EIP-AGRI Focus Group
Protecting fruit production from frost damage

MINIPAPER 02: Assessing costs and benefits of frost protection measures in fruit production

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Objective of this mini paper

This paper presents a systematic approach to supporting decisions on frost protection. It includes guidance for collecting information, considering uncertainty and identifying trade-offs between competing objectives in production system establishment. It also compiles a list of the types of costs and benefits that decision-makers should keep in mind in choosing among frost protection options. We aim to provide practitioners with a guide that supports decision-making on frost protection in fruit production, describing the basic steps and listing all major aspects to consider.
We emphasize that effective frost protection in fruit production requires considering a number of aspects during both design and management of production orchards.

Introduction

How to protect fruit production from frost damage is an important question for producers of a large variety of fruits and in many production areas spanning a wide range of climatic conditions. Numerous different frost protection measures exist, which can be grouped into passive and active methods. Passive methods aim to reduce frost exposure during sensitive plant development stages through orchard design and management (e.g. selection of sites and crop varieties, nutrient management, soil and cover crop management, pruning etc.). Active methods are deployed during acute frost events and aim at increasing temperature in the crop/orchard (e.g. moving warm air into the crop, employing sprinklers or installing heating devices). The choice of method is a complex decision, in which orchard managers have to consider climatic conditions and risks, technical feasibility and effectiveness and economic aspects. In general, active methods are more expensive than passive methods, although there might be indirect costs of passive methods that should not be ignored, e.g. increased risk of soil erosion, when planting tree rows downward the slope to facilitate cold air drainage.

Challenges in deciding about frost protection measures

- There are a range of passive and active frost protection methods, which differ in technical feasibility and effectiveness in a given production site (e.g. water availability for frost irrigation, wind machines are only effective in case of inversion frost events).
- There are often trade-offs between investment costs (fixed costs), operational costs (variable costs) and indirect costs (quality effects from netting or specific pruning schemes).
- Evaluating potential benefits of frost protection measures requires anticipation of market and price effects: to what extent do frost events affect fruit production at regional, national or European level? How strong are price effects when yields are low?
- There is often substantial uncertainty about expected frequency and severity of frost events – and recent experiences may be a poor guide in evaluating future risk.

Approach to decision making

Step 1: Identify frost protection measures that are effective and technically feasible on the given site and for a given crop.

Site-specific characteristics are the key factor that determines which passive and active methods should be considered. Although site selection is an important measure, the range of available sites will be rather small in most cases, as is the range of fruit crops that promise good returns in a given farm and producing region.
The following site factors should be considered when designing a frost management strategy:

- Climate conditions: Frequency and severity of frost events during critical plant development stages, to determine if frost protection is needed, whether passive methods are sufficient or if active methods will be needed. Radiation can be important, too: if sun burn is a risk and shading required, netting can serve two purposes – frost protection and shading, thus improving the benefit-cost ratio.

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- Topography of the orchard - slope and low (cold) spots: Can cold air drainage be used to prevent frost damage? How to weigh advantages from cold air drainage against erosion control (direction of rows, obstacles? Are there particularly cold spots within the orchard where the application of active methods may be necessary? Are there sufficient flat spots to place heaters, wind machines or frost candles?
- Soil type: Will the soil characteristics help to retain energy and buffer against frost, e.g. when removing cover crops or avoiding soil cultivation? Which soil covers can be used?
- Water supply and drainage: Is there sufficient water for using sprinklers against frost? Is surface irrigation feasible? Can longer frost periods or several consecutive nights of frost be covered? Can the applied water drain to prevent damage to root systems and to allow entering the orchard with tractors when needed?
- Size and shape of the plot and cluster effects: How big is the orchard, what size or capacity of the frost protection equipment is needed? Can wind machines be applied? What is the proportion of borders to the total area of the orchard? Are there regional clusters of fruit production and could frost protection be organized in cooperation with neighbouring farms (e.g. use of helicopters, irrigation infrastructure, wind machines)

The following factors concerning the crop and crop management need consideration:

- Crop variety: How susceptible are different varieties to frost, e.g. timing of flowering period, hardiness against spring frost at different plant stages? What are the critical temperatures for the specific crop and variety during the different plant stages? Is risk management by diversifying varieties an option?
- Orchard design and layout: Do certain pruning or trellising systems help to reduce frost damage, e.g. minimum pruning in wine grapes? Are plant covers available and how would they affect crop yield and quality? Are there (negative or positive) side effects (e.g. roofing or netting can affect light interception and fruit colour or sweetness, but it can also prevent damage from rain, sunburn or hail)?
- Response of the crop to nutrient management: How does the crop respond to different fertilization strategies? Is there a trade-off between yield, quality and frost resistance of the tissues?
- Risk of plant damage through ice loads: Frost protection using overhead sprinklers is only possible in crops that can resist ice loads. There might be a trade-off between plant damage from ice and prevented yield loss.

Step 2: Identifying costs and benefits

In the next step, the expected costs and benefits need to be identified for those frost protection measures that are both technically feasible and likely to be effective for the given site and crops. For a comprehensive evaluation, it is useful to take into account that costs accrue at different points in time and thus differ in their effect on liquidity. Investment costs are usually one-off costs. They have to be paid at the moment of purchase, e.g. when the orchard is established and frost irrigation is installed, when a weather station is bought or when a wind machine is set up. Other costs are recurrent e.g. the costs for operating the frost protection equipment or costs for maintenance or fees to service providers. Also, it is useful to distinguish between fixed costs and variable costs. Fixed costs are independent of the actual use of the frost protection method, while variable costs are directly linked to the use.

Fixed costs include

- investment costs for technical equipment (wind machines, installation of sprinklers or irrigation systems, structures for covering plants, early warning systems and sensors, heaters etc.). These types of fixed costs are usually subject to economies of scale, i.e. the costs per unit decrease with increasing size of the orchard. They also depend on the length of the utilization period.
- maintenance and repair of installed technical equipment. In order to ensure that equipment will function in case of a frost event, regular checks and maintenance have to be carried out, resulting in costs that are independent of actual use. Repairs and maintenance costs may increase over time.
- costs for provision of required materials on time can be considered as fixed costs: storage of fuel, storage of heaters or plant cover materials, lagoons or water basins, or fees for water rights etc.

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- also recurrent costs of the passive frost protection methods should also be regarded as fixed costs, e.g. in case there are trade-offs concerning pruning systems, nutrient management, soil cultivation etc.

Variable costs include:

- all operational costs of using frost protection measures, such as fuel or electric energy, labour, water.
- indirect costs, e.g. damage to the trees from ice loads, phytosanitary problems when large amounts of water have been applied.

Often, fixed and variable costs are negatively correlated i.e. methods with low fixed costs require higher operational costs in the moment of use and vice versa. As an example: wind machines imply rather large investment costs, but once established, operational costs are relatively low. Sprinkler systems have a similar cost structure with high investment costs and low operational costs. On the other hand, the purchase of mobile heaters, e.g. frost candles can probably be delayed until actually needed, which implies low fixed costs. However, labour demand for placing and lighting them is very high and labour availability during frost events can be a severe limitation for using the system. Since variable costs are much less subject to economies of scale, small farms will tend to favour frost protection measures with higher variable costs and low investment costs.

Benefits:

A quantitative ex-ante assessment of the benefits of frost protection is probably the most difficult part of preparing the decision for frost protection measures. The ex-ante assessment of how many times critical temperatures will occur during the utilization period of the frost protection equipment or the lifetime of the orchard, and the quantification of the expected losses that will be prevented is subject to uncertainty.
Even with a good estimate of the amount of harvest saved by frost protection measures, the impact on revenues will depend on market conditions. How much of the production of the region or country is affected in case of frost? How is the coverage with frost protection measures – will frost events have an impact on fruit supply? Do prices increase in years with reduced fruit supply? Average prices can be a poor basis for estimating the value of saved harvest.

Step 3: Calculation of net benefits

The basic calculation is simple and serves as starting point for further analysis as explained in the next section. For any given frost protection measure FP, the profitability or net benefits can be expressed as the difference between benefits and costs. Note, that both costs and benefits occur at different times during the lifetime of the orchard, and time matters: The sooner a payment is due, the more it is weighted as compared to a later payment. This time preference is accounted for with the interest or discount rate that is applied to compare payments at different points in time. Hence the net benefits should be expressed as the net present value of the investment in frost protection. For simplification, the discounting of costs and benefits are not further explained in this paper, the reader may refer to any financial textbook for details. An example and tool for a detailed calculation of cost components, benefits and the present values is the EXCEL tool FrostEcon, which is described in detail in Snyder and Melo-Abreu (2005).

Total costs (TC) are calculated as the sum of fixed (FC) and variable costs (VC).

1) $TC = FC + VC$

Total benefits (TB) are calculated as the value of saved yield (Y_s), using an estimate for the output price (P), and the number of years (T_{fe}) in which frost occurs, hence the frost protection equipment leads to yield savings:

2) $TB = Y_s * P * T_{fe}$

where the saved yield depends on the potential yield (Y_p), the yield without frost protection in years with frost events (Y_{fe}) and the share of yield that can be saved with the specific frost protection measure ($\%_{FP}$)

3) $Y_s = (Y_p - Y_{fe}) * \%_{FP}$

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Dealing with uncertainty

A key challenge for decision-making about investment in frost protection measures is to deal with uncertainty. Different approaches for assessing uncertainty are possible. An easy method could be to quantify potential benefits of frost protection by comparing the maximum damage that might arise with a frost-protected situation, in which all losses are avoided. This, however, is an extreme approach, since in most fruit producing regions, frost during critical crop stages will not occur in every year. While the costs of taking frost-protection measures can be quantified with relative certainty, the potential losses that can be avoided range from total crop failure to rather mild losses, depending on the severity and duration of frost.
More importantly still, for all measures that require installation of infrastructure, profitability assessments need to consider the risk that frost during a sensitive time period will arise in the first place. Hence, the number of times during the expected lifetime of the infrastructure that it will actually produce benefits is a key determinant of profitability.
Growers should not take decisions based only on the recent experience of severe frost damage or based on the hope that they will keep escaping the kind of frost damage that has afflicted growers in similar climatic settings. They should instead make a serious effort to objectively assess their risks and factoring these considerations into their decision-making processes.

Risk assessments cannot be done by simply calculating net benefits based on one set of costs and one set of benefits. They need to account for the range of possible outcomes that can plausibly arise. Major determinants of the expected benefits are listed in table 1. In fruit production, the potential yield in a given year can vary greatly and depends not only on the occurrence or absence of frost during flowering. Other factors that determine the yield level and hence the potential benefit of frost protection are e.g. weather conditions during the whole growing season, crop management, pests and diseases. Often, a simple expected average yield level is used in the calculations. The yield without frost protection measures in a year with late frost will vary according to severity and duration of critical temperatures and will not be zero in most cases. Also the effectiveness of the different frost protection measures might change, depending on the weather conditions in a specific year.
A risk assessment of the frost protection methods should enable the grower to anticipate the range of possible outcomes of the investment, rather than relying on average values based on data from the past. If possible investments in frost protection measures have a similar level of expected net benefits, according to the simple calculation with mean values, they still could differ substantially with respect to the range of possible outcomes, revealed in calculations considering the probabilistic nature of the analysis. The grower can then select the best option according to his or her individual risk preferences.
A commonly applied technique in risk assessment is the so-called Monte Carlo simulation, which can be carried out with EXCEL or other calculation software[1] (Anderson et al. 1977, Hardaker et al 2015). The basic principle is to identify those variables of the cost benefit calculation (as shown in the equations above) that cannot be predicted with certainty, i.e. are stochastic. Instead of estimating one mean value, a probability distribution of possible values is specified. As an example, minimum, maximum and most likely values are defined for stochastic factors in the calculations (see also table 1), dependent on the specific conditions on the farm and according to the growers' own perceptions. In the Monte-Carlo simulation, the simulation tool repeats the cost benefit calculations many times, e.g. 10,000 times. In these calculations, the values for each of the specified stochastic variables are drawn randomly from previously defined ranges of possible values. Hence the result of each of the calculations is the combination of different possible values and shows a possible outcome of net benefits. The distribution of possible outcomes now can be further analysed: How broad is the range of possible outcomes? What is the share of simulation results with negative net benefits? Based on these indicators, the different technologies can be compared against each other and against a reference situation without frost protection.

[1] Examples for simple software tools for Monte Carlo simulation are: @risk from Palisade Corporation or ModelRisk from Vose Software. Many others are available, too. FrostEcon by Melo-Abreu (2005) also includes risk analysis.

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Taken together, the resulting figures constitute a risk-adjusted cost-benefit analysis that helps make rational decisions in the face of the kind of uncertainty that is an inevitable aspect of all agricultural risk management strategies.

Table 1: Stochastic factors of the benefit - cost analysis of frost protection measures

Factor	Example	Data source
Potential yield without frost in a given year, site and variety	Range of yield level, minimum and maximum yield per ha	Regional fruit production statistics, experimental stations and yield trials, on-farm records of yields
Yield in case of frost event without protection	Range of yield levels, minimum and maximum yield per ha	Regional experimental stations and yield trials, on-farm records of yields
Saved yield/prevented losses for each frost protection measure under consideration	Technical efficiency, range of the share of yield that is saved.	Technical reports, experimental stations
Frequency of frost events with potential yield losses	Minimum and maximum number of years with frost events during lifetime of the orchard	Historical weather data, records of regional flowering dates
Output price in year with frost event	Minimum, maximum and most likely price of output	Price statistics, trends

Research Needs

In principle, frost protection decisions can be supported by well-established decision analysis procedures, but fruit growers do not commonly use such approaches. One reason is probably that the calculations they involve are somewhat more complex than classic business accounting practices, but we suspect that lack of awareness of advanced risk assessment methods is a major cause for limited adoption. This leads us to identify the following research needs:

- Identify barriers to adoption of adequate methodologies
- Design decision support tools and training materials that can help growers prepare better for the particular frost risk in their orchard.

In addition to these needs, growers also face fundamental uncertainties that limit their ability to make well-informed decisions. To remedy some of these, researchers should

- Quantify historic and future frost risk, considering occurrence and severity
- Improve bloom time prediction models
- Compile and refine information on the frost susceptibility of fruit species and varieties
- Assess the effectiveness of various frost risk management strategies
- Develop a cost-estimate database on the fixed and variable costs involved in each available frost risk management strategy.
- Compile a database on potential yields (for different species/varieties) and damage critical temperatures (for species/variety) for use by growers/farmers;

Further research needs coming from practice, ideas for EIP AGRI operational groups and other proposals for innovation can be found at the final report of the focus group, available at the FG webpage https://ec.europa.eu/eip/agriculture/en/focus-groups/protecting-fruit-production-frost-damage

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Conclusions

Frost risk management decisions are difficult to make, because they require considering long planning horizons, accounting for various fixed and variable costs and estimating parameters that are not precisely known. Current and future frost risk, bloom times, frost damage levels and price responses in the event of widespread frost damage are among the critical variables that should be considered but whose precise values are usually unknown. Guessing values is just as unsatisfying as having the choice of frost management strategy guided by impressions of recent good or bad years.

Decision analysis based on probabilistic simulation is a commonly used approach to risk management in many fields. It can account for risk and uncertainty and help growers objectively quantify their frost challenges and select appropriate ways forward. To date, such methods are rarely applied by orchard managers, because many are unfamiliar with these approaches and tools to support them are not readily available. Research and extension should try to assist growers in bridging these methodological gaps, so that they can be optimally equipped for choosing frost protection strategies that fully account for the frost risk profile of their particular location.

References

Anderson JR, Dillon JL and Hardaker B (1977): Agricultural decision analysis. Iowa State University Press. Ames, Iowa, USA.

Hardaker B, Gudbrand L, Anderson JR and Huirne RBM (2015): Coping with Risk in Agriculture, 3rd edition. CABI, Oxfordshire, UK and Boston, USA.

Snyder RL, Melo-Abreu JP, Matulich S (2005): Frost protection: fundamentals, practice, and economics, Vol 2. Environment and Natural Resources Series 10. Food and Agriculture Organization of the United Nations. Rome, Italy.

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