

Frost protection: fundamentals, practice, and economics



Volume 2

ENVIRONMENT AND NATURAL RESOURCES SERIES
GEO-SPATIAL DATA AND INFORMATION ENVIRONMENTAL MANAGEMENT [ASSESSMENT AND MONITORING] GLOBAL ENVIRONMENTAL CHANGE



Front cover photos Left: *Over-tree sprinkler experiment in Northern California* (photographer: unknown)
Middle: *Russet patches near the eyes and rings developed on small apple fruits damaged by frost in Northern Portugal* (photographer: António Castro Ribeiro)
Right: *The use of hoops and plastic to protect Alstroemeria plants in Northern California* (photographer: Richard L. Snyder)

Back cover photos Left: *Ice accumulation from the use of under-tree sprinklers in Northern California* (photographer: Richard L. Snyder)
Middle: *Apple flowers damaged by frost depicting darkened petals a few days after a frost event in an orchard in Northern Portugal* (photographer: António Castro Ribeiro)
Right: *Ice accumulation from operation of targeted sprinklers over grapevines* (photographer: Robert Corrella)

Background image in this page Illustration elaborated from
“L’Encyclopédie Diderot et D’Alembert”

Copies of FAO publications can be requested from Sales and Marketing Group - Information Division
Food and Agriculture Organization of the United Nations
Viale delle Terme di Caracalla - 00100 Rome, Italy

E-mail: publications-sales@fao.org
Fax: (+39) 06 57053360
Web site: <http://www.fao.org>



Frost Protection: fundamentals, practice and economics

Volume ②

Richard L Snyder

University of California, Atmospheric Science,
Department of Land, Air and Water Resources - Davis, California, USA

J. Paulo de Melo-Abreu

Technical University of Lisbon, Instituto Superior de Agronomia (ISA)
Departamento de Ciencias do Ambiente
Apartado 3381, 1305-905 Lisboa, Portugal

Scott Matulich

Washington State University
School of Economic Sciences
Washington State University, Pullman, WA 99164-6210, USA

10

ENVIRONMENT AND NATURAL RESOURCES SERIES
ENVIRONMENTAL MANAGEMENT [ASSESSMENT AND MONITORING] GLOBAL ENVIRONMENTAL CHANGE
GEO-SPATIAL DATA AND INFORMATION

The conclusions given in this report are considered appropriate at the time of its preparation. They may be modified in the light of further knowledge gained at subsequent stages of the project.

The designations employed and the presentation of material in this information product do not imply the expression of any opinion whatsoever on the part of the Food and Agriculture Organization of the United Nations concerning the legal or development status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

FAO declines all responsibility for errors or deficiencies in the database or software or in the documentation accompanying it, for program maintenance and upgrading as well as for any damage that may arise from them. FAO also declines any responsibility for updating the data and assumes no responsibility for errors and omissions in the data provided. Users are, however, kindly asked to report any errors or deficiencies in this product to FAO.

ISBN: 92-5-105329-4

All rights reserved. Reproduction and dissemination of material in this information product for educational or other non-commercial purposes are authorized without any prior written permission from the copyright holders provided the source is fully acknowledged. Reproduction of material in this information product for resale or other commercial purposes is prohibited without written permission of the copyright holders.

Applications for such permission should be addressed to:

Chief
Publishing Management Service
Information Division
FAO
Viale delle Terme di Caracalla, 00100 Rome, Italy

or by e-mail to:
copyright@fao.org

© FAO 2005

PREFACE

This volume reviews concepts of probability and risk of frost damage and uses that information to help readers make economic decisions about frost protection. Computer application programs are included with the book to help simplify complex calculations. The TempRisk.xls application computes the probability of temperature falling below critical temperatures and then, determines the certainty that such an event will happen at least once over a defined number of years. This application is useful to determine the probability and risk of frost damage occurring when the damage sensitivity is fixed during the period of interest. The FriskS.xls application calculates probability that a particular date will experience the last frost in the spring, the first frost in the autumn and the length of the growing season between the spring and autumn dates. The FriskS.xls application is useful to help people decide the physical risk of early planting or late harvest of field and row crops.

The DEST.xls application program is used to compute the risk of frost damage specific to a tree or vine crop that has changing sensitivity to frost during critical phenological stages. The program uses climate data and critical temperatures associated with 90 percent (T_{90}) and 10 percent (T_{10}) damage, which are input corresponding to specific phenological dates. It analyses the data between the first and last dates with sensitive phenological stages and produces tables of (1) yearly percentage frost damage for an unprotected crop and for 11 protection methods, (2) yearly yield for the unprotected crop and the 11 protection methods, (3) means and standard deviations of percentage fruit losses and crop yields and damages over years of record and (4) the mean and standard deviation of the number of frost events and the duration of the frost events.

Finally, the FrostEcon.xls program is provided to help users determine the economic risk of frost damage protection as well as the cost-effectiveness of various methods of frost protection. This is an elaborate program that combines probability and risk with cost and revenue information on various protection methods to determine which if any frost protection method should be adopted. The text contains illustrative examples and the FrostEcon.xls application will help growers and consultants to make wise decisions when considering the adoption of frost protection.

ACKNOWLEDGEMENTS

We want to thank Dr Michele Bernardi and Dr Rene Gomme from the Agrometeorology Group, Environment and Natural Resources Service Research, Extension and Training Division, Sustainable Development Department of the Food and Agriculture Organization of the United Nations for their assistance in planning and writing the Frost book. We want to thank our friends: Dr Luciano Mateos for encouraging us to write the book and Dr Helena Gomez MacPherson and Angela Scappaticci for their friendship and support during visits to FAO in Rome. Some thanks are due to Professors Donatella Spano and Pietro Deidda in the Dipartimento di Economia e Sistemi Arborei for providing encouragement and facilities during part of the book preparation at the University of Sassari, Italy. We also thank Dr Kyaw Tha Paw U and Dr Michael J. Singer from the Department of Land, Air and Water Resources for their continued support throughout this effort.

The authors thank their respective institutions, Department of Land, Air and Water Resources – University of California at Davis; Instituto Superior de Agronomia – Technical University of Lisbon; and Department of Agricultural and Resource Economics – Washington State University. We also thank the Food and Agriculture Organization of the United Nations and the University of California for financially supporting Dr Snyder's Sabbatical Leave to work on the book in Italy. We thank the Fundação para a Ciência e Tecnologia (FCT) and Fundação Luso-Americana para o Desenvolvimento for financially supporting Dr de Melo-Abreu's missions to the University of California at Davis to work on this book.

The authors thank Dr António Castro Ribeiro for supplying data from his thesis, which helped us to develop the analysis for wind machines. Professor Herb Hinman, School of Economic Sciences, Washington State University offered many valuable suggestions concerning financial analysis of farm assets. We also thank Neil O'Connell from the Tulare County Cooperative Extension – University of California for supplying information on the costs of frost protection. In addition, numerous people took the time to answer our survey on Appropriate Technologies and we thank them for their responses. Finally we want to thank the reviewers of the book for their valuable comments and suggestions.

Final editing of language and style on behalf of FAO was by Thorgerir Lawrence, Reykjavik, and layout and pre-press preparation was by Studio Bartoleschi, Rome, Italy.

CONTENTS

iii	Preface
iv	Acknowledgments
	1 – FROST PROBABILITY AND RISK OF DAMAGE
1	Importance of probability and risk
2	Risk and certainty calculations
4	Event probability calculations
4	Crops with fixed sensitivity
5	Data entry
5	Probability output
5	Risk worksheet and chart
7	Last spring and first autumn frost dates
7	Data entry
8	Probability output
8	Growing-season chart
8	Risk worksheet and chart
11	Calculation methods
11	Damage Estimator (DEST.xls) application
	2 – ECONOMIC EVALUATION OF PROTECTION METHODS
17	Introduction
19	Model overview
21	Initialization
26	Technology Selection
26	Budgets
30	<i>Acquisition cost of equipment</i>
30	<i>Annual Variable Costs</i>
31	<i>Total Annual Cost Summary</i>
33	Cost-Effectiveness
36	Risk
44	Other protection methods
46	REFERENCES
47	APPENDIX – EXAMPLES OF BUDGET SHEETS

FROST PROBABILITY AND RISK OF DAMAGE

IMPORTANCE OF PROBABILITY AND RISK

The most effective methods of frost protection are to plant crops that are not sensitive to freezing, plant in locations without freezing temperatures, or plant a crop that emerges or blooms after the danger of frost has passed. The first two methods are rarely achievable if you want to produce a particular product in a site that has freezing temperatures. In most areas of the world outside of regions with only tropical climates, subzero temperature is possible. Even in countries with tropical climates, frost events can occur at high elevations. The probability and risk of damaging temperatures changes with time of the year and, for some crops, sensitivity to damaging subzero temperatures also changes. Knowing the probability and risk is important because it helps growers to decide whether, what and when to plant at a particular location. The probability gives you the 'odds' that you will experience damaging temperature in any given year and the risk tells you the probability that this is likely to occur over a design period (e.g. the expected life in years of a tree crop or a frost protection method). Therefore, frost probability and risk analysis is a useful decision-making tool.

Making decisions about frost protection depends on the type of crop to be grown. For example, frost can damage annual 'field and row' crops and the probability of frost damage is mainly affected by plant selection for winter crops and when you sow for spring-planted crops. For winter crops, the damage will often occur in the coldest part of the winter. Using probability and risk calculations, one can determine the odds that the crop is damaged by frost. If the risk is high, the winter cereal could be replaced with a spring cereal to reduce losses. Haan (1979) presented the methodology to determine the probability and risk for crops that are commonly damaged by severe freezes in midwinter. He showed how to calculate the probability that temperature will fall below a critical damage temperature in any given year and he showed how to determine the risk of this happening one or more times over a given number of years. The approach is similar to that used by hydrologists when determining flood return periods or geologists estimating the probability and risk of earthquakes. Probability and risk statistics for floods and earthquakes are used to make decisions about how much money to invest in buildings and structures to avoid damage and loss of life.

Similarly, probability and risk information on minimum temperatures is used to make decisions about the odds that a crop will be lost to frost damage in any given year or over several years. The odds are then used to decide if the crop should be planted, if it is worthwhile to invest in insurance, if a different crop should be planted, or if frost protection is cost-effective.

Knowing the exact probability of reaching a specified critical damage temperature on any given date in the spring and autumn is useful for determining annual crop plant and harvest dates and the desirable length of growing season to avoid frost damage. The procedure to estimate these probabilities and an Excel application program 'FriskS.xls' to make the calculations is provided with this book.

For fruit trees and vines, the critical damage temperatures change with developmental stage of the crop and the dates of the growth stages vary from year-to-year. Consequently, determining probability and risk for orchard and vine crops is more complicated than for annual crops. For example, a critical damage temperature (T_c) might be -7 °C or lower at early bud break but it can increase to -2 °C or higher during small fruit stage a month or so later. An application program (TempRisk.xls) is provided with this book to calculate the probability and risk associated with a critical damage temperature during a specified period of time corresponding to a growth stage. For example, the T_c and beginning and ending dates for the period of interest are input into the application. Then, using 20 years or more of minimum temperature climate data, the probability that the temperature will fall below T_c during that period in any given year and the risk that it will happen one or more times within 5, 10, ..., 30 years are computed and graphically displayed. The calculation methods and instructions to use the TempRisk.xls are discussed in this chapter.

RISK AND CERTAINTY CALCULATIONS

Risk analysis is used to estimate the chances that a damaging event will or will not occur in the long term (i.e. over several years). For example, a grower wants to know the risk that a particular crop will be lost to frost over the expected lifetime of the crop or the design life for a frost protection method. In this book, the risk is determined using a method presented by Haan (1979) using a binomial distribution (i.e. a Bernoulli process). In a binomial distribution, the risk (R) of having one or more occurrences of temperature below the selected minimum temperature over a period of n years is calculated as:

$$R = 1 - \left(\sum_{i=0}^{n-1} \binom{n-1}{i} p^i (1-p)^{n-1-i} \right)$$

where $\binom{n}{0} = 1$ is the combination of n things taken 0 at a time and $P^0 = 1.0$.

Simplifying this expression gives the equation:

$$1 - P^n = 1 - \binom{n}{0} P^0 \quad \text{Eq. 1.2}$$

where $P = P(T < T_c)$. Since this is the risk of having one or more damaging frost events within n years, the certainty (C) of having no frost events is given by:

$$C = 1 - P^n \quad \text{Eq. 1.3}$$

Therefore, the probability (P) of having a frost event within any given year can be calculated from the certainty (C) as:

$$P = 1 - C^{1/n} \quad \text{Eq. 1.4}$$

where C is the fractional probability that the event will not occur within a specified number of years (n). A table of one-year event probabilities corresponding to a range of certainty and design periods (years) is given in Table 1.1. For example, to be 90 percent certain (i.e. $C = 0.90$) that the minimum temperature will not fall below a particular damaging temperature (T_c) within the next 15 years, the probability that this event will occur in any given year must be less than 0.007 or 0.7 percent (i.e. in 1 000 years, it should not happen more than seven times).

TABLE 1.1

Probability (P) of an event occurring in any given year corresponding to the certainty (%) that the event will not occur during the design period

CERTAINTY	DESIGN PERIOD (years)					
	%	5	10	15	20	25
30	0.2140	0.1134	0.0771	0.0584	0.0470	0.0393
35	0.1894	0.0997	0.0676	0.0511	0.0411	0.0344
40	0.1674	0.0876	0.0593	0.0448	0.0360	0.0301
45	0.1476	0.0767	0.0518	0.0391	0.0314	0.0263
50	0.1294	0.0670	0.0452	0.0341	0.0273	0.0228
55	0.1127	0.0580	0.0391	0.0294	0.0236	0.0197
60	0.0971	0.0498	0.0335	0.0252	0.0202	0.0169
65	0.0825	0.0422	0.0283	0.0213	0.0171	0.0143
70	0.0689	0.0350	0.0235	0.0177	0.0142	0.0118
75	0.0559	0.0284	0.0190	0.0143	0.0114	0.0095
80	0.0436	0.0221	0.0148	0.0111	0.0089	0.0074
85	0.0320	0.0161	0.0108	0.0081	0.0065	0.0054
90	0.0209	0.0105	0.0070	0.0053	0.0042	0.0035
95	0.0102	0.0051	0.0034	0.0026	0.0020	0.0017

EVENT PROBABILITY CALCULATIONS

Recall in the previous section that a probability $P = 0.007$ corresponded to a 90 percent certainty that an extreme event would occur in no more than 7 years of 1 000 years. The probability of an extreme event happening in any given year would ideally be determined by calculating the ratio of the observed extreme events over the number of years of record. However, typically one is fortunate to have 20 or 30 years of data, rather than the 1 000 or more years needed. Since data are limiting, the best approach is to determine a probability density function from the existing data set. The probability density function is an approximation for what is expected if a 1 000 or more years of data were available. There are many types of probability density functions, but Haan (1979) reported good results for minimum temperature data using a type I extreme value probability density function. The cumulative curve for a type I extreme value probability density function is:

$$P = 1 - \exp\left\{-\exp\left[\frac{T_c - \beta}{\alpha}\right]\right\} \quad \text{Eq. 1.5}$$

where $\alpha = \sigma/1.283$, $\beta = \mu + 0.45\alpha$, μ is the mean minimum temperature and σ is the standard deviation of the minimum temperatures over the years of record. Therefore, by calculating the mean and standard deviation of the minimum temperatures over years, calculating α and β and inserting them into Equation 1.5, one can find the probability that the minimum temperature in any given year will fall below T_c . The resulting probability (P) of the event occurring within any given year can be input into Equation 1.3 with the design period (n) to estimate the certainty that an extreme temperature below T_c will not occur within the n years. For example, if $P = 0.0111$ and the design period is 20 years, this corresponds to $C = 80$ percent certainty that the event will not occur within a 20-year period (Table 1.1).

CROPS WITH FIXED SENSITIVITY

Haan (1979) presented a method to estimate probability and risk of temperature falling below a critical value when the sensitivity of the crop to damage is fixed. The model was modified and an MS Excel application program 'TempRisk.xls' was written to make the calculations for a user-selected time period. Probabilities are calculated using a type I extreme value function and the risk is calculated using a Bernoulli process. The TempRisk.xls application program is included with this book.

Data entry

Up to 50 years of minimum temperature data can be input into the ‘Data’ worksheet of TempRisk.xls (Figure 1.1) and analysed to calculate the probability and risk. More accuracy is associated with more years of data, but a minimum of 20 years of data are required for reliable analysis. The beginning and ending dates for the time period being evaluated and the critical temperature are input in cells in the upper left of the ‘Data’ worksheet and the probability of exceeding the event is displayed below the critical temperature cell.

Probability output

The probability of the minimum temperature falling below the critical temperature within the period in any given year is displayed on the ‘Data’ worksheet. However, the probability of having a lower temperature for a range of subzero temperature is plotted in the ‘FrostProb’ chart (Figure 1.2). For example, from Figure 1.2, there is about an 8 percent probability that the minimum temperature will fall below -4 °C during the period 1 May through 20 December for the data that were entered into TempRisk.xls.

Risk worksheet and chart

The certainty of having no minimum temperature below the critical damage temperature for design periods of 5, 10, ... , 30 years are plotted in the ‘Risk’ chart of TempRisk.xls (Figure 1.3). For example, there is about 65 percent certainty that the minimum temperature will not fall below -4 °C within a 5-year period. At the same time, there is only about 10 percent certainty that this will not occur during a 30-year period. Clearly, a longer design period has more chances for damage to occur.

FIGURE 1.1

A sample of the ‘Data’ worksheet for the TempRisk.xls application program

Data example:		2-Feb										
Beginning Date:	1-May	Enter the year number in this light gray highlighted cell. In the first row, you should										
Ending Date:	20-Dec	be prepared to enter values of 0 for the first 4 years (as representing the data for previous 4										
Critical Temp (°C):	-4.0	years later) to avoid "Not enough data."										
Probability (%)	8											
		YE-4	YE-3	YE-2	YE-1	YE-0	YE-1	YE-2	YE-3	YE-4	YE-5	
DATE	DOY	1988	1987	1988	1989	1990	1991	1992	1993	1994	1995	
1-Jan	1	7	5.5	-2.8	-1.3	2.8		2.5	2.1	2.1	2.8	
2-Jan	2	8.3	7.1	8.8	-0.1	2.5	-3.8	8.8	8.8	2.8	2.7	
3-Jan	3	5.5	8.5	2.5		-1.3	-0.1	2.7	-0.8	8.1	8.7	
4-Jan	4	8.8	2.5	2.7		-2.8	-2.1	8.1	-2.7	8.1	7.5	
5-Jan	5	8.7	1.3	8.1	-8.7	-2.3		8.3	-2.3	2.1	8.8	
6-Jan	6	5.7	2.1	-0.8	-2.7	1.3	2.8	7.3	-1.1	1.3	7.1	

FIGURE 1.2

The probability of having a lower minimum temperature during a specified time period (from the 'FrostProb' chart of the TempRisk.xls application program) plotted against the corresponding minimum temperature

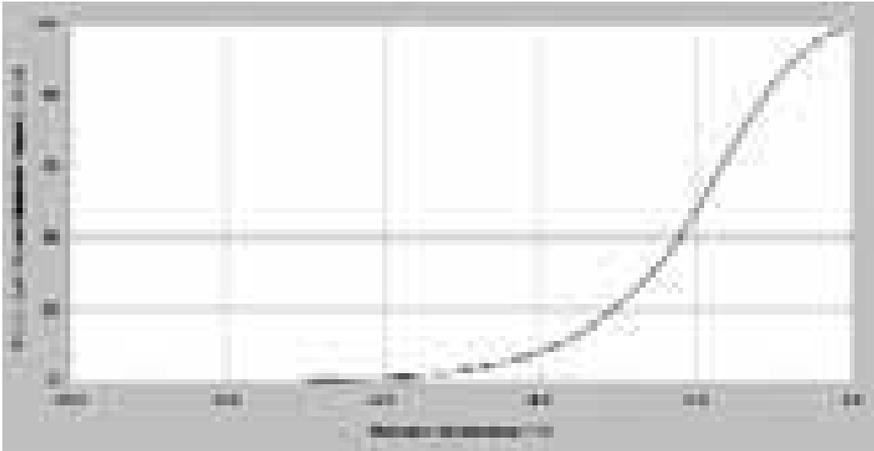
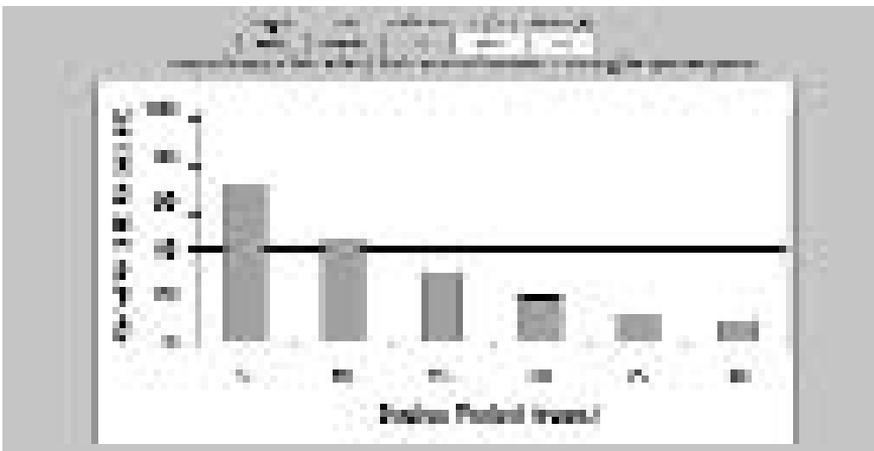


FIGURE 1.3

Certainty (%) of no events with the minimum temperature falling below the input critical temperature (i.e. -4.0 °C) between 1 May and 20 December within a 5, 10, ..., 30-year design life (from the 'Risk' worksheet and chart of the TempRisk.xls application program)



LAST SPRING AND FIRST AUTUMN FROST DATES

Knowing the probability associated with the last damaging frost date in the spring and the first damaging frost date in the autumn are important for planning when to plant a crop. For example, a later planting date is appropriate if the probability of damaging temperature is too high in the spring. If the probability of damaging temperature is high before harvest in the autumn, then planting a shorter season variety is wise. It is also advantageous to know the probability and risk when evolving longer-term strategies for planting and harvesting dates, and for variety selection. In addition to identifying possible frost problems, analysing probability and risk provides information on the odds that these problems will occur. Therefore, it is useful to decide an acceptable level of risk for growing a crop as well as for deciding if frost protection is justifiable. The application program FriskS.xls is provided with this book to make the probability and risk calculations associated with the last spring and first autumn frost dates.

Data entry

The accuracy of probability calculations from temperature data is limited by the years of data, so a greater number of years gives a more accurate estimate. To use the FriskS.xls application, input a minimum of 20 years of daily minimum temperature data into the Data worksheet. However, use more years of data if available. It is important to put the year corresponding to the temperature data at the top of the data column. A critical temperature is input in a cell near the top left hand side of the Data worksheet (Figure 1.4).

FIGURE 1.4

A sample of data input into the Data worksheet of the FriskS.xls application program, with a critical temperature $T_c = 0.0$ °C

The screenshot shows a spreadsheet interface with a title bar 'FriskS.xls' and a menu bar. A text box at the top provides instructions: 'Enter the year (between 1 and the right-most highlighted year) Enter the minimum temperature comparison by the column the next year the spreadsheet is the data in column B. Enter a value to input into the worksheet data.' The main data area is a grid with columns for years 1988 through 1997. The first row contains the years. The first column contains numerical values, with the top cell containing '0.0'. The rest of the grid is filled with numerical data points representing temperature readings.

Probability output

After data entry, FriskS.xls calculates the probabilities that a minimum temperature below the input critical temperature will occur on a date later in the spring. Similarly, the probabilities that a minimum temperature below the input critical temperature will occur on a date earlier in the autumn are computed. Then the probabilities for having a minimum temperature lower than the input critical temperature on a date later in the springtime or earlier in the autumn is plotted versus date in the 'FrostProb' chart (Figure 1.5).

Growing-season chart

The FriskS.xls application also calculates probabilities for the length of growing season. Here the length of the growing season is defined as number of days between the mean last date with a minimum temperature below the input critical temperature in the spring and the mean first date with a minimum temperature below the input critical temperature in the autumn. The probabilities are plotted versus date in the 'GrowingSeason' chart. An example is shown in Figure 1.6.

Risk worksheet and chart

The certainty of having no dates after a selected date in the spring with a minimum temperature below the critical temperature (e.g. $T_c = 0.0$ °C) is calculated and displayed in the 'SpringRisk' worksheet and chart (Figure 1.7). The selected date (i.e. to determine the probability that $T < T_c$ on a later date) is input at the top of the SpringRisk worksheet (e.g. 20 March in Figure 1.7). The probability (%) that a day with $T < T_c$ will occur after that date in any given year is calculated and displayed. Then the certainties (%) that no temperature below T_c will be observed during a 5, 10, ... , 30-year design period are displayed as a column graph. For example, there is about 45 percent certainty that no temperature below $T_c = 0$ °C will be observed after 20 March, but there is less than 1 percent certainty that no temperature below 0 °C will occur after 20 March during a 30 year period (Figure 1.7).

A similar procedure is used to calculate and display certainties that a minimum temperature will fall below T_c before a selected date in the autumn. Figure 1.8 shows a sample from the 'FallRisk' worksheet with a selected date of 1 November and a $T_c = 0.0$ °C. The certainties are again displayed as a column graph. For example, there is close to 85 percent certainty that there will be no minimum temperatures below 0 °C before 1 November during a 5-year period. For a 30-year period, the certainty is only about 35 percent.

FIGURE 1.5

A plot of the probability of having a date with the minimum temperature lower later in the spring or earlier in the autumn versus date (from the FrostProb chart of the FriskS.xls application program)

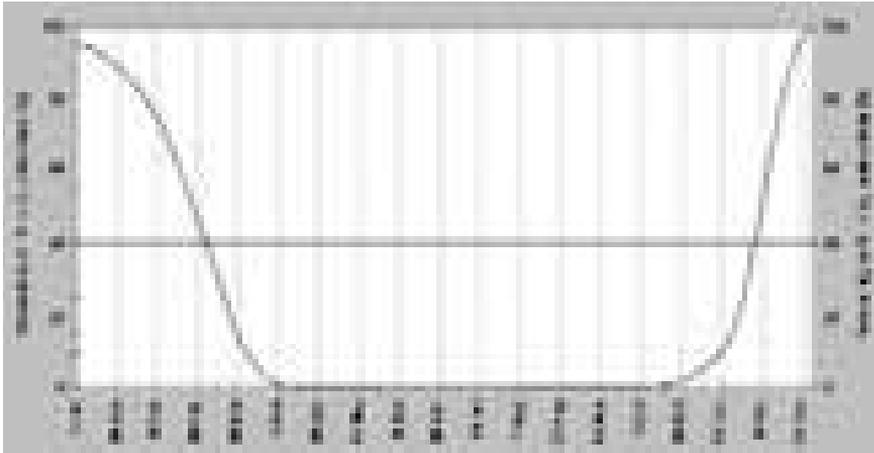


FIGURE 1.6

Probability of fewer days between the last date in the spring and the first date in the autumn with minimum temperature below the input critical temperature (from the 'GrowingSeason' chart of the FriskS.xls application program)

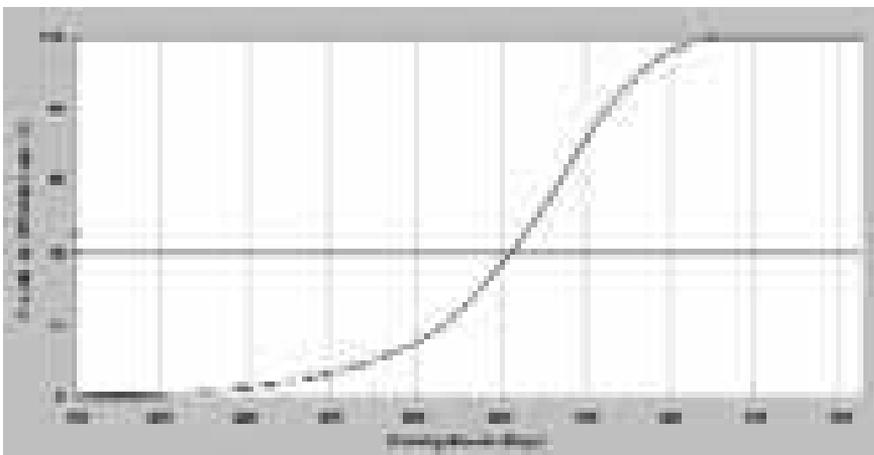


FIGURE 1.7

Certainty (%) of no events of the minimum temperature falling below the input T_c after '20 March' over 5, 10, ... , 30 years (from the 'SpringRisk' worksheet and chart of the FriskS.xls application program)

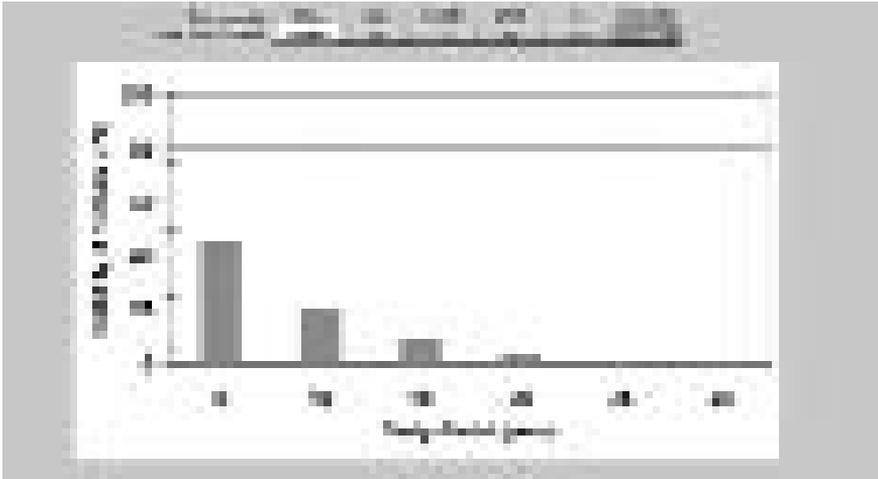
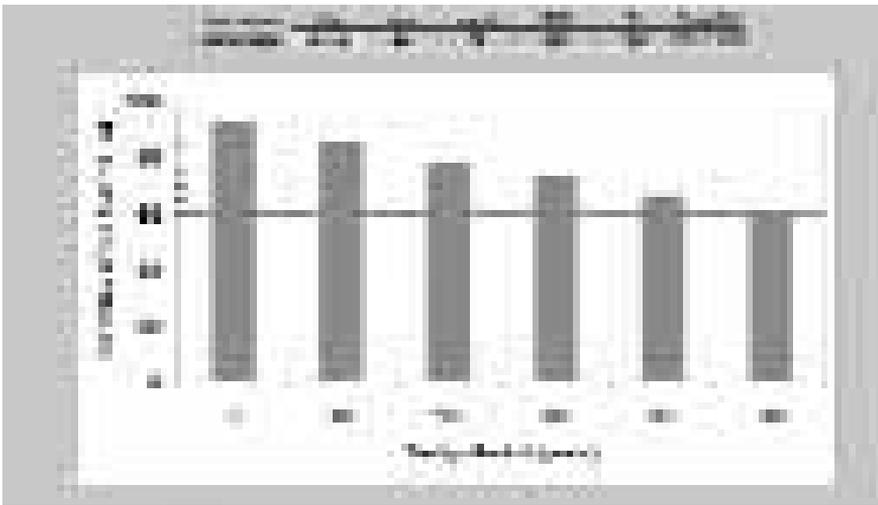


FIGURE 1.8

Certainty (%) of no events of the minimum temperature falling below T_c before 1 November over 5, 10, ... , 30 years (from the 'FallRisk' worksheet and chart of the FriskS.xls application program)



Calculation methods

The FriskS.xls application program first determines the last spring date when the minimum temperature falls below the input critical temperature for each year. Then it calculates the mean (μ_d) and standard deviation (σ_d) of the last spring date over the years of record. The probabilities for the last spring date are calculated using:

$$P(T_n < T) = \frac{1}{\sigma_d} \int_0^d \exp\left[-\frac{1}{\sigma_d} \left(\frac{d-t}{\alpha_d}\right)\right] dt \quad \text{Eq. 1.3}$$

where 'd' is the day of the year, $\alpha_d = \sigma_d / 1.283$ and $\beta_d = \mu_d + 0.45\alpha_d$.

For the first date of damaging temperature in the autumn, the mean and standard deviation of the first date in the autumn is computed over the years of record and the probabilities are calculated using the same equations for α_d , β_d and $P(T_n < T)$. The certainty calculations for the SpringRisk and FallRisk charts are done using Equation 1.3. For the growing season calculations, the yearly difference between the last spring date and the first autumn date are used to compute the mean and standard deviation over years. Then the same equations used for the last spring and first autumn dates are used to calculate the probabilities of having fewer days in the growing season.

DAMAGE ESTIMATOR (DEST.XLS) APPLICATION

The MS Excel Damage Estimator application program – DEST.xls – is used to calculate expected frost damage and crop yield using site-specific maximum and minimum temperature climate data for crops having no protection against frost, and using up to 11 different frost protection methods. Up to 50 years of maximum and minimum temperature data can be used in the analysis. Critical temperatures associated with 90 percent (T_{90}) and 10 percent (T_{10}) damage are input corresponding to specific phenological dates. Frost damage is assumed to be multiplicative. For example a frost causing 50 percent damage followed by a second event of 50 percent damage will result in a 75 percent yield loss (i.e. 50 percent in the first event and 50 percent of 50 percent = 25 percent in the second event). It is assumed that damage is directly related to the minimum temperature and it is unrelated to the duration at a minimum temperature.

The program is structured into three steps. In the first step, the estimated °C of protection expected for the 11 protection methods are input into the 'Start here' worksheet (Figure 1.9). Then input the crop name, crop height, plants per

hectare, type of plant and expected yield without frost damage. If the crop is thinned, input the percentage of fruit to remove in the appropriate cell. If the crop is not thinned, leave 0 percent in the thinning cell. When re-running the application, type 'Y' in the "Erase all previous inputs" cell to remove earlier entries. Leave in 'N' or type 'N' to leave the entries shown in the worksheet. When finished with entries, click on 'Complete Step 1 of 3' to continue to Step 2.

FIGURE 1.9

Sample entries for the 'Start here' worksheet



In the second step, input the maximum and minimum temperature climate data. An example of the first few days of several years of maximum and minimum temperature data is shown in Figure 1.10. It is only necessary to enter data for the period when frost damage is likely to occur. This period should bracket the dates when critical temperatures exist in the table included in the "Crop" worksheet. When finished, click on 'Complete Step 2 of 3' to continue.

Finally, the third step is to input the critical temperature data corresponding to dates of sensitive phenological stages. For example, Figure 1.11 shows the entry of T_{90} and T_{10} data and dates for phenological stages of apple cv. Golden Delicious. The program will only analyse the data between the first and last date with critical stages. Therefore, a “last stage” entry should be made as shown in Figure 1.11 so the last period is identified.

FIGURE 1.10

A sample of entry of maximum and minimum temperature for the ‘Weather’ worksheet

Date	Max Temp	Min Temp
01/03	10	-5
05/03	12	-3
10/03	15	-1
15/03	18	1
20/03	20	3
25/03	22	5
30/03	25	7
05/04	28	10
10/04	30	12
15/04	32	15
20/04	35	18
25/04	38	20
30/04	40	22
05/05	42	25
10/05	45	28
15/05	48	30
20/05	50	32
25/05	52	35
30/05	55	38

FIGURE 1.11

Sample entry of T_{90} and T_{10} data corresponding to the dates of critical phenological stages into the ‘Crop’ worksheet

Date	T_{90}	T_{10}
01/03	10	-5
05/03	12	-3
10/03	15	-1
15/03	18	1
20/03	20	3
25/03	22	5
30/03	25	7
05/04	28	10
10/04	30	12
15/04	32	15
20/04	35	18
25/04	38	20
30/04	40	22
05/05	42	25
10/05	45	28
15/05	48	30
20/05	50	32
25/05	52	35
30/05	55	38

When finished with the 'Crop' worksheet, click on 'Complete Step 3 of 3' and the application displays the output in the RESULTS worksheet where you will find:

1. A table of yearly percentage frost damage to the fruit or nut set for an unprotected crop and the 11 protection methods (Figure 1.12)

FIGURE 1.12

A sample of the 'RESULTS' worksheet showing the means and standard deviations of percentage damage and yield for the 11 protection methods and for no protection

The screenshot displays the 'RESULTS' worksheet. At the top, there is a summary table for 'Damage' and 'Yield Loss' across 11 protection methods and a 'No Protection' control. Below this is a large table showing 'Frost Damage to Fruit or Nut Set' for each year (1990-2000) across the 11 methods. The bottom section shows 'Expected Marketable Yield' for each year and method, with a total yield for each year.

The worksheet also shows the fraction of potential yield lost to frost damage and the expected marketable yield by year and protection method. In the DEST.xls application, the bottom table is displayed to the right of the middle table.

2. A table of yearly yield on a tonnes per hectare basis for the unprotected crop and the 11 protection methods. If a percentage of the fruit or nut thinning was input into the 'Start here' worksheet, there is no yield reduction until that percentage of fruit or nut set is lost to frost damage first. Thus, if there is a frost event, it is assumed that the frost damage thinned the crop and only losses in addition to the thinning will affect final yield.
3. A summary table with yearly averages and standard deviations of percentage losses of the fruit or nut set and means and standard deviations of crop yields (Figure 1.12).
4. The mean and standard deviation of the number of frost events and the duration of the frost events are shown in a summary table.

Calculation of the physical risk of frost damage was investigated in this chapter, and use and interpretation of the physical risk damage calculator (DEST.xls) was presented. In the next chapter, the financial decision of whether or not to implement frost protection is investigated, and evaluated in economic terms. The concept of risk is therefore extended from physical risk to financial risk. A personal computer program is presented to support decision-making.

ECONOMIC EVALUATION OF PROTECTION METHODS

INTRODUCTION

Financial problems often arise from bad investments in land, machinery, buildings and other capital assets. The decision to adopt a particular frost protection technology is no different. Some frost protection technologies involve large capital investments, often with borrowed funds that require repayment of principal and interest. Others may involve a smaller initial investment in equipment, but larger annual variable operating expenses. Each technology must be evaluated on a common, after-tax financial basis, if applicable, that properly accounts for all annual costs of protection.¹ This way, the individual farmer is able to choose the best technology for their financial circumstances (i.e. the farmer is better able to judge the financial benefits and costs of frost protection). Large capital outlays, coupled with the inherent risk of a long-term investment, extensive debt and volatile weather impacts accentuate risk in a volatile economy. An unwise decision to adopt a particular frost protection method can have serious and long-lasting consequences.

A thorough financial analysis should be conducted before committing capital to frost protection. Such financial analysis will identify those investments with the potential for the best possible financial performance. In general, a sound investment must satisfy three criteria:

- It must be profitable.
- The cash flow must be financially feasible.
- The risk must be compatible with the preferences and financial position of the investor.

Economic analysis of frost protection is complicated by the random or stochastic nature of weather and thus the stochastic nature of net benefits

1. Most middle- to upper-income countries collect income taxes from farmers. The various costs of production are deductible expenses that reduce income tax liability. This practice is less common in poorer countries, where sales taxes are collected on inputs and products.

(i.e. benefits minus costs) that derive from adopting a particular frost protection technology. It follows that risk is a fundamental element of the financial decision to adopt frost protection, whereas risk often plays a less prominent role in many agricultural investment analyses. Nevertheless, one may not be able to evaluate the financial risk of the adoption decision unless adequate (e.g. a 20- to 50-year time series) minimum and maximum temperature data are available to capture the stochastic nature of frost damage and protection. It is for this reason that the decision process presented here involves two levels of analysis.

Whenever insufficient weather data are available, which is common in less developed parts of the world, the financial analysis must default to cost-effectiveness – the least-cost way of achieving a given level of protection (measured in temperature degrees). Cost-effectiveness assumes that the number of frost events, their duration and extent of damage are known with reasonable certainty, presumably at the mean or expected level. Each of the frost protection methods providing a given amount of protection is simply ranked from lowest to highest expected annualized cost.

Whenever sufficient weather data exist, the economic analysis should incorporate the stochastic elements of frequency, duration and temperature of frost events and thus the stochastic nature of net benefits (i.e. incremental profitability) that derive from adopting a particular technology. Frost protection methods providing given minimum degrees of protection are ranked in descending order of expected net benefits. The stochastic distribution of net benefits must also be adequately characterized if a farmer is to make an intelligent decision concerning the degree of acceptable financial risk. It should be noted that net benefits or incremental profitability are measured by discounted, after-tax cash flow techniques that adjust for the impact of time on the value of money. A unit of currency, say a USA dollar, is worth more than a dollar some time in the future because there are alternative uses for capital; inflation devalues buying power; and the future is inherently uncertain. Meaningful financial analysis of the decision to adopt durable frost protection methods requires minimizing the influence of time by expressing the stream of benefits and costs in terms of current or “present value” monetary units (e.g. present value or *PV* dollars ²). The interest rate used to remove the influence of time on future monetary values is the inflation-removed, opportunity cost of

2. The present value of a future amount of money is calculated as $PV = (1+i)^{-n} FV$ where i is the interest rate, n is the number of years and FV is the future value or amount of money at some future point in time.

capital. It is perhaps easiest to think of the interest rate as the rate of return capital could earn in the farmer's next best alternative investment.

Net benefits of frost protection are calculated as annualized after-tax net present values.³ Annualization allows one to compare investments across different asset lives. It is the financial equivalent of averaging across financial streams of different annual amounts and different numbers of years. This process makes annualized *PVs* directly comparable across frost protection methods.

Alternative measures of profitability, like internal rate of return or realizable rate of return, are not examined. Cash flow performance (i.e. whether the investment in frost protection is likely to be recovered within the asset's expected useful life or whether the debt can be recovered before the loan matures) is left to a more detailed financial analysis.⁴

The remainder of this chapter is dedicated to the presentation of a personal computer-based program (FrostEcon.xls) to help farmers anywhere in the world conduct the cost-effectiveness and risk analyses essential to making wise financial decisions concerning the adoption of frost protection methods. The program is built on a Microsoft Excel platform to facilitate broad usage, with minimal start-up and learning time. Visual Basic macros guide the user through the program and through internal simulations. Modest familiarity with Microsoft Excel and elementary financial concepts, or the assistance of a qualified professional, is useful. We begin with an overview of the model and then illustrate each of the components with an example on a 10 ha orchard growing apples, cv. Golden Delicious.

MODEL OVERVIEW

The FrostEcon.xls decision model consists of four interlinked sections. The first section is the initialization data that links common, farm-specific parameters into the subsequent sections. For example, farm size, frost information and financial information are specified here. The second section contains the list of nine frost-protection methods; all or some may be checked

-
3. Investments with different lives have different present values of annuity factors (*PVAF*). The annualized net present value of an investment is calculated as $NPV_A = NPV / PVAF = NPV / (1-(1+i)^{-n})/i$, where *NPV* is the net present value, *i* is the interest rate and *n* is the number of years. It should be noted that the annualized present value of a constant payment, cost or net benefit is simply the constant present value amount.
 4. The interested reader is encouraged to consult more generic financial management programs, such as: Hinman, H.R. and Boyer, J. *FINANCE: A Computer Program to Analyze Agricultural Investments*, ver.3.0, CD0005. Cooperative Extension, Washington State University, November 2002. Copies available online at <http://pubs.wsu.edu/>.

for analysis. The third section contains the various frost-protection budgets. The fourth and final section contains output or report files that summarize the cost-effectiveness and/or the risk analysis results. The user is moved automatically to the next section once a current section is complete.

Following introduction of data that initialize the method-specific frost protection budgets and subsequent analysis, the budget process is illustrated for a single protection technology, namely electric-powered wind machines. Budgets for the eight additional technologies, in addition to electric-powered wind machines, are presented in the Appendix. It is during the budgeting process that after-tax financial considerations first arise. We next illustrate the essential financial elements of cost-effectiveness analysis or risk analysis through examples.

One should keep in mind that this program is designed to assist farmers in making rational economic decisions, regardless of country of origin. Aspects of the computer program consequently are generic, involving less specificity than might otherwise occur if developed for a particular farm in a particular country. All costs of protection should be regarded only as illustrative. The budgets were developed around representative costs that might be incurred in the western USA for apples, cv. Golden Delicious. Obviously, all costs are site and application specific; the cost of labour in California will differ greatly from that incurred in Portugal or another country. The user may change any of the default costs to customize the budgets to local conditions or applications. Similarly, detailed tax laws are not embedded in the program. Users are simply queried as to the tax-deductibility of capital equipment, variable costs and interest charges, and then they are asked to stipulate the applicable tax rate, if any. After-tax calculations are based on the various combinations of possible answers to the general tax questions that initialize the analysis. Depreciation is assumed to be straight line.

Tailoring the prototypical budgets is facilitated through a colour-coding scheme. The user will find many cells are write-protected, while others can be changed. The budgets involve four distinct elements: initialization data; the initial capital investment costs; variable annual operating costs; and a total annual cost summary section that incorporates both the annualized capital cost plus the annualized variable costs. The summary section presents both annualized present value (PV) cash costs and annualized PV after-tax costs, if applicable.

Availability of minimum and maximum temperature data dictates whether the analysis is limited to cost-effectiveness or whether a full risk analysis is conducted. During data initialization the user is prompted for suitable weather data. If 20 to 50 years of weather data are available, a risk analysis will be

conducted. Otherwise, the program generates only a cost-effectiveness table, in which frost protection methods are ranked according to least annual cost of attaining a particular level of protection. If adequate weather data are available for a risk analysis, the program is linked to the production risk or damage calculator model described in Chapter 1. The damage calculator sub-model generates the average and standard deviation of the number of frost events per year and average hours of duration, adjusting for the temperature and stage of plant growth. This sub-model also runs in the background to yield various statistics of the estimated crop losses and actual yields for the selected technologies, where the thinning requirement of the crop is taken into account. If adequate weather data are absent, one must specify the average number of frost events per year and their average duration.

It will be shown later that the financial risk from frost protection is not adequately characterized by first and second moments (mean and standard deviation) of the net benefit distribution. An alternative characterization of risk is presented that provides decision-makers with adequate information to make informed assessment of tradeoffs between expected net benefits and associated risk of loss or gain.

Initialization

The first spreadsheet (Figures 2.1.a and 2.1.b) in the financial analysis program initializes subsequent analyses. There are four elements to initialization: legend; general information; number and duration of frost events per year; and financial input. Once this sheet is completed, the user must press a “Continue” button at the bottom to proceed to the next step in the analysis. All subsequent spreadsheets and analyses are automatically updated or linked, or both, to this initialization data when used for the various calculations.

The legend indicates the colour-coding scheme used throughout the workbook to identify different types of cells. Black-boxed cells allow user input, but input is not necessarily mandatory. This cell type includes both empty cells and cells that contain values previously input or illustrative values. Permission to override non-empty cell values is granted. Solid yellow cells are default values that are locked and can not be changed. These default values are often present in hidden columns so that a user may refer to them as needed, especially when tailoring the budgets. Cells outlined in red require user input. Grey cells outlined in blue are linked to other parts of the sheet or workbook and locked. Finally, bright blue cells outlined in blue indicate internal calculations and are locked.

FIGURE 2.1a

Top section of Initialization worksheet

INITIALIZATION DATA

Legend

 Field Input (green cell default) Input (black cell)

 Exclude (grey cell) Validation (red cell default)

 Required (blue legend)

PLEASE BE CAREFUL PROVIDING DATA TO INITIALIZE THE MODEL. YOU MUST PROVIDE ALL NECESSARY DATA TO RUN THE MODEL. YOU MUST PROVIDE ALL NECESSARY DATA TO RUN THE MODEL. YOU MUST PROVIDE ALL NECESSARY DATA TO RUN THE MODEL.

PLEASE BE CAREFUL PROVIDING DATA TO INITIALIZE THE MODEL. YOU MUST PROVIDE ALL NECESSARY DATA TO RUN THE MODEL. YOU MUST PROVIDE ALL NECESSARY DATA TO RUN THE MODEL. YOU MUST PROVIDE ALL NECESSARY DATA TO RUN THE MODEL.

<p>VEGETABLE PRODUCTION</p> <p>Field Name</p> <p>Year from 1980</p> <p>Crop name</p> <p>Date of harvest (dd/mm/yyyy)</p> <p>Default value for yield (kg/ha)</p> <p>Required yield for minimum crop yield (kg/ha)?</p> <p>Default % of yield for harvest (kg/ha/ha)</p> <p>Yield (kg/ha)</p>	<p>Soils Data</p> <p>Soil</p> <p>Calves To Harvest / Apply</p> <p>10/10/00</p> <p>100</p> <p>100</p> <p>100</p>
--	--

Number and duration of frost events per year

PLEASE BE CAREFUL PROVIDING DATA TO INITIALIZE THE MODEL. YOU MUST PROVIDE ALL NECESSARY DATA TO RUN THE MODEL. YOU MUST PROVIDE ALL NECESSARY DATA TO RUN THE MODEL. YOU MUST PROVIDE ALL NECESSARY DATA TO RUN THE MODEL.

PLEASE BE CAREFUL PROVIDING DATA TO INITIALIZE THE MODEL. YOU MUST PROVIDE ALL NECESSARY DATA TO RUN THE MODEL. YOU MUST PROVIDE ALL NECESSARY DATA TO RUN THE MODEL. YOU MUST PROVIDE ALL NECESSARY DATA TO RUN THE MODEL.

Please input all frost event years of minimum harvest data (dd/mm/yyyy) for "Validation" for the model to run. In the file and four cells.

Average frost events per year (days)	
Standard deviation events per year (days)	
Average event duration (days)	
Standard deviation event duration (days)	

PLEASE BE CAREFUL PROVIDING DATA TO INITIALIZE THE MODEL. YOU MUST PROVIDE ALL NECESSARY DATA TO RUN THE MODEL. YOU MUST PROVIDE ALL NECESSARY DATA TO RUN THE MODEL. YOU MUST PROVIDE ALL NECESSARY DATA TO RUN THE MODEL.

Average frost event duration (days)	
Standard deviation event duration (days)	

FIGURE 2.1b

Bottom section of Initialization worksheet

Financial inputs

The default values are in the cells shown (B). The changes if available for your local area may be input. The local currency symbol for this initiative) and under B is the exchange rate to local currency, per U.S.

Local currency to United States \$	<input type="text" value="3"/>	
Per-hour cost per U.S.	<input type="text" value="1.66"/>	
LABOR INPUTS (F0044, F0050)		
Is labor not available?	<input type="text" value="0"/>	
Are capital equipment costs not available?	<input type="text" value="0"/>	
Are materials not available?	<input type="text" value="0"/>	
What is the maximum wage rate per hour?	<input type="text" value="20"/>	
Enter information for capital equipment		
What is the maximum capital equipment available in your world (enter a value between 1 and 2)? This is not below the standard.	<input type="text" value="1000"/>	U.S.
% Return default: 20%	<input type="text" value="20"/>	%
% Time payment	<input type="text" value="100"/>	%
Interest rate (default is 10 percent)	<input type="text" value="10"/>	%
Real interest rate (%)	<input type="text" value="17"/>	%
Local information for variable costs		
% Return default: 20%	<input type="text" value="20"/>	%
The discount rate (or real interest rate on capital equipment)	<input type="text" value="20"/>	%
Discount Rate %	<input type="text" value="20"/>	%
Revenue information		
What is the WUO00 VALUE for each WUO00 VALUE you receive per hour (enter 0 if none)?	<input type="text" value="100"/>	U.S.
MINIMUMS		
Minimum cost (minimum) and time	<input type="text" value="1.66"/>	%

The user is required to supply eight elements of general information. Some of this information is solely for identification purposes (farm name, user, date prepared) but other elements (i.e. crop, protection area, expected yield without protection, typical percent of small fruit thinned, and farm latitude) are critical to subsequent analysis.

Number and duration of frost events per year are essential to determine whether the analysis proceeds as a cost-effectiveness or a risk analysis. There are two ways to input the number and duration of frost events per year. If at least 20 years of maximum and minimum temperature data are available, a “Calculator” button links the user directly to the frost damage calculator (see Chapter 1) to determine the statistical mean number of events and duration and their standard deviations. When sufficient weather data are not available, the user must estimate the mean number of frost events per year and mean event duration. Only one of the alternatives to input the average number of events per year and their average duration per night may be chosen. Since thirty years of data are available for this illustration, the damage calculator computed the mean and standard deviation of number of events (2.1 days and 1.9 days) and duration (5.5 hrs and 2.4 hrs), respectively.

The final section of the initialization sheet involves financial data that are used to compute after-tax, annualized present value net benefits. This section is compartmentalized into seven subsections. Some input data are required from all users (red-boxed cells); other input data are not required from all users (black-boxed cells). Since elements of the seven subsections have not been previously discussed and are vital to understanding the subsequent economic analysis, each subsection is discussed below.

The default currency used throughout this program is USA dollars (\$). Universal application, however, requires the flexibility to change the default currency to a local currency and automatically update all \$ denominated values to local currency denominations. The currency is changed in two steps. First, a local currency symbol or name must be stipulated and second the exchange rate (i.e. the ratio of local currency to US\$ 1) must be specified. If the local currency is \$, it must be stipulated as such and the exchange rate is 1.00 (i.e. \$/\$). Once a local currency is specified, new currency symbols and monetized values reflecting the exchange rate will be applied automatically throughout the analysis.

After-tax calculations, if applicable, are based on the user-specified inputs provided in this subsection. As noted above, most middle- to upper-income countries collect income taxes from farmers. Often, the various costs of

production (e.g. capital costs, annual operating or variable costs, and interest costs) are tax-deductible expenses that reduce income tax liability. Since this practice is not universal, initialization requires the user to stipulate whether any of the three types of expenses are tax deductible. The user is also required to stipulate the appropriate marginal tax rate as a percentage, 0 percent if no income tax applies.⁵ All expenses are tax deductible at a 20 percent rate in this example.

The next two financial subsections (loan information for capital equipment and loan information for variable costs) are essential to calculate the after-tax, annualized *PV* stream of expenses. Capital equipment may or may not be debt financed, depending upon the cost, and the cost threshold that defines when firms will debt finance equipment purchases differs across firms. Accordingly, the user is asked to specify various loan parameters. First, the user must specify the minimum capital equipment expenditure that would be financed with borrowed capital. Amounts below that threshold are assumed to be cash purchases. All amounts above that threshold are funded with a blend of borrowed funds and cash-down payment. An illustrative threshold of \$ 2 000 is specified, but may be changed by the user. If the equipment is debt financed, the user must specify the percent of equipment expenditure borrowed (default is 70 percent); the down-payment percentage is calculated as (1 minus the fraction borrowed). Life of the loan also must be specified (default is 10 years). Finally, the interest rate must be specified as the “real interest rate” (i.e. market rate minus inflation rate). Use of the real interest rate simplifies subsequent financial calculations. The real interest rate on borrowed capital for equipment purchases is 4 percent in this example.

All variable costs may be financed with an operating loan or a line of credit against current-year production. It is assumed that the average draw on the line of credit is 50 percent, though the user may change this default. All variable expenses, including interest charges, are repaid in a single year. The real interest rate on the line of credit, 4 percent in this example, must be user specified and ordinarily is greater than or equal to the real interest rate on borrowed funds used to finance capital equipment.

The final piece of essential user-specified information is the before-tax, expected gross price (revenue) received per metric tonne (t) of output. This price is the weighted average price paid per tonne for fresh and processed apples. It is

5. This simplification avoids any attempt at capturing tax-law intricacies that differ from country to country. Accordingly, one should regard the after-tax calculations as only a rough guide to the adoption decision. The user is advised to consult a tax professional.

used in the calculation of frost protection benefits whenever a risk analysis is performed. In this example, it is assumed that the weighted average price of Golden Delicious apples is \$ 550/t.

The user is also asked to specify the average inflation rate, though this information currently is not incorporated in the subsequent analysis. Upon completing the initialization data entry, the user should press the “Continue” button to move to the next sheet.

Technology Selection

Nine frost protection technologies may be analysed with this program. However, not every technology is appropriate or of interest to every user. The user may select any or all of the frost protection methods to be analysed by placing an X in the box next to the protection method (Figure 2.2). Those methods left unchecked will not be analysed. It is important to understand that there is a cost to checking all technologies. While prototypical budgets are prepared for each technology, changes in budget elements are necessary to reflect local conditions and costs. For example, hourly wage rates must reflect local conditions. Equipment costs may also need to be tailored to local markets and to specific applications. Such changes are essential to prepare accurate cost-effectiveness or risk analysis of frost protection. The program is developed to provide a flexible and simple mechanical process to customize budgets. Nevertheless, acquiring location-specific cost data can be time consuming. All technologies are checked in the example.

Once the technologies are selected, the “Continue” button at the bottom of the TechSelect sheet should be pressed. The user will be taken to the budgets for each of the selected frost protection method, one at a time.

Budgets

The structure of budgets for each protection method is identical. Each budget begins with a restatement of data copied and locked from the first section of the Initialization sheet, followed by some method-specific initialization data that define the frost protection technology. For example, electric fan wind machines may be purchased in a variety of sizes and power units. If the default specification is considered inappropriate, the user may revise the fan-specific data to reflect the design being evaluated (e.g. the required number of size-specific fans for protecting the farm and the estimated °C of protection. Guidance concerning the degrees of protection offered by each method may be found in Chapter 7 (Volume I).

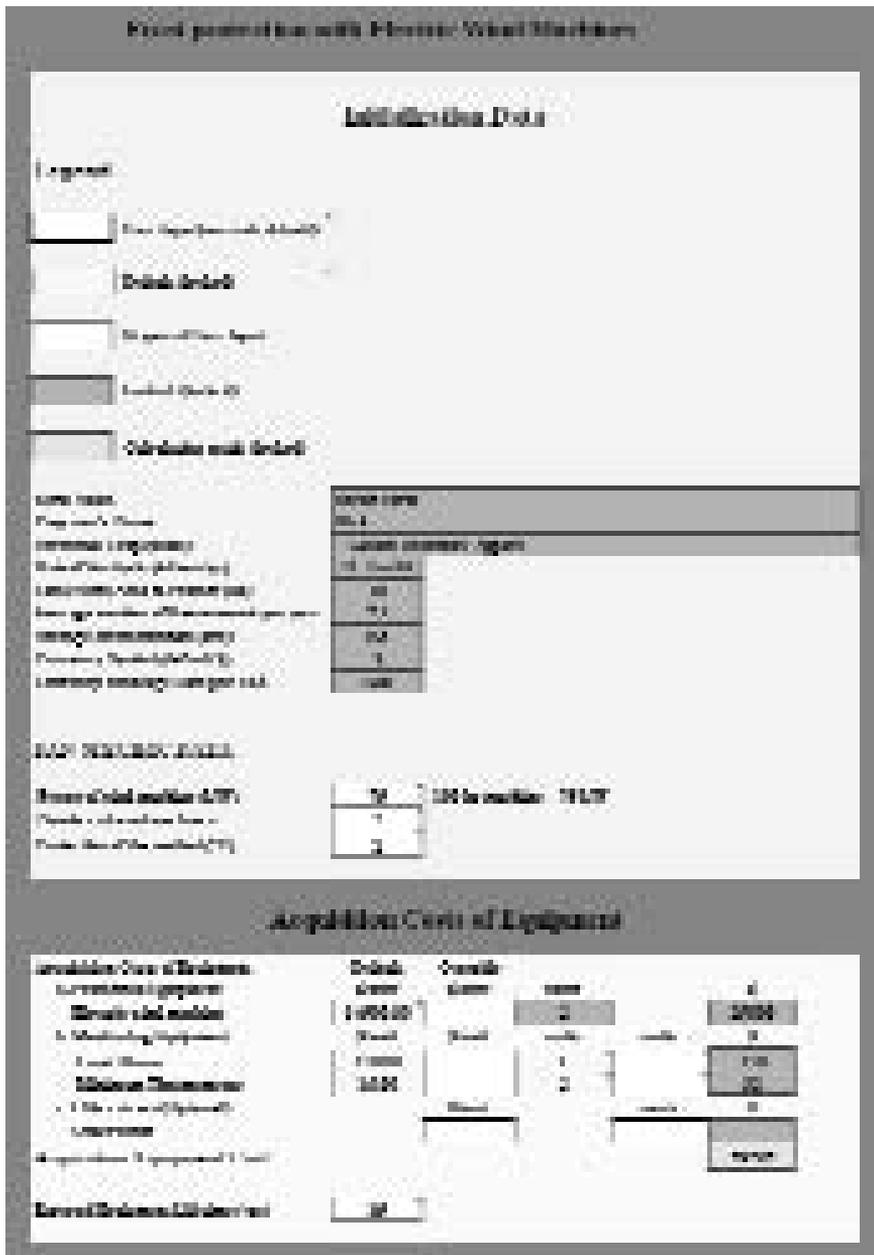
FIGURE 2.2

TechSelect worksheet

The body of each budget involves three additional sections: acquisition costs of equipment, annual variable costs and a total annual cost summary. Equipment acquisition costs and the annual variable operating costs must be adjusted to reflect that particular technology specification and unique application. The row labels in columns B and C define the various component cost elements; the associated unit costs, number of units per farm and costs per farm are given in columns D to I. The Total Annual Cost Summary section has a slightly different format. Row labels are shown in columns B to F, and summary cost data are calculated in column I.

The budget process is illustrated in Figures 2.3.a and 2.3.b for a single frost protection technology: electric-powered fan wind machines. The user is encouraged to pay attention to all comments embedded in cells throughout the budgets. It should be remembered the numerical example is illustrative, reflecting a hypothetical 10-ha orchard application. Actual costs may vary widely from this illustration. Budget sheets for the other eight frost protection methods are provided in the Appendix.

FIGURE 2.3a
Top section of the budget sheet for electric-powered wind machines



Acquisition cost of equipment

This section of the budget (Figure 2.3.a) contains the total cost of purchasing equipment, itemized by row category. Freeze protection with electric fans requires a variety of investments. Each fan unit is comprised of a tower, fan, motor and control unit. Two 75 kW fan units are needed for the 10-ha apple orchard. Monitoring equipment includes a single freeze alarm for the entire farm, regardless of size, and one minimum thermometer per 5 ha. Particular applications may require “other equipment”, which must be user defined. The first data column (D) contains default costs per unit, specified as \$/unit. This column is hidden and write protected so that the user always has a reference point when tailoring the budgets. The second column (E) converts the hidden default cost per unit to local currency. Column (F) is to be used whenever the user wishes to override the default cost per unit (local currency). The default number of units required to protect the entire farm and the optional override are given in columns (G) and (H). The last column, (I), summarizes the row-specific category costs. Each cell in this column is locked (blue bordered) because each has an important formula that calculates the various subtotals. The bright blue shaded cell in column (I) is an aggregated category total, and is also a locked formula. The prototype presented here involves a \$ 29 202 investment. The final element of this cost category is the expected equipment life (15 years). Although not a cost per se, the estimated equipment life must be specified for subsequent use in calculating after-tax, annualized PV costs in the summary section. The reader is cautioned that equipment life must match or exceed the loan period specified in Initialization.

Annual Variable Costs

This section of the analysis (Figure 2.3.b) addresses the direct operating costs of frost protection. It is compartmentalized into three subsections of variable costs:

- costs unrelated to events (i.e. set-up costs);
- costs related to the number of events; and
- costs related to protection hours (i.e. event duration).

Electric fans incur at least four different variable costs unrelated to the number of frost events. Standby electricity costs are estimated to be \$ 2 431/yr. Routine, off-season maintenance labour costs are \$ 240/yr and the corresponding vehicle charge is \$ 80/yr. Replacement parts average \$ 200/yr. A fifth category, “other items”, is an optional category provided in case the user wishes to specify additional set-up annual costs that are incurred in a particular application. Annual variable costs unrelated to events are estimated to total \$ 2 951.

Electric-powered fans are capital intensive and involve little in the way of variable costs related to the number of frost events. It is estimated that only one hour of labour (\$ 12) is required to start and stop the fans every time there is an event. A premium is included for night-time work. The user may specify an optional “other items” category. Annual variable costs related to the number of frost events total only \$ 25, based on the estimated number of events (2.1 days) provided in the Initialization section.

As before, variable costs related to protection hours are first calculated on a per-unit basis (per hour) and then for the entire year ($\$/\text{hr} \times \text{hrs}/\text{event} \times \text{events}/\text{yr}$). Variable costs that depend on event duration are surveillance labour (\$ 12/hr) and electricity consumption (\$ 20/hr). The default hourly labour charge assumes that a premium is paid for night-time work. Electricity charges are fan-size dependent and will vary widely across locations. The user may specify an optional “other items” category, as needed. Annual total variable costs related to protection hours are estimated at \$ 367. This amount is the product of $\$ 32/\text{hr} \times 5.5 \text{ hrs}/\text{event} \times 2.1 \text{ events}/\text{yr}$; the latter two elements come from Initialization.

Total Annual Cost Summary

The final section of the budget sheet (Figure 2.3.b) summarizes the total annual frost protection costs for the 10-ha apple orchard. Total annual cash costs are presented, followed by the total after-tax costs, both as annualized present values. The annualized cash costs lend insight into cash flow, whereas the after-tax costs measure the effective true cost of frost protection.

Total annual cash cost of frost protection with electric fans on this hypothetical 10 ha farm is \$ 6 514, annualized *PV* dollars. This total cash cost is the sum of the average annual equipment cash cost and the average annual variable cash cost.

Average annual equipment cash cost depends upon whether the equipment acquisition costs were debt-financed or self-financed. If total capital acquisition cost exceeds the self-financing threshold specified in Initialization, then the annualized costs equal the sum of the down payment divided by the equipment life, plus the level principal and interest (P&I) payment on borrowed capital. Level annual payments imply the annual P&I payment is the annualized (i.e. financial average) value. If the equipment purchase is self-financed, then the average annual equipment cost equals the straight-line depreciation expense (i.e. total acquisition cost divided by the expected life). In this example, the cost of purchasing the electric fans exceeds the Initialization default threshold of \$ 2 000, so the annualized equipment cash cost equals \$ 3 104.

Average annual variable cash cost equals the level principal and interest (P&I) payment on the one-year, recurring line of credit. Recall the assumption that variable expenses are financed for a fixed, user-specified, percentage of a year (i.e. the average draw is a user-specified fraction of a year). The Initialization average draw default of 50 percent is used in this illustration. Average annual variable costs equal \$ 3 409 (i.e. \$ 3 343 in principal plus \$ 66 in interest).

Total annual after-tax cost of frost protection with electric fans on this 10-ha orchard is \$ 4 681 annualized *PV*. That is, the actual cost of this protection method is \$ 1 833 less than the annualized cash cost because capital costs, variable costs and interest costs are all assumed to be tax deductible at a 20 percent tax rate (see Initialization data). More generally, the ratio of Total Average Annual After-Tax Cost to Total Average Annual Cash Cost decreases when capital costs are a smaller share of total costs. This general relationship is due to losing the after-tax benefit of capital purchases.

Like the calculation of cash costs, total after-tax cost is the sum of average annual after-tax equipment cost and average annual after-tax variable costs. The calculations for both of these component costs are dependent upon whether the user answered, “Yes” or “No” to the tax-deductible status of interest, equipment and variable costs. The average annual after-tax cost of equipment is further dependent on whether the equipment was debt financed.

Average annual after-tax equipment cost of electric fans in this illustration is estimated to be \$ 1 954. This cost is calculated based on the fact that total equipment costs exceeded the self-financing (\$ 2 000) threshold stipulated in Initialization and both capital and interest costs were stipulated as tax deductible. The conditional after-tax cost calculation used in this illustration involved the first of four alternative calculations.⁶

1. If both capital cost and interest are tax deductible, the average annual after-tax cost is:

$$(1-TR) \times (\text{annualized } PV \text{ interest} + \text{annual depreciation})$$

where *TR* is the tax rate; *annualized PV interest* equals the net present value of the stream of interest charges divided by the *PV* annuity factor; and *annual depreciation* is calculated as straight-line depreciation. The three remaining alternative conditional calculations are detailed here for completeness. Each assumes the frost protection technology is debt financed.

6. While there are four logical condition combinations, not all are likely.

2. If capital cost is not deductible but interest is deductible, the average annual after-tax cost is:
 $(1-TR) \times \text{annualized } PV \text{ interest} + \text{annual depreciation.}$
3. If capital cost is deductible but interest is not tax deductible, the average annual after-tax cost is:
 $(1-TR) \times \text{annual depreciation} + \text{annualized } PV \text{ interest.}$
4. If neither capital nor interest costs are deductible, the average annual after-tax cost equals the average annual equipment cash cost. Note that if the self-financing threshold were not exceeded in any of the four calculations above, average annual equipment cost simply equals the straight-line depreciation expense.

Average annual after-tax variable costs for electric-powered fans are estimated to be \$ 2 728. This cost is calculated in a conditional manner similar to the after tax equipment cost, though self-financing is not an issue. The conditional after-tax cost calculation used in this illustration involved the first of four alternative calculations.

1. If both variable cost and interest are deductible:
 $(1-TR) \times \text{variable cost payment.}$
2. If variable costs are not deductible but interest is deductible:
 $(1-TR) \times \text{annualized } PV \text{ interest} + \text{total variable costs.}$
3. If variable costs are deductible but interest is not:
 $(1-TR) \times \text{total variable costs} + \text{annualized } PV \text{ interest.}$
4. If neither variable costs nor interest are deductible:
 average annual variable cost.

Upon completing each budget, the user must press the continue button to be taken to the next budget among those stipulated in the “TechSelect” sheet. Once the last budget is completed and the continue button is pressed, the user is taken to the first of two output reports: Cost-Effectiveness.

Cost-effectiveness

At least 20 years of minimum and maximum temperature data are necessary to analyse the risk of frost damage. The user has to initialize the program with an estimate of the expected or typical number of frost events and duration. Then the economic decision defaults to the most cost-effective (i.e. lowest cost) method of achieving a given level of protection. Cost-effectiveness assumes that the number of frost events, their duration and extent of damage are known with certainty, presumably at a mean or expected level. This illustration is based on the mean

number of events and duration generated by the damage calculator during the initialization step.

There are two output tables related to cost-effectiveness. The first (Table 2.1) is the first table in the CostEffectReport worksheet. This table ranks each of the nine frost protection methods in ascending order of the *Annualized Present Value After-Tax Cost of Frost Protection by °C*, regardless of the amount of protection. The last column indicates the annual after-tax cost per degree of protection, which highlights the fact that a lower cost method may, in fact, be an expensive way to achieve higher levels of frost protection. Stated differently, not all methods yield the same amount of protection; the lowest annualized cost of protection is not necessarily the best way to discriminate among alternative technologies.

Table 2.2, which corresponds to the second table in the CostEffectReport worksheet, lists the *cost-effective methods of achieving minimum protection, ranked by annualized after-tax costs*. This table presents a more comprehensive way to evaluate the cost-effectiveness of the nine different frost protection methods. The annualized after-tax costs for all methods that provide a minimum amount of protection are ranked in ascending order. For example, all nine methods offer at least 1 °C or 2 °C of protection. However, only seven methods offer at least 3 °C of protection, four protect against a 4 °C frost, and only three offer 5 °C or 6 °C of protection.

TABLE 2.1
Annualized present value (PV) after-tax cost of frost protection by °C

ACTUAL PROTECTION °C	FROST PROTECTION METHOD	PV ANNUAL AFTER-TAX COSTS	PV ANNUAL AFTER-TAX COSTS PER DEGREE OF PROTECTION
2	ICFan	3 788 \$	1 894 \$
2	ElecFan	4 681 \$	2 341 \$
6	Sprinklers	4 787 \$	798 \$
6	ICFan + Sprinklers	8 393 \$	1 399 \$
6	ElecFan + Sprinklers	9 389 \$	1 565 \$
3	ICFan + Heaters	9 885 \$	3 295 \$
3	ElecFan + Heaters	10 531 \$	3 510 \$
3	LiqFuelHeaters	10 734 \$	3 578 \$
4	SolidFuelHeaters	29 772 \$	7 443 \$

KEY: ICFan = internal-combustion0engine-powered fan. ElecFan = electric-motor-powered fan. LiqFuelHeaters = liquid-fuel heaters. SolidFuelHeaters = solid-fuel heaters.

TABLE 2.2

Cost-effective methods of achieving minimum protection, ranked by annualized after-tax costs

MINIMUM PROTECTION (°C)	ACTUAL PROTECTION (°C)	FROST PROTECTION METHOD	PV ANNUAL AFTER-TAX COSTS
1°C	2	ICFan	3 788 \$
	2	ElecFan	4 681 \$
	6	Sprinklers	4 787 \$
	6	ICFan + Sprinklers	8 393 \$
	6	ElecFan + Sprinklers	9 389 \$
	3	ICFan + Heaters	9 885 \$
	3	ElecFan + Heaters	10 531 \$
	3	LiqFuelHeaters	10 734 \$
	4	SolidFuelHeaters	29 772 \$
	2°C	2	ICFan
2		ElecFan	4 681 \$
6		Sprinklers	4 787 \$
6		ICFan + Sprinklers	8 393 \$
6		ElecFan + Sprinklers	9 389 \$
3		ICFan + Heaters	9 885 \$
3		ElecFan + Heaters	10 531 \$
3		LiqFuelHeaters	10 734 \$
4		SolidFuelHeaters	29 772 \$
3°C		6	Sprinklers
	6	ICFan + Sprinklers	8 393 \$
	6	ElecFan + Sprinklers	9 389 \$
	3	ICFan + Heaters	9 885 \$
	3	ElecFan + Heaters	10 531 \$
	3	LiqFuelHeaters	10 734 \$
	4	SolidFuelHeaters	29 772 \$
	4°C	6	Sprinklers
6		ICFan + Sprinklers	8 393 \$
6		ElecFan + Sprinklers	9 389 \$
4		SolidFuelHeaters	29 772 \$
5°C	6	Sprinklers	4 787 \$
	6	ICFan + Sprinklers	8 393 \$
	6	ElecFan + Sprinklers	9 389 \$
6°C	6	Sprinklers	4 787 \$
	6	ICFan + Sprinklers	8 393 \$
	6	ElecFan + Sprinklers	9 389 \$

KEY: ICFan = internal-combustion-engine-powered fan. ElecFan = electric-motor-powered fan.
LiqFuelHeaters = liquid-fuel heaters. SolidFuelHeaters = solid-fuel heaters.

Internal-combustion-engine-powered fans (ICFans) are shown to be most cost-effective but provide only 2 °C of protection. It has an expected annualized after-tax cost of \$ 3 788. Electric-motor-powered fans (also offering only 2 °C of protection) are a close second at \$ 4 681, followed closely by sprinklers (6 °C of protection) at \$ 4 787. The proximity of sprinklers to the least-cost ICFan draws attention to an important consideration when using this cost-effectiveness table. Although the stochastic nature of frost protection is absent from cost-effectiveness, limited but crucial insight into risk management is possible. For less than \$ 1 000/yr, sprinklers offer three times the protection of ICFans. Unless the user is very confident that frost events rarely exceed 2 °C, the appropriate technology based on a combination of costs and protection may be sprinklers, not the least-cost ICFan. The user should review all aspects of this second table to make the best possible economic decision, given the limited information.

If frost event and duration data were input in Initialization using the damage calculator, the user needs to depress the “Go to Risk Report” button located next to the first table. Note that this option is available without reviewing the cost-effectiveness results. The following discussion of risk begins with a conceptual overview of risk management because this is the heart of the decision to adopt frost protection. The discussion is followed by details illustrating the risk-minimizing choice among the nine alternatives considered in this analysis.

Risk

Decision-making under uncertainty has a long tradition in agricultural economics. At the centre of the risk literature is the problem of choosing among alternative risky actions or portfolios, whether choosing different crop rotations or hedging strategies that maximize expected earnings, while minimizing acceptable levels of risk. Assuming there is a probability distribution of revenues for all actions and this distribution can be defined adequately in terms of its first and second moments [i.e. mean or expected income (E) and associated variance (V)], then the choice among alternative actions may be conceptualized as a trade-off between net income expectations (commonly plotted on the horizontal axis) and net income variance (commonly plotted on the vertical axis). Greater risks imply greater income variability, which require greater expected payoffs to justify the risk. The set of so-called risk-efficient decisions lies on the mean-variance (E - V) frontier that is defined by the minimum variance (or standard deviation) for each level of expected income. As illustrated in Figure 2.4, the

E - V frontier increases at an increasing rate (i.e. has positive first and second derivatives in the positive quadrant). Protection techniques with points above this boundary are dominated by methods on the risk-efficient frontier. Methods above the E - V frontier represent more risk (i.e. variance) for a given level of expected income or less income for the same level of risk.

FIGURE 2.4

Hypothetical E - V frontier without frost protection (—) and with frost protection (— —)



The optimal decision along this frontier differs from firm to firm, in accordance with firm-specific risk preferences that are functions of expected income and variance. Economists have dedicated considerable energy to the problem of soliciting and specifying risk preferences for individuals, with limited success. Inability to specify the risk preference function for every possible farmer simply means the framework precludes an optimal choice. Nevertheless, the E - V framework simplifies the choices confronting the decision-maker to those efficient ones on the frontier; all others are inferior to the profit-maximizing firm.

Frost protection extends the E - V framework in a straightforward way. Protection raises temperature, reduces damage and thereby increases expected yields and reduces yield variation. All else being constant, these physical benefits translate into increased expected income and reduced income variation (i.e. the benefits of frost protection). Providing the enhanced expected yield generates economic benefits that exceed the annual protection costs, the E - V -frontier with protection would lie below one without protection. Thus, adoption of frost protection offers the possibility of shifting the risk-efficient E - V frontier downward and to the right, providing that the net benefits (i.e. benefits minus costs) are positive. Deciding whether to adopt a method requires one to contrast

the stochastic net benefits from the farming enterprise without protection against the stochastic net benefits with protection.

Two manifestations of risk must be accounted for when measuring net benefits of frost protection. There is yield risk attributable to the stochastic nature of weather (temperature, t) during different plant growth stages. This is sufficient to make revenues (i.e. gross benefits) from protection stochastic. There is also risk associated with the costs of frost protection, which includes both the annualized acquisition costs and the annual operating costs. The annual operating costs are related to the number and duration of frost events, both of which are stochastic and, in turn, functions of t . Recall that the variable cost of protection consists of three parts: variable costs unrelated to events; variable costs related to the number of events; and variable costs related to event duration. Thus, both benefits and costs are stochastic functions of the random variable, temperature.

Expected yield loss is a function of temperature, where the probability of a particular temperature is the weight assigned to the associated crop damage. One can think of two types of damage: total loss if the temperature, T , drops below T_{100} or a continuously increasing loss function as temperature falls below T_0 , until the entire crop is lost. Regardless of the type of damage function, one must first measure expected damages and associated variances with and without frost protection. The difference between maximum expected yield (Y) without protection, $Y(T)$, and with protection, $Y_z(T)$, varies by protection technology (z). Thus, $[Y(T) - Y_z(T)]$ is the vector of stochastic yield damages and $[Y_z(T) - Y(T)]$ is the vector of stochastic yield benefits. Maximum potential yield benefits correspond to the subset of z technologies offering the greatest elevation in temperature.

Stochastic yield benefits are translated into net economic benefits in two steps. First, net benefits (NB) without protection are defined as $NB = P \times Y(T)$, where P is the price of the crop grown net of all production costs except the cost of protection. Next, the vector of net benefits with protection (NB_z) requires a similar calculation, plus recognition that the operating costs of different frost protection methods depend on frost event frequency and duration, each of which is a function of T . Therefore, the method-specific cost of protection can be written as $C_z(T)$. The vector of stochastic net benefits with protection is defined as $NB_z = P [Y_z(T) - Y(T) - C_z(T)]$. The frost protection method(s) yielding the greatest expected net benefit and lowest variance are risk efficient.

One need not examine the correlation or co-variation among the elements of risk (i.e. yield, events and duration) to measure composite risk. Instead, risk can be measured directly from the stream of net benefits. However, the nature of

frost protection poses special challenges to measuring associated risk. The net benefit function is truncated from below and above, and probably is not a normal distribution.⁷ Closer examination of the frost protection process reveals why one cannot simply assume the net benefits are normally distributed and adequately characterized by first and second moments (i.e. the mean and standard deviation).

The decision to initiate protection on a given day must be made before frost is observed. That is, protection is started in anticipation of a frost event – at roughly +1 °C above the growth stage-specific critical temperature (T_o) – whether or not temperature continues to drop and protection is needed. This consideration means frost events are defined by , even though damage without protection might not occur. Alternatively, protection may be inadequate and either some crop damage occurs or the event is so severe ($T \leq T_{100}$) that the entire crop is lost, despite protection efforts. Thus, one can think of net benefits from protection as falling into two categories: losses and gains, both of which have truncated distributions.

Losses occur whenever annual costs exceed benefits. Maximum potential economic loss for a given protection technology occurs in severe-weather years when protection is implemented but without benefit of any offsetting yield enhancement. Economic losses also occur in those years when the benefits of protection (the value of increased yield) are insufficient to offset the annualized acquisition cost plus operating costs. Losses also occur in those years when temperature never drops below critical levels, $T > (T_o + 1 \text{ °C})$ capital acquisition costs are still incurred because the equipment must be paid for whether used or not and variable costs unrelated to the number of events (i.e. set-up costs) are also incurred. Gains in net benefits for any practice are similarly truncated from above at the value of maximum potential yield gain, less annual costs. Maximum net benefits for any given protection method occurs whenever yield without protection is zero (complete crop damage) but when maximum potential yield is realized because of protection.

The truncated nature of net benefit losses and gains, combined with the fact that it is doubtful whether the net benefit function arising from frost protection is normally distributed, renders a standard *E-V* table inadequate for farmers for evaluating the trade-off between expected pay-off and the associated risk.

7. It is unclear what distribution best characterizes the net benefit function. Sufficient weather data rarely exist to estimate the underlying distribution.

Characterizing the likelihood of an incremental loss or a gain, in conjunction with the overall mean, provides a better decision-making tool. Accordingly, the approach taken here is to present the overall mean or expected net benefits and three additional parameters for losses and gains. Losses are characterized by the probability of loss, the expected (mean) loss, and the maximum loss. Gains are similarly characterized as the probability of gain, the mean gain and the maximum gain. These elements of a frost protection risk table enable the user to judge the merits of alternative risky investments in a manner that is analogous to an *E-V* table. The individual decision-maker has all essential information to evaluate the overall expected net benefit and the risk of loss or gain, given his or her risk preferences.

The trade-off between expected after-tax *PV* net benefits and risk associated with that payoff is summarized in Table 2.3, which corresponds to the first table in the RiskReport worksheet. Frost protection methods are ranked by the expected present value annual net benefits. The associated percentage probabilities of losses and gains, mean *PV* losses and gains, and maximum *PV* losses and gains are given. We begin the discussion of this table by first examining the risk elements associated with our example technology, electric fans, and then by examining the overall risk implications across all nine frost-protection methods.

The truncated nature of after-tax net benefits is illustrated by examining the detailed year-by-year after-tax net benefits without and with frost protection (not shown in Table 2.3). Maximum annual net benefits without protection is \$ 110 000 under the assumptions specified in the Initialization data, the 30 years of weather data and the yield estimates derived from the damage calculator. Expected net benefits without protection equal \$ 74 242, with a standard deviation of \$ 48 257.

Table 2.3 shows that electric-powered fans, the illustrative example technology, are estimated to provide 2 °C of protection, generating an additional \$ 26 797 of expected net benefits – the third-largest mean *PV* annual net benefit. The standard deviation of the additional net benefits, which is not shown in Table 2.3, is \$ 45 640.

Closer examination of the year-by-year, after-tax net benefit from electric-powered fans reveals that a loss is more likely than a gain. A loss occurred in 17 of 30 years (i.e. 57 percent of the time), though the mean loss is only \$ -4 528, while the maximum loss is \$ -5 632. In seven of 30 years, protection was never implemented, resulting in an annual loss of \$ -4 362; the annualized after-tax equipment costs (\$ 1 954) plus the annualized after-tax P&I payment on variable costs unrelated to events (\$ 2 408) still had to be paid. Protection was initiated in nine years, though no damage would occur even without protection.

TABLE 2.3

Frost protection methods ranked by expected PV annual net benefits and associated percentage probabilities of PV losses and gains, mean PV losses and gains and maximum PV losses and gains

PROTECTION	METHOD	ANNUAL PV NET BENEFIT	PROB. OF LOSS	ANNUAL LOSS		ANNUAL GAIN		
				Mean PV	Max. PV	Prob. of PV	Mean PV	Max. PV
°C		\$	%	\$	\$	%	\$	\$
6	Sprinklers	30 172	53.3	-4 591	-4 830	46.7	69 901	105 299
2	ICFan	27 712	56.7	-3 596	-4 768	43.3	68 653	106 346
2	ElecFan	26 797	56.7	-4 528	-5 632	43.3	67 760	105 409
6	ICFan+Sprinklers	26 567	56.7	-7 652	-8 474	43.3	71 314	101 770
6	ElecFan+Sprinklers	25 949	56.7	-8 527	-9 043	43.3	71 034	101 043
3	ICFan+Heaters	22 207	63.3	-7 468	-19 209	36.7	73 463	101 303
3	ElecFan+Heaters	21 560	63.3	-8 243	-19 188	36.7	73 038	100 520
3	LiqFuel+Heaters	21 357	63.3	-7 341	-26 421	36.7	70 928	101 102
4	SolidFuel+Heaters	2 319	70.0	-17 309	-112 805	30.0	48 118	89 494

KEY: ICFan = internal-combustion-engine-powered fan. ElecFan = electric-motor-powered fan. LiqFuelHeaters = liquid-fuel heaters. SolidFuelHeaters = solid-fuel heaters.

A resulting after-tax loss of up to \$ -4 762 was incurred in these nine years. Finally, protection was implemented but did no good in one year, even though there were six frost events. Temperature dropped to the point of killing the crop, with or without protection, eliminating any possible yield benefits. In that one year, the after-tax annualized PV cost of protection was \$ -5 632, the sum of all variable costs plus the annualized capital cost.

Turning to the gains side of protection, electric fans provided positive after-tax net benefits just 43 percent of the time. But the positive net benefits were large, averaging \$ 67 760 and ranging up to a maximum \$ 105 409 per year – just \$ 4 591 less than maximum potential benefit. These results suggest that expected benefits from electric fan wind machines are associated with the risk of a relatively small loss but large potential gain. Electric fans are relatively risk free, despite the fact that 53 percent of the time protection is not needed and 3 percent of the time protection is not sufficiently effective to yield positive net economic benefits. Nevertheless, electric fan wind machines offer sufficiently large positive net benefits from frost protection the remaining 47 percent of the time to more than pay for themselves.

Before comparing risk across all nine-protection methods, it is instructive to detail the net-benefit calculations. First, all net benefits are after tax, unless capital

and interest costs are defined in the Initialization worksheet as not deductible. Second, all benefits and costs are annualized *PV*. Annualized *PV* are the financial equivalent of average annual values expressed in current monetary units (i.e. removing the time value of money). Annualization allows a comparison among investments with unequal lives, as in the case of frost protection.

The after-tax annualized *PV* of net benefits is computed as the after-tax annualized *PV* revenues minus after-tax annualized *PV* equipment costs minus after-tax annualized *PV* variable costs. Annualized *PV* revenues are computed as the net price without frost protection, times yield per ha, times number of ha on the farm. Annualized *PV* equipment costs are computed as in the after-tax section of the budgets. Annualized *PV* variable costs comprise variable costs unrelated to events, variable costs related to the number of events and variable costs related to the number of events and the average event duration. These latter two variable cost categories differ from the budget calculations because the number and duration of events are year specific. Recall that the budgets were constructed on mean number of events and duration over the weather data series used in the damage calculator. Accordingly, year-specific variable costs comprise the sum of the three variable cash costs and the associated operating loan or line of credit interest. Use of real interest rates (i.e. net of inflation) makes the aggregate year-specific costs fully equivalent to annualized *PV* costs.

Each year of the weather data is treated as though it is a single, recurring observation of yield, events and duration, over the life of the particular frost protection method being analysed. Thus, the after-tax *PV* net benefits corresponding to a particular observation (year) are annualized *PV* net benefits over the life of the particular frost protection method. This analytical simplification avoids the problem of replacing different frost protection equipment at different times during the duration of weather data used in the damage calculator. Since each *PV* net benefit is annualized, average *PV* net benefits over all years of weather data are calculated as a simple mean. It follows that the additional \$ 26 797 of expected net benefit generated by electric-powered fans is the simple average of 30 after-tax annualized *PV* net benefits. The expected after-tax *PV* net benefits for electric fans is similarly calculated, except each observation would reflect annualized *PV* net benefits for equipment that lasts 15 years, instead of, say, a 10-year life that might be expected from solid-fuel heaters.

Returning to Table 2.3, sprinklers (6 °C) offer the greatest overall mean *PV* net benefits, equal to \$ 30 172, \$ 3 375 more than electric fans (2 °C). The magnitude of potential losses and gains with sprinklers differs somewhat from electric fans, though the probabilities of gain or loss are within 3 percent of each other.

Sprinklers have a slightly larger expected loss (i.e. \$ -4 591 versus \$ -4 528), though this protection method is exposed to a 16 percent smaller maximum annual loss than electric fans (\$ -4 830 versus \$ -5 632). The expected annual gains are \$ 83 516, or roughly \$ 1 400 more than with electric-powered fans. This greater gain is due in part to the additional 4 °C of protection offered by sprinklers and in part due to the different cost structure. The additional 4 °C of protection was needed in only two years, but provided an additional 24 t/ha of apples. Maximum possible annual gain is similar between the technologies. Sprinklers offer a higher expected net benefit similar risk relative to electric fans, yielding comparable expected losses in years of loss and somewhat higher expected gains in years of gains.

Perhaps a more interesting comparison is between solid-fuel heaters (4 °C), the least attractive protection method, and sprinklers (6 °C). Even though solid-fuel heaters offer only 2 °C less protection, they provide less than one-tenth the expected annual net benefits (\$ 2 319). Solid-fuel heaters are also more risky in the loss direction, but comparable in the gain direction. Solid-fuel heaters face a higher probability of loss (70.0 percent versus 56.7 percent) and incur a mean annual loss of \$ -17 309 in contrast with \$ -4 591. Turning to gains, solid-fuel heaters have a 17 percent lower probability of gain (30.0 percent versus 46.7 percent) and the expected gain is roughly half that of sprinklers (e.g. \$ 48 118 versus \$ 69 901). Maximum annual gain is also less.

Review of the remaining six frost-protection methods shows variations of the foregoing discussion of expected pay-off versus risk of loss or gain. Particular attention should be given to risk of loss because it can have serious detrimental impact on the financial well-being of a farmer in a single year or the ability to generate sufficient cash flow to pay off debt associated with frost protection. This observation is especially true when losses are more frequent than gains.

Table 2.4 depicts the second table in the RiskReport worksheet. It shows the relative risk associated with methods capable of providing 1°, 2°, ..., 6 °C of protection. Frost protection methods yielding minimum protection are ranked in descending order by expected *PV* annual net benefits and the associated risk of annual loss or gain captured by the probability (the mean and the maximum loss or gain). Tables 2.3 and 2.4 reinforce an important feature of decision-making under risk. While it is both tempting and common to think in terms of achieving a given amount of protection, such an approach to the adoption decision is generally flawed. Even though the hypothetical farmer operates in an area where 2 °C of protection is inadequate to avoid all damage, a 2 °C technology (ICFans) may be the preferred investment.

Based strictly on expected net *PV* benefits, sprinklers dominate all other frost-protection methods. Sprinklers yield \$ 2 460 greater expected net *PV* benefits than the next closest technology, ICFans. However, considering the exposure to risk makes the decision more ambiguous. Notice that sprinklers have a 25 percent higher expected loss and a slightly higher maximum loss. These two factors augur in favour of ICFans. Sprinklers do have a slightly higher mean *PV* gain, but ICFans have a larger potential maximum gain. The probability of losses (gains) is 3 percent lower (higher) for sprinklers.

The primary downside to sprinklers is the higher expected *PV* annual loss. This aspect of financial risk could be an important consideration to a farmer who is especially sensitive to a negative cash flow in any given year. The individual farmer must judge whether this adverse financial exposure is acceptable or too risky, given the upside trade-off. If unacceptable, sprinklers might be less appealing than ICFans. Keep in mind that the numerical trade-off between expected *PV* annual net benefits and mean and maximum losses is unique to each application.

In summary, the risk analysis presented here differs from the cost-effectiveness analysis, in which methods were ranked according to least annualized after-tax cost. Recall that the ICFans wind machines (2 °C) were the least-cost protection method on the hypothetical farm. Sprinklers ranked third, with an annual cost 25 percent greater than that of ICFans. On a per-degree-of-protection basis, however, sprinklers ranked first, at \$ 789/degree. This observation highlights the importance of tradeoffs among the economic benefits of protection, the level and structure of protection costs, and the risk of inadequate protection. If the user were obliged to make a decision based only on after-tax cost-effectiveness because sufficient weather data were not available to examine risk, considering the trade-off between cost and degrees of protection (a proxy for benefits) might lessen adoption errors. Such consideration would lead one to adopt sprinklers over ICFans, even though sprinklers are less cost effective. Nevertheless, sprinklers provide three times the protection (6 °C versus 2 °C). Notice that this slightly extended view of cost-effectiveness better approximates the choice of sprinklers that was guided by the risk analysis.

Other protection methods

Sample budget sheets for the other eight frost protection methods are given in the Appendix. All of the budget sheets represent protection of a 10 ha apple orchard with cv. Golden Delicious, which was used as an example in Chapter 2. A listing of the budget sheets by protection method is provided at the beginning of the Appendix.

TABLE 2.4

Frost protection methods yielding minimum protection ranked by expected PV annual net benefits (i.e. associated risk of annual loss or gain)

MIN. PROT.	METHOD	MEAN PV ANNUAL NET BENEFITS	PROB. OF LOSS	ANNUAL LOSS		ANNUAL GAIN			
				Mean PV	Max. PV	Prob. of PV	Mean PV	Max. PV	
		\$	%	\$	\$	%	\$	\$	
1.0	Sprinklers	30 172	53.3	-4 591	-4 830	46.7	69 901	105 299	
	ICFan	27 712	56.7	-3 596	-4 768	43.3	68 653	106 346	
	ElecFan	26 797	56.7	-4 528	-5 632	43.3	67 760	105 409	
	ICFan+Sprinklers	26 567	56.7	-7 652	-8 474	43.3	71 314	101 770	
	ElecFan+Sprinklers	25 949	56.7	-8 527	-9 043	43.3	71 034	101 043	
	ICFan+Heaters	22 207	63.3	-7 468	-19 209	36.7	73 463	101 303	
	ElecFan+Heaters	21 560	63.3	-8 243	-19 188	36.7	73 038	100 520	
	LiqFuelHeaters	21 357	63.3	-7 341	-26 421	36.7	70 928	101 102	
	SolidFuelHeaters	2 319	70.0	-17 309	-112 805	30.0	48 118	89 494	
2.0	Sprinklers	30 172	53.3	-4 591	-4 830	46.7	69 901	105 299	
	ICFan	27 712	56.7	-3 596	-4 768	43.3	68 653	106 346	
	ElecFan	26 797	56.7	-4 528	-5 632	43.3	67 760	105 409	
	ICFan+Sprinklers	26 567	56.7	-7 652	-8 474	43.3	71 314	101 770	
	ElecFan+Sprinklers	25 949	56.7	-8 527	-9 043	43.3	71 034	101 043	
	ICFan+Heaters	22 207	63.3	-7 468	-19 209	36.7	73 463	101 303	
	ElecFan+Heaters	21 560	63.3	-8 243	-19 188	36.7	73 038	100 520	
	LiqFuelHeaters	21 357	63.3	-7 341	-26 421	36.7	70 928	101 102	
	SolidFuelHeaters	2 319	70.0	-17 309	-112 805	30.0	48 118	89 494	
3.0	Sprinklers	30 172	53.3	-4 591	-4 830	46.7	69 901	105 299	
	ICFan+Sprinklers	26 567	56.7	-7 652	-8 474	43.3	71 314	101 770	
	ElecFan+Sprinklers	25 949	56.7	-8 527	-9 043	43.3	71 034	101 043	
	ICFan+Heaters	22 207	63.3	-7 468	-19 209	36.7	73 463	101 303	
	ElecFan+Heaters	21 560	63.3	-8 243	-19 188	36.7	73 038	100 520	
	LiqFuelHeaters	21 357	63.3	-7 341	-26 421	36.7	70 928	101 102	
	SolidFuelHeaters	2 319	70.0	-17 309	-112 805	30.0	48 118	89 494	
	4.0	Sprinklers	30 172	53.3	-4 591	-4 830	46.7	69 901	105 299
		ICFan+Sprinklers	26 567	56.7	-7 652	-8 474	43.3	71 314	101 770
ElecFan+Sprinklers		25 949	56.7	-527	-9 043	43.3	71 034	101 043	
SolidFuelHeaters		2 319	70.0	-17 309	-112 805	30.0	48 118	89 494	
5.0		Sprinklers	30 172	53.3	-4 591	-4 830	46.7	69 901	105 299
	ICFan+Sprinklers	26 567	56.7	-7 652	-8 474	43.3	71 314	101 770	
	ElecFan+Sprinklers	25 949	56.7	-8 527	-9 043	43.3	71 034	101 043	
6.0	Sprinklers	30 172	53.3	-4 591	-4 830	46.7	69 901	105 299	
	ICFan+Sprinklers	26 567	56.7	-7 652	-8 474	43.3	71 314	101 770	
	ElecFan+Sprinklers	25 949	56.7	-8 527	-9 043	43.3	71 034	101 043	

KEY: ICFan = internal-combustion-engine-powered fan. ElecFan = electric-motor-powered fan. LiqFuelHeaters = liquid-fuel heaters. SolidFuelHeaters = solid-fuel heaters.

REFERENCES

- Haan, C.T.** 1979. Risk analysis in environmental modifications. pp. 30–51, *in*: B.J. Barfield & J.F. Gerber (eds). *Modification of the Aerial Environment of Crops*. American Society of Agricultural Engineering (ASAE), Monograph No.2. St Joseph, Michigan: ASAE.

EXAMPLES OF BUDGET SHEETS

Sample budget sheets are presented for various frost protection methods. The budget sheets were developed for the protection of 10 ha of apple orchard (cv Delicious), which was used as an example in Chapter 2. The tables include the following budget sheets:

Top section of the budget sheet for solid-fuel heaters.	Fig. A.1a
Bottom section of the budget sheet for solid-fuel heaters.	Fig. A.1b
Top section of the budget sheet for liquid-fuel heaters.	Fig. A.2a
Bottom section of the budget sheet for liquid-fuel heaters.	Fig. A.2b
Top section of the budget sheet for sprinklers.	Fig. A.3a
Bottom section of the budget sheet for sprinklers.	Fig. A.3b
Top section of the budget sheet for electric fans and heaters.	Fig. A.4a
Bottom section of the budget sheet for electric fans and heaters.	Fig. A.4b
Bottom section of the budget sheet for electric fans and sprinklers.	Fig. A.5a
Bottom section of the budget sheet for electric fans and sprinklers.	Fig. A.5b
Top section of the budget sheet for ICFans.	Fig. A.6a
Bottom section of the budget sheet for ICFans.	Fig. A.6b
Top section of the budget sheet for ICFans and heaters.	Fig. A.7a
Middle section of the budget sheet for ICFans and heaters.	Fig. A.7b
Bottom section of the budget sheet for ICFans and heaters.	Fig. A.7c
Top section of the budget sheet for ICFans and sprinklers.	Fig. A.8a
Bottom section of the budget sheet for ICFans and sprinklers.	Fig. A.8b

FIGURE A.2a

Top section of the budget sheet for liquid-fuel heaters

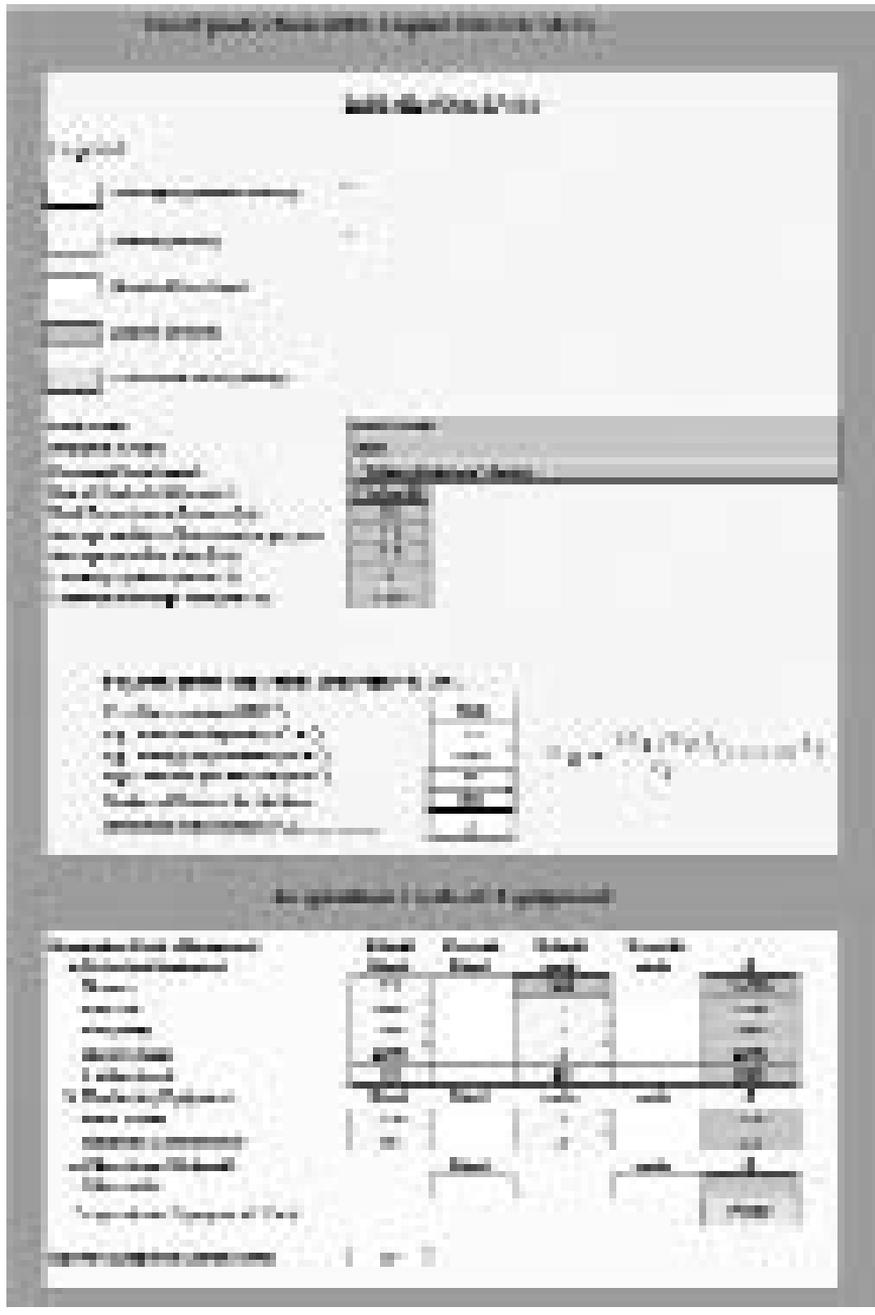


FIGURE A.2b

Bottom section of the budget sheet for liquid-fuel heaters

Operating Expenses - Fuel

Account	2000	2001	2002	2003
Operating Expenses				
Fuel	100	100	100	100
Maintenance	50	50	50	50
Repairs	20	20	20	20
Utilities	10	10	10	10
Travel	5	5	5	5
Miscellaneous	5	5	5	5
Total Operating Expenses	190	190	190	190
Operating Income				
Sales	200	200	200	200
Expenses	(190)	(190)	(190)	(190)
Total Operating Income	10	10	10	10

Operating Expenses - Labor

Account	2000	2001	2002	2003
Operating Expenses				
Wages	150	150	150	150
Benefits	30	30	30	30
Travel	10	10	10	10
Miscellaneous	5	5	5	5
Total Operating Expenses	195	195	195	195
Operating Income				
Sales	200	200	200	200
Expenses	(195)	(195)	(195)	(195)
Total Operating Income	5	5	5	5

Operating Expenses - Other

Account	2000	2001	2002	2003
Operating Expenses				
Travel	10	10	10	10
Miscellaneous	5	5	5	5
Total Operating Expenses	15	15	15	15
Operating Income				
Sales	200	200	200	200
Expenses	(15)	(15)	(15)	(15)
Total Operating Income	185	185	185	185

Operating Expenses - Total

Account	2000	2001	2002	2003
Operating Expenses				
Fuel	100	100	100	100
Labor	195	195	195	195
Other	15	15	15	15
Total Operating Expenses	310	310	310	310
Operating Income				
Sales	200	200	200	200
Expenses	(310)	(310)	(310)	(310)
Total Operating Income	(110)	(110)	(110)	(110)

FIGURE A.3b
Bottom section of the budget sheet for sprinklers

Annual Variable Costs					
	2011 Budget	2012 Budget	% Diff. 2012/2011	2012 Actual	% Diff. 2012/2011
Manufacturing					
• Direct Materials	100	100	100%	100	0%
• Manufacturing Overhead	100	100	100%	100	0%
Total Manufacturing	200	200	100%	200	0%
Logistics Costs					
• Freight (Weighted)	100	100	100%	100	0%
• Other (Fixed)	100	100	100%	100	0%
Total Logistics Costs	200	200	100%	200	0%
Marketing and Sales					
• Advertising (Fixed)	100	100	100%	100	0%
• Other (Fixed)	100	100	100%	100	0%
Total Marketing and Sales	200	200	100%	200	0%
Total Annual Variable Costs	400	400	100%	400	0%

Total Annual (2012) Expenses	
Total Annual Variable Costs	400
Total Annual Fixed Costs	400
Total Annual Budgeted Expenses	800
Total Annual Actual Expenses	800
Total Annual Budgeted Expenses	800
Total Annual Actual Expenses	800

100%

FIGURE A.4b

Bottom section of the budget sheet for electric fans and heaters

Required Financial Provisions

Account	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total
1. Operating Expenses												
a. Salaries												
b. Benefits												
c. Travel												
d. Printing												
e. Telephone												
f. Postage												
g. Supplies												
h. Repairs												
i. Utilities												
j. Insurance												
k. Depreciation												
l. Other												
2. Capital Expenses												
a. Equipment												
b. Construction												
c. Other												
3. Other Provisions												
a. Reserve for Contingencies												
b. Reserve for Debt Service												
c. Reserve for Other												
Total												

Additional Information

<p>Notes:</p> <ul style="list-style-type: none"> 1. Operating Expenses: <ul style="list-style-type: none"> a. Salaries: \$100,000 b. Benefits: \$20,000 c. Travel: \$5,000 d. Printing: \$3,000 e. Telephone: \$2,000 f. Postage: \$1,000 g. Supplies: \$1,000 h. Repairs: \$1,000 i. Utilities: \$1,000 j. Insurance: \$1,000 k. Depreciation: \$1,000 l. Other: \$1,000 2. Capital Expenses: <ul style="list-style-type: none"> a. Equipment: \$50,000 b. Construction: \$10,000 c. Other: \$5,000 3. Other Provisions: <ul style="list-style-type: none"> a. Reserve for Contingencies: \$10,000 b. Reserve for Debt Service: \$5,000 c. Reserve for Other: \$5,000 	
--	--

FIGURE A.6a
Top section of the budget sheet for ICFans

Budget sheet for ICFans		Year 1		Year 2		Year 3		Year 4	
<p>Revenue</p> <p>Revenue from ticket sales</p> <p>Revenue from merchandise</p> <p>Revenue from sponsorships</p> <p>Revenue from other sources</p>									
<p>Operating Expenses</p> <p>Salaries and wages</p> <p>Travel and transportation</p> <p>Marketing and advertising</p> <p>Utilities and rent</p> <p>Insurance</p> <p>Depreciation</p> <p>Interest</p> <p>Other operating expenses</p>									
<p>Operating Income</p> <p>Operating income before taxes</p> <p>Income tax expense</p> <p>Operating income after taxes</p>									
<p>Capital Expenditures</p> <p>Equipment</p> <p>Buildings</p> <p>Other capital expenditures</p>									
<p>Financing</p> <p>Debt</p> <p>Equity</p>									
<p>Summary</p> <p>Total revenue</p> <p>Total operating expenses</p> <p>Total capital expenditures</p> <p>Total financing</p> <p>Net change in cash</p>									

FIGURE A.6b

Bottom section of the budget sheet for ICFans

Part 2: Budget for the ICFans

	2010	2011	2012	2013	Total
Operating Expenses					
• Salaries	100	100	100	100	400
• Franchise fees	50	50	50	50	200
• Advertising	20	20	20	20	80
• Depreciation	10	10	10	10	40
• Other	10	10	10	10	40
Total Operating Expenses	190	190	190	190	760
Operating Income					
• Sales	200	200	200	200	800
• Other Income	10	10	10	10	40
Total Operating Income	210	210	210	210	840
Net Income	20	20	20	20	80

Part 3: Cash Flow Statement

Total Cash Flow from Operations	80	80	80	80	320
• Increase in cash	80	80	80	80	320
Total Cash Flow from Financing					
• Issuance of common stock	100	100	100	100	400
• Issuance of debt	100	100	100	100	400
Total Cash Flow from Financing	200	200	200	200	800
Total Cash Flow	280	280	280	280	1120

[Next Page]

FIGURE A.7a

Top section of the budget sheet for ICFans and heaters

Material items (100)	
1. Fan	
2. Heater	
3. Fan heater	
4. Fan heater	
5. Fan heater	
6. Fan heater	
7. Fan heater	
8. Fan heater	
9. Fan heater	
10. Fan heater	
11. Fan heater	
12. Fan heater	
13. Fan heater	
14. Fan heater	
15. Fan heater	
16. Fan heater	
17. Fan heater	
18. Fan heater	
19. Fan heater	
20. Fan heater	
21. Fan heater	
22. Fan heater	
23. Fan heater	
24. Fan heater	
25. Fan heater	
26. Fan heater	
27. Fan heater	
28. Fan heater	
29. Fan heater	
30. Fan heater	
31. Fan heater	
32. Fan heater	
33. Fan heater	
34. Fan heater	
35. Fan heater	
36. Fan heater	
37. Fan heater	
38. Fan heater	
39. Fan heater	
40. Fan heater	
41. Fan heater	
42. Fan heater	
43. Fan heater	
44. Fan heater	
45. Fan heater	
46. Fan heater	
47. Fan heater	
48. Fan heater	
49. Fan heater	
50. Fan heater	
51. Fan heater	
52. Fan heater	
53. Fan heater	
54. Fan heater	
55. Fan heater	
56. Fan heater	
57. Fan heater	
58. Fan heater	
59. Fan heater	
60. Fan heater	
61. Fan heater	
62. Fan heater	
63. Fan heater	
64. Fan heater	
65. Fan heater	
66. Fan heater	
67. Fan heater	
68. Fan heater	
69. Fan heater	
70. Fan heater	
71. Fan heater	
72. Fan heater	
73. Fan heater	
74. Fan heater	
75. Fan heater	
76. Fan heater	
77. Fan heater	
78. Fan heater	
79. Fan heater	
80. Fan heater	
81. Fan heater	
82. Fan heater	
83. Fan heater	
84. Fan heater	
85. Fan heater	
86. Fan heater	
87. Fan heater	
88. Fan heater	
89. Fan heater	
90. Fan heater	
91. Fan heater	
92. Fan heater	
93. Fan heater	
94. Fan heater	
95. Fan heater	
96. Fan heater	
97. Fan heater	
98. Fan heater	
99. Fan heater	
100. Fan heater	

FIGURE A.7b

Middle section of the budget sheet for ICFans and heaters

Construction Costs of Components

Component	2010	2011	2012	2013	2014
Structure and Enclosure					
- Steel Reinforcement	1000	1000	1000	1000	1000
Concrete	1000	1000	1000	1000	1000
Formwork	1000	1000	1000	1000	1000
Steel Bars	1000	1000	1000	1000	1000
Other	1000	1000	1000	1000	1000
- Masonry	1000	1000	1000	1000	1000
Brickwork	1000	1000	1000	1000	1000
Plaster	1000	1000	1000	1000	1000
Other	1000	1000	1000	1000	1000
- Roofing	1000	1000	1000	1000	1000
Roofing	1000	1000	1000	1000	1000
Other	1000	1000	1000	1000	1000
- Windows	1000	1000	1000	1000	1000
Windows	1000	1000	1000	1000	1000
Other	1000	1000	1000	1000	1000
- Doors	1000	1000	1000	1000	1000
Doors	1000	1000	1000	1000	1000
Other	1000	1000	1000	1000	1000
- Other	1000	1000	1000	1000	1000
Other	1000	1000	1000	1000	1000
Interior Finishes					
- Plaster	1000	1000	1000	1000	1000
Plaster	1000	1000	1000	1000	1000
Other	1000	1000	1000	1000	1000
- Painting	1000	1000	1000	1000	1000
Painting	1000	1000	1000	1000	1000
Other	1000	1000	1000	1000	1000
- Flooring	1000	1000	1000	1000	1000
Flooring	1000	1000	1000	1000	1000
Other	1000	1000	1000	1000	1000
- Other	1000	1000	1000	1000	1000
Other	1000	1000	1000	1000	1000
Electrical and Mechanical					
- Electrical	1000	1000	1000	1000	1000
Wiring	1000	1000	1000	1000	1000
Other	1000	1000	1000	1000	1000
- Mechanical	1000	1000	1000	1000	1000
Mechanical	1000	1000	1000	1000	1000
Other	1000	1000	1000	1000	1000
- Other	1000	1000	1000	1000	1000
Other	1000	1000	1000	1000	1000
Other	1000	1000	1000	1000	1000
Other	1000	1000	1000	1000	1000
Total	10000	10000	10000	10000	10000

Interior Finishes

Component	2010	2011	2012	2013	2014
Interior Finishes					
- Plaster	1000	1000	1000	1000	1000
Plaster	1000	1000	1000	1000	1000
Other	1000	1000	1000	1000	1000
- Painting	1000	1000	1000	1000	1000
Painting	1000	1000	1000	1000	1000
Other	1000	1000	1000	1000	1000
- Flooring	1000	1000	1000	1000	1000
Flooring	1000	1000	1000	1000	1000
Other	1000	1000	1000	1000	1000
- Other	1000	1000	1000	1000	1000
Other	1000	1000	1000	1000	1000
Total	10000	10000	10000	10000	10000

FIGURE A.8a

Top section of the budget sheet for ICFans and sprinklers

Installation		Equipment		Labor		Material	
Installation Data							
Location							
Room							
Room No.							
Room Name							
Room Area							
Room Volume							
Room Height							
Room Perimeter							
Room Shape							
Room Orientation							
Room Access							
Room Condition							
Room Notes							
Equipment Data							
Equipment Type							
Equipment Model							
Equipment Size							
Equipment Weight							
Equipment Volume							
Equipment Perimeter							
Equipment Orientation							
Equipment Condition							
Equipment Notes							
Labor Data							
Labor Type							
Labor Rate							
Labor Hours							
Labor Cost							
Labor Notes							
Material Data							
Material Type							
Material Quantity							
Material Cost							
Material Notes							

FAO ENVIRONMENT AND NATURAL RESOURCES SERIES

1. Africover: Specifications for geometry and cartography, 2000 (E)
2. Terrestrial Carbon Observation: The Ottawa assessment of requirements, status and next steps, 2002 (E)
3. Terrestrial Carbon Observation: The Rio de Janeiro recommendations for terrestrial and atmospheric measurements, 2002 (E)
4. Organic agriculture: Environment and food security, 2003 (E and S)
5. Terrestrial Carbon Observation: The Frascati report on *in situ* carbon data and information, 2002 (E)
6. The Clean Development Mechanism: Implications for energy and sustainable agriculture and rural development projects, 2003 (E)*
7. The application of a spatial regression model to the analysis and mapping of poverty, 2003 (E)
8. Land Cover Classification System (LCCS), version 2, 2005 (E)
9. Coastal GTOS. Strategic design and phase 1 implementation plan, 2005 (E)
10. Frost Protection: fundamentals, practice and economics- Volume I and II + CD, 2005 (E)

Availability: February 2005

Ar Arabic	F French	Multil Multilingual
C Chinese	P Portuguese	* Out of print
E English	S Spanish	** In preparation



The FAO Technical Papers
are available through the authorized
FAO Sales Agents or directly from:

Sales and Marketing Group - FAO
Viale delle Terme di Caracalla
00100 Rome - Italy



This volume reviews concepts of probability and risk of frost damage and uses that information to help readers make economic decisions about frost protection. Computer application programs are included with the book to help simplify complex calculations. The application programs are written in Microsoft Excel and sample calculations are presented in the text. Programs include TempRisk.xls, FriskS.xls, DEST.xls and FrostEcon.xls, and these applications are used to determine the

probability and risk of frost damage when the damage sensitivity is fixed, the certainty that an event with the computed probability will occur at least once over a selected number of years, the physical risk of early planting or late harvest of field and row crops, the risk of frost damage specific to a tree or vine crop that has changing sensitivity to frost during critical phenological stages and to determine the economic risk of frost damage and cost-effectiveness of frost protection methods.



Environment and Natural Resources Service (SDRN) publications

www.fao.org/sd/enpub1_en.htm

SDRN contact: Chief-SDRN@fao.org

Food and Agriculture Organization of the United Nations (FAO)

www.fao.org

