C-10. Duration, Level, and Temperature of Critical Freezes When an Overhead Sprinkler System is Used for Bloom Delay

Season	Stage of Bloom Development When Freeze Occurred	Hours of Freeze	Date of Freeze	Percent of Blooms Killed	Temperature of Freeze (C°)	Critical Temperature (C°) of Freezes During That Stage and Level of Kill
1	6	2	May 1	90%	-3.9	-3.9
3	4	4	April 23	50%	-5.0	-4.4
4	6	4	April 28	50%	-2.8	-2.8
15	6	4	April 6	10%	-2.2	-2.2
30	6	2	May 1	10%	-2.2	-2.2
36	6	2	May 10	50%	-2.8	-2.8

Source: Calculated by using dates of stages of bloom development delay by sprinkling, temperatures, and critical temperatures for the three levels of bloom kill.

Table C-11. Effectiveness of Overhead Sprinklers in Directly Altering Freezes.

Season	Original Temp. (C°)	Modified Temp. (C°)	Change in Temp. (C°)	Previous Level of Bloom Kill	New Level of Bloom Kill
1	-3.90	-2.82	1.08	90%	50%
3	-5.00	-3.97	1.07	50%	10%
4	-2.80	-1.78	1.02	50%	0%
15	-2.20	-1.19	1.01	10%	0%
30	-2.20	-1.23	0.97	10%	0%
36	-2.80	-1.17	1.03	50%	0%

Source: Calculated from the Freeze Modification Model, using effectiveness of overhead sprinkler systems used directly for freeze control.

Table C-12. The Number of Hours the Overhead Sprinkler System Will be Used for Direct Freeze Control.

Season	Hours Used	Season	Hours Used	Season	Hours Used	Season	Hours Used
1	10	12	0	23	8	34	0
2	0	13	2	24	0	35	0
3	6	14	2	25	0	36	12
4	14	15	14	26	6	37	4
5	0	16	4	27	2	38	12
6	0	17	10	28	0	39	0
7	0	18	6	29	0	40	2
8	4	19	2	30	10	41	0
9	0	20	0	31	2	42	4
10	0	21	0	32	8	43	2
11	0	22	0	33	12	44	4

Source: Calculated from the Freeze Modification Model

Table C-13. July plus August Rainfall Accumulation for the Different Orchard Situations not Using Irrigation

Season	July and August Rainfall in Inches	Season	July and August Rainfall in Inches	Season	July and August Rainfall in Inches
1	9.68	16	6.83	31	5.53
2	7.17	17	5.72	32	6.68
3	11.26	18	8.24	33	4.02
4	7.89	19	9.86	34	2.40
5	6.01	20	4.67	35	6.68
6	3.81	21	6.63	36	4.23
7	10.30	22	8.54	37	8.86
8	7.75	23	3.04	38	7.24
9	11.26	24	11.37	39	10.42
10	10.00	25	7.30	40	11.04
11	9.36	26	3.25	41	9.35
12	14.46	27	13.09	42	8.55
13	3.14	28	5.58	43	7.12
14	3.41	29	7.11	44	8.11
15	10.37	30			

Source: Taken from Weather Information gathered at Woodstock Weather Station

Table C-14. Seasons, Amount of Irrigation Water Needed, and Hours Required to Apply the Water

Season	Irrigation Added	Hours of Sprinkler Use	Season	Irrigation Added	Hours of Sprinkler Use
5	0.49	3.30	27	3.25	21.70
6	2.69	17.90	29	0.92	6.10
13	3.36	22.40	31	0.97	6.50
14	3.09	20.60	33	2.48	16.50
17	0.78	5.20	34	4.10	27.30
20	1.83	12.20	36	2.27	15.10
23	3.46	23.10			

Source: Calculated from the Yield Response Model and Weather Information

VITA

George Greaser was born in Altoona, Pennsylvania on March 30, 1949. He was the second born of eleven children of Mr. and Mrs. Willis L. Greaser. He was reared on a dairy farm near Williamsburg, Pennsylvania, where he graduated from Williamsburg High School in 1967. He then entered Pennsylvania State University in the fall of 1967. While at Pennsylvania State University, he married Rosemari Juhl and later had two boys, Jason, who is now 6, and Karl-Heinze, who is 3. He graduated in March, 1971 with a Bachelor of Science degree in Agricultural Economics. Im March, 1971, he was admitted to the Graduate School of Pennsylvania State University, where he completed his Masters of Science degree in Agricultural Economics in September, 1972.

In September 1972, he was admitted to the Graduate School of Virginia Polytechnic Institute and State University. In March, 1973, he accepted a position in the Agricultural Economics Department at Virginia Polytechnic Institute and State University and worked there until January, 1977. He completed the requirements for the degree of Doctor of Philosophy in Agricultural Economics in February, 1977. He will begin working for the Arkansas Cooperative Extension Service in February, 1977.

George L Greaser

ECONOMIC FEASIBILITY OF USING WEATHER-ALTERING TECHNOLOGY ON APPLE ORCHARDS IN VIRGINIA

by

George Landis Greaser

(ABSTRACT)

Apple producers in Virginia are affected by adverse weather factors which cause poor or lower than normal yields. These weather factors such as freeze kill of bloom and lack of rainfall cause decreases in production and, therefore, decreases in revenues received by apple producers. These weather factors, although they can not be completely controlled, can be altered by wind machines and overhead sprinkler systems. Therefore, the major purpose of the study was to determine if these types of weather-altering technologies could be economically feasible for use in Virginia.

The first step in determining the economic feasibility of the two systems was to determine which weather factors are effected by the adaptable technology stated above. This information was received from studies completed in Utah, Georgia, Florida, California, and Washington State.

The second step was to gather production data and weather data in the same general geographical location in Virginia to be used to develop a yield response equation and determine the weather variables which affect production. This information was then trans-

ferred to a simulation model, which determined the values of the economic criteria used when making investment decisions.

The major findings of the study were: (1) that the overhead sprinkler system is the investment with the best economic criteria values and should be the investment used in situations where an orchard is of dwarf and semi-dwarf type rootstock and where there is an adequate supply of water, and (2) wind machines are also shown to be economically feasible to use in orchard situations and can be implemented in orchards with older seedling type trees and in orchards where there is an inadequate supply of water to operate an overhead sprinkler system.