Supplementary material for Rojas et al. 2020

Eduardo Fernandez\textsuperscript{a,*}, Gonzalo Rojas\textsuperscript{b}, Cory Whitney\textsuperscript{a}, Italo F. Cuneo\textsuperscript{b}, and Eike Luedeling\textsuperscript{a}

\textsuperscript{a} Department of Horticultural Sciences, Institute of Crop Science and Resource Conservation (INRES), Auf dem Hügel 6, D-53121 Bonn, Germany
\textsuperscript{b} Escuela de Agronomía, Pontificia Universidad Católica de Valparaíso, Casilla 4-D, Quillota, Chile

The following document is a supplement to the work “Adapting sweet cherry orchards to hazardous weather events — Decision Analysis in support of farmers’ investments in central Chile” by Gonzalo Rojas, Eduardo Fernandez, Cory Whitney, Eike Luedeling and Italo F. Cuneo, published in the journal Agricultural Systems.

Introduction
Farming systems are among the most vulnerable schemes regarding the impacts of climate change. Growers in subtropical regions may expect an increase in the frequency and magnitude of what are currently considered unusual weather events. To deal with this situation, and remain productive under future scenarios, growers must adapt their orchards by implementing technologies that mitigate the impacts of climate change on agricultural systems. However, available options for mitigating these impacts involve a number of risks and uncertainties, leaving growers hesitant about the benefits of implementing new technologies to protect their orchards. Here we use a case study in northern- and southern-central Chile to demonstrate the applicability of Decision Analysis approaches to embrace the inherent uncertainty when making decisions. We applied a participatory modeling approach to collect and analyze qualitative and quantitative knowledge regarding the decision to apply polyethylene covers in sweet cherry orchards. We gathered relevant experts and key stakeholders to identify important variables and develop a causal impact pathway model for the adoption decision. We implemented the model as a Monte Carlo simulation and projected probability distributions for the Net Present Value (NPV) and the annual cash flow. Additionally, we determined the most relevant variables affecting the decision via Partial Least Squares regression and Expected Value of Perfect Information analysis.

We provide information on the focus group meeting procedure as well as a working example to demonstrate the applicability of the \texttt{decisionSupport} package (Luedeling et al., 2020) for comparing two investment options through decision analysis approaches. This working example is focused on the process we adopted after obtaining the conceptual pathway of the decision in the workshop with stakeholders. For more on the preliminary processes see the main manuscript.

Focus group meeting procedure
As mentioned in the main manuscript, the focus group meetings aimed to identify the growers’ major concerns regarding the impacts of climate change on the cultivation of sweet cherry trees in central Chile. The procedure consisted of statements and conversations that were guided by the meeting moderator. Major concerns were identified through a qualitative approach based on agreement among the participants. In this approach, farmers generated a prioritized list of potential risks under a changing climate. These prioritized lists (i.e. one for each of the zones) helped us frame our work. Since this manuscript is part of a bigger project, for a detailed document on the complete procedure, please contact the corresponding author.

\textsuperscript{*}Eduardo Fernández (efernand@uni-bonn.de)
Model development

After defining the decision and establishing the conceptual framework in a workshop with stakeholders (Fig. 1), we asked the participants for estimates on the key variables they had identified. The input table is a collection of calibrated confidence intervals for variables that are included in the impact pathway model. We used two versions of the input table ("input_table1.csv" and "input_table2.csv") according to two climatic-risk zones: northern- and southern-central Chile. These tables contain the same variables but represent different climatic scenarios with different estimates.

Figure 1: Impact pathway describing the relation between key variables identified by the stakeholders in our workshop
Adapting sweet cherry orchards to hazardous weather events

The following table corresponds to the inputs estimated for the first 10 variables in the low-risk zone (i.e. northern-central Chile). The column Description aims to provide detailed information on the respective variable. The column distribution represents the distribution of the variable assessed with values norm and posnorm for normally distributed inputs (posnorm excludes negative values), const for constant values, and tnorm_0_1 for positive probabilities between 0 and 1. The columns lower and upper represent the lower and upper bound for the estimates provided by the experts. Since multiple experts provided inputs, in the final joint table we used the broadest range in order to account for the overall uncertainty among experts regarding a specific variable. The column variable is the abbreviated name of the variable for use in the programming interface when defining the structure of the model. For the complete input table and estimates for both the northern- and southern-central zone, please see annexes.

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Model function of Net Present Value comparing covered and uncovered orchards

The impact pathway model obtained in the workshop with stakeholders (Fig. 1) is programmed as a function that we call cover() and feed with data from the input tables. This function will later be implemented as a Monte Carlo simulation through functions in the decisionSupport package (Luedeling et al., 2020). The function cover() was programmed to return the Net Present Value as well as the cash flow in the case of applying covers (i.e. outputs for orchards with cover minus outputs for orchards without cover).

```r
cover <- function(){

  # This section defines general risks associated with the cultivation of
  # sweet cherries in Chile

  # Define internal functions to estimate the risk of some climate events
  event_occurrence <- function (x) {
    events <- decisionSupport::chance_event(x, n = n_years)
    return(events)
  }

  # Add functions for specific climate risks

  # Other functions...

  # Return the Net Present Value and cash flow

  return()
}
```
Adapting sweet cherry orchards to hazardous weather events

```r
# Estimated risks of production
# As cover implementation is a long-term investment, we estimated the number of rain events in the period of project duration. This is based on "rain_risk" variable from the input table.

rain_events <- event_occurrence(rain_risk)

# Depending on the severity of a rain event, it can be considered catastrophic or not. Use catast_rain_event from input table as prior for probability of catastrophic event

number_of_catastrophic_events <- round(sum(rain_events) * prob_catast_rain_event)

# Then we estimate which year or years were not catastrophic based on the number of catastrophic events vector

if (sum(rain_events) == 1) {
  if (number_of_catastrophic_events == 1) {
    not_catastrophic_years <- 0
  } else {
    not_catastrophic_years <- which(rain_events == 1)
  }
} else {
  not_catastrophic_years <- sample(which(rain_events == 1), size = (sum(rain_events) - number_of_catastrophic_events))
}

# Here we change the category of catastrophic year for the year(s) that were or were not catastrophic

# (pre-set catast_rain_event to normal rain events)
catast_rain_event <- rain_events

if (length(not_catastrophic_years)){
  catast_rain_event[not_catastrophic_years] <- 0
}

# Losses for rain events can be extremely high and that is the reason for using the catastrophic rain event vector. The new vector "Rain losses" is to differentiate between catastrophic losses and normal rain losses

Rain_losses <- rep(NA, n_years)
rain_losses <- splitting_loss + fungus_loss
```
for (i in 1 : n_years){
    if (rain_events[i] == 1 & catast_rain_event[i] == 1){
        Rain_losses[i] <- catast_yield_loss
        if(rain_events[i] == 1 & catast_rain_event[i] == 0){
            Rain_losses[i] <- event_severity(rain_losses)[i]
        }
        Rain_losses[i] <- 0
    }

    if (Frost_event[i] == 1){
        Frost_losses[i] <- event_severity(frost_losses)[i]
    }
    else {
        Frost_losses[i] <- 0
    }

    if (Hail_event[i] == 1){
        Hail_losses[i] <- event_severity(hail_losses)[i]
    }
    else {
        Hail_losses[i] <- 0
    }

    if (Wind_events[i] == 1){
        Wind_losses[i] <- event_severity(wind_losses)[i]
    }
    else {
        Wind_losses[i] <- 0
    }

    # Losses due to frost events
    Frost_event <- event_ocurrence(frost_risk)
    Frost_losses <- rep(NA, n_years)

    # Losses due to hail events
    Hail_event <- event_ocurrence(hail_risk)
    Hail_losses <- rep(NA, n_years)

    # Losses due to wind events
    Wind_events <- event_ocurrence(wind_risk)
    Wind_losses <- rep(NA, n_years)

    # Intervention loop
    # This loop will test both scenarios for the decision. This is
    # FALSE in the case of not adopting the covers and TRUE in the case that
    # covers are applied
    for (decision_cover in c(FALSE, TRUE)){

        # Costs of using covers
        # Estimated costs per hectare when using covers (farmers' decision to implement)
        # Define initial cover costs (materials, structure and labor of installation)
Adapting sweet cherry orchards to hazardous weather events

```r
if (decision_cover) {
    initial_cost <- structure_cost + instalation_labor_cost + cover_material_cost
    initial_cost <- c(initial_cost, rep(0, n_years - 1))
} else {
    initial_cost <- c(rep(0, n_years))
}

# Tree management costs for using the cover
# Varieties can be sensitive to cover use
if (decision_cover) {

    if (variety_sensitivity > 0.5) variety_sensitivity <- TRUE else
    variety_sensitivity <- FALSE

    # Depending on the classification the cost associated with tree management
    # can increase or not.

    # Foliage management

    if (variety_sensitivity) all_foliage_management_cost <-
    event_severity(increased_foliage_management_cost +
    foliage_management_cost) else
    all_foliage_management_cost <- event_severity(foliage_management_cost)

    # Nutrient management

    if (variety_sensitivity) all_nutrient_management_cost <-
    event_severity(nutrient_management_cost *
    (1 + increased_nutrient_management_cost)) else
    all_nutrient_management_cost <- event_severity(nutrient_management_cost)

    # Water management

    if (variety_sensitivity) all_water_management_cost <-
    event_severity(water_management_cost *
    (1 + increased_water_management_cost)) else
    all_water_management_cost <- event_severity(water_management_cost)

    # Add all the additional costs for the whole project period (n_years)
    # associated with tree management due to the use of covers

    total_tree_management_costs <-
    all_foliage_management_cost +
    all_nutrient_management_cost +
    all_water_management_cost

    # This else is in case of not using cover...
} else {
```
all_foliage_management_cost <- event_severity(foliage_management_cost)
all_nutrient_management_cost <- event_severity(nutrient_management_cost)
all_water_management_cost <- event_severity(water_management_cost)

total_tree_management_costs <- all_foliage_management_cost +
all_nutrient_management_cost +
all_water_management_cost

# Cover maintenance, operation and renovation

# At this point is better to start with the initial investment that
# is affected by design, quality of materials, and structure.

# Chance of having bad design of the cover (0 = no; 1 = yes)?
if (decision_cover){
  bad_design <- decisionSupport::chance_event(probability_of_bad_design,
                                            value_if = 1, value_if_not = 0,
                                            one_draw = TRUE)
}

# Chance of having poor materials for the cover (0 = no; 1 = yes)?
poor_materials <- decisionSupport::chance_event(probability_of_poor_materials,
                                            value_if = 1,
                                            value_if_not = 0,
                                            one_draw = TRUE)

# Chance of poorly constructed cover structure (0 = no; 1 = yes)?
bad_construction <- decisionSupport::chance_event(probability_of_bad_construction,
                                            value_if = 1,
                                            value_if_not = 0,
                                            one_draw = TRUE)

# If we have a bad cover (result of bad design, poor materials or bad construction)
# growers will need more renovations during the duration of the project
additional_renovation_need_poor_cover <- bad_design + poor_materials +
  bad_construction

# Increase the frequency of necessary renovations due to bad design etc.
# cover_renovation_freq is the number of years between changing the cover
updated_cover_renovation_freq <- round(cover_renovation_freq -
  additional_renovation_need_poor_cover,
  digits = 0)

# Create a column of 0 and 1 for years of renovation
cover_renovation <- rep(c(rep(0, updated_cover_renovation_freq), 1),
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updated_cover_renovation_freq, length.out = n_years)

} else{
    # here we assign zero values for variables that should not have any effect in
    # the 'no cover' decision
    updated_cover_renovation_freq <- 0
    additional_renovation_need_poor_cover <- 0
    cover_renovation <- rep(0, n_years) }

# Renovation cost is equal to the number of renovations multiplied by the cost of cover material
if (decision_cover){
    cover_renovation_cost <- ifelse(cover_renovation == 1,
                                    yes = event_severity(cover_material_cost),
                                    no = 0)
}
else{
    cover_renovation_cost <- 0 }

# Operational cost is result of working days for opening and closing the covers, and
# the cost of one working day. Maintenance cost is an annual expense the farmers incur
# to keep the covers in good state. It should imply cleaning the surface of the cover,
# tighten the wires, etc.
if (decision_cover){
    cover_operational_cost <- event_severity(round(working_days_open_and_close +
                                              working_days_maintain) *
                                              working_day_cost)
    total_standard_cost <- initial_cost +
                          total_tree_management_costs +
                          cover_renovation_cost +
                          cover_operational_cost
}
else {
    cover_operational_cost <- 0
    total_standard_cost <- total_tree_management_costs}

# Default total operational costs related to the cover decision

# Alternative costs
# The use of helicopter as an alternative strategy for reducing the
# impacts of a rain event without cover
if (!decision_cover){
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Helicopter <- rain_events

# Assign the value of helicopter as an alternative cost
# Total alternative strategy cost for whole period of intervention (n_years)

total_alternative_costs_no_cover_and_rain <- ifelse(Helicopter == 1,
    yes = event_severity(helicopter_costs_visit),
    no = 0)

} else{
    total_alternative_costs_no_cover_and_rain <- 0
    Helicopter <- 0 }

# Estimating the benefits and negative impacts for the use of covers

# Estimating yield for rain.
# We have to assume an equal normal yield in order to compare both systems

Potential_yield <- event_severity(yield)

# Yield depends on the event of rain and on the decision of applying covers or not.
# Here we used two columns for yield estimations (under cover and without covers).
# In a scenario with the use of cover and rain event yield should be less affected.

if (decision_cover){
    losses_rain <- Potential_yield * (Rain_losses * (1 - cover_effectiveness_rain))
} else{
    losses_rain <- Potential_yield * (Rain_losses)
}

# Yield for cover and non-cover systems considering frost losses

if (decision_cover){
    losses_frost <- Potential_yield * (Frost_losses * (1 - cover_effectiveness_frost))
} else{
    losses_frost <- Potential_yield * (Frost_losses) }

# Yield for cover and non-cover systems considering hail losses

if (decision_cover){
    losses_hail <- Potential_yield * (Hail_losses * (1 - cover_effectiveness_hail))
} else{
    losses_hail <- Potential_yield * (Hail_losses) }

# Yield for cover and non-cover systems considering wind losses

if (decision_cover){
    losses_wind <- Potential_yield * (Wind_losses * (1 - cover_effectiveness_wind))
} else{
    losses_wind <- Potential_yield * (Wind_losses) }

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# Yield for cover systems considering firmness problem

```r
if (decision_cover){
  losses_low_firmness <- Potential_yield * low_firmness
} else{
  losses_low_firmness <- 0
}
```

# Sum yield for covering and non-covering systems

# Add all the potential losses

```r
all_losses <- losses_rain + losses_frost + losses_hail + losses_wind +
  losses_low_firmness
```

Yield <- Potential_yield - all_losses

# As you cannot get a negative yield, this corrects for this issue

```r
Yield[which(Yield < 0)] <- 0
```

```r
## Estimating the market price

if (decision_cover){
  # Advantage in market price due to early ripening by using covers

  if (round(adv_ripe_time) <= adv_ripe_time_threshold)
    increase_in_price <- adv_ripe_time_min_price_increase else
    increase_in_price <- adv_ripe_time_max_price_increase

  # market price per kg when using the cover

  farmgate_market_price <- market_price * (1 + increase_in_price)

  ## The income per sales is computed between the price and the yield.
  # In the case of yield under cover the price could be affected as we estimated above.

  Sales <- Yield * event_severity(farmgate_market_price)

  ## Calculate farm income

  income <- Sales - (total_standard_cost + event_severity(production_costs))

  cashflow_with_cover <- income
} else {
  # Price in the case where no covers are used should be the same as market price
```
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Sales <- Yield * event_severity(market_price)

income <- Sales - (total_standard_cost +
                   total_alternative_costs_no_cover_and_rain +
                   event_severity(production_costs))

cashflow_no_cover <- income

} # close intervention loop bracket

## Net present value

NPV_no_cover <- decisionSupport::discount(cashflow_no_cover,
                                          discount_rate = discount_rate,
                                          calculate_NPV = TRUE)

NPV_cover <- decisionSupport::discount(cashflow_with_cover,
                                         discount_rate = discount_rate,
                                         calculate_NPV = TRUE)

# Here we define the return of the model function. In this case,
# we aimed to obtain the comparison between the systems when the
# covers are used in one case and not used in
# the other

return(list(Diff_NPV_cover_no_cover = NPV_cover - NPV_no_cover,
            Diff_Cashflow_cover_no_cover = cashflow_with_cover - cashflow_no_cover))

After defining the structure of the model, we applied a Monte Carlo simulation that takes inputs from the input table and runs the model with one set of draws at a time. This is replicated 10,000 times yielding distributions of random draws for all the outputs defined in the return of the model function (e.g. 10,000 NPV values).

Call the decisionSupport() function for Monte Carlo simulations

In the following loop, we call the same model function using estimates from different input tables (i.e. for northern- and southern-central Chile). This assumes that the main variables and interactions remain the same between production zones, thus allowing us to compare different climate scenarios.

for (i in 1 : 2)

  decisionSupport(inputFilePath = paste("input_table", i, ", .csv", sep = ""),
                 outputPath = paste(getwd(), "/MCResults_zone_", i, sep = ""),
                 write_table = TRUE,
                 welfareFunction = cover,
                 numberOfModelRuns = 1e4,
                 functionSyntax = "plainNames",
                 verbosity = 0)
Graphical comparison of the outputs

As mentioned before, the decisionSupport() function generates a distribution of the outputs defined in the return of the model function. We first compared the distributions of both NPV and cash flow between zones. Later, we applied two post-hoc analyses to these distributions, i.e. a Partial Least Squares regression analysis, and the Expected Value of Perfect Information analysis between variables in the input table and projected NPV.

Net present value

The distribution for NPV in the case of applying covers can be visualized with a density plot. We plot the NPV distribution for the decision across zones using the ggplot2 package (Wickham et al., 2020).

Figure 2: NPV comparison in case of adopting covers in sweet cherry orchards in northern and southern-central Chile

This figure illustrates that applying covers in southern-central Chile is likely to produce positive NPV values. On the contrary, applying covers in northern-central Chile may produce a more uncertain outcome.
Cash flow

Cash flow represents the annual income in the orchard in the case of adopting covers in sweet cherry orchards. Our Monte Carlo approach then generated 10,000 expected values for annual farm income in both cultivation zones. Illustrating cash flow over the duration of the project may help farmers in planning future investments in the same project (e.g. renovations, replanting) or in other strategies.

Figure 3: Cash flow comparison in case of adopting covers in sweet cherry orchards in northern and southern-central Chile

The cash flow analysis revealed that, after a considerable initial investment in year 1, farmers are likely to reach positive annual income in both zones. Nonetheless, the probability of positive outcomes is higher in southern-central Chile than in the northern-central zone.
**Expected Value of Perfect Information**

We implemented Expected Value of Perfect Information analysis to determine which variables would provide valuable information for improving the decision-making process.

![Expected Value of Perfect Information analysis for sweet cherry orchards applying covers in northern and southern-central Chile](image)

**Figure 4: Expected Value of Perfect Information analysis for sweet cherry orchards applying covers in northern and southern-central Chile**

Our results suggest that farmers in the northern-central zone of the country should be willing to invest a bit of effort in reducing the uncertainty on variables like *yield*, *market price* and *yield lost to lack of fruit firmness* in order to make a better decision. Our analysis highlighted the same variables were important in the southern-central zone, but the EVPI values were low enough to suggest that an investment in information gathering would not be worthwhile.
Partial Least Squares regression

We implemented a Partial Least Squares regression analysis to determine the most relevant variables affecting the NPV in the case of applying the covers. The following plot shows variables displaying a Variable Importance in the Projection (VIP) score equal to or higher than 0.8.

Figure 5: Results of PLS regression between the input variables and the output (NPV in this case) when covers are used in sweet cherry orchards in northern and southern-central Chile

In the northern-central part of the country, NPV estimates were highly affected by the loss of yield to low firmness when using covers. Cover effectiveness was found key in the southern-central zone.
Final analysis

We merged all figures to obtaining a compound figure and contextualize the overall analysis.

Figure 6: Compound figure showing results for NPV, cash flow, VIP and EVPI analysis in two major zones for the cultivation of sweet cherry in central Chile
Conclusions

Our approach demonstrated the applicability of decision analysis to assess the decision of applying covers in sweet cherry orchards in northern- and southern-central Chile. Such an approach is helpful to gather and collect expert knowledge from relevant stakeholders associated with the decision. This example might serve as a guideline for future assessments in agricultural or other fields facing complex decisions under scenarios with high uncertainty.

References


**Appendix**

Here we reproduce the estimates we used for the complete analysis. The original input files can be downloaded from the links provided as supplementary materials in the DOI for this article.

Table 2: Estimates of inputs provided to the decision model for the northern-central zone

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<td>Proportion of yield lost due in the case of a severe frost event without a cover (%)</td>
<td>tnorm_0_1</td>
<td>0.30</td>
<td>0.60</td>
<td>frost_losses</td>
</tr>
<tr>
<td>Proportion of yield lost due to severe hail event without a cover (%)</td>
<td>tnorm_0_1</td>
<td>0.50</td>
<td>0.80</td>
<td>hail_losses</td>
</tr>
<tr>
<td>Proportion of yield lost due to severe wind event without a cover (%)</td>
<td>tnorm_0_1</td>
<td>0.01</td>
<td>0.10</td>
<td>wind_losses</td>
</tr>
<tr>
<td>Proportion of rain damage avoided by using the cover (%)</td>
<td>tnorm_0_1</td>
<td>0.70</td>
<td>0.95</td>
<td>cover_effectiveness_rain</td>
</tr>
<tr>
<td>Proportion of frost damage avoided by using the cover (%)</td>
<td>tnorm_0_1</td>
<td>0.60</td>
<td>0.95</td>
<td>cover_effectiveness_frost</td>
</tr>
<tr>
<td>Proportion of hail damage avoided by using the cover (%)</td>
<td>tnorm_0_1</td>
<td>0.70</td>
<td>0.95</td>
<td>cover_effectiveness_hail</td>
</tr>
<tr>
<td>Proportion of wind damage avoided by using the cover (%)</td>
<td>tnorm_0_1</td>
<td>0.90</td>
<td>0.95</td>
<td>cover_effectiveness_wind</td>
</tr>
<tr>
<td>Advantage in ripening time due to using covers (days)</td>
<td>posnorm</td>
<td>2.00</td>
<td>10.00</td>
<td>adv_ripe_time</td>
</tr>
<tr>
<td>Time at which advanced ripening time offers a new price for the farmer (better market price) days</td>
<td>posnorm</td>
<td>3.00</td>
<td>9.00</td>
<td>adv_ripe_time_threshold</td>
</tr>
<tr>
<td>Minimum increased price as an advantage to earlier fruit ripening time due to using covers (%) below the advanced ripening time threshold</td>
<td>tnorm_0_1</td>
<td>0.20</td>
<td>0.30</td>
<td>adv_ripe_time_min_price_increase</td>
</tr>
<tr>
<td>Maximum increased price as an advantage to earlier fruit ripening time due to using covers (%) above the advanced ripening time threshold</td>
<td>tnorm_0_1</td>
<td>0.30</td>
<td>0.50</td>
<td>adv_ripe_time_max_price_increase</td>
</tr>
<tr>
<td>Proportion of yield lost due to firmness problems (%) (changed to yield according to experts)</td>
<td>tnorm_0_1</td>
<td>0.10</td>
<td>0.40</td>
<td>low_firmness</td>
</tr>
</tbody>
</table>
Table 3: Estimates of inputs provided to the decision model for the northern-central zone (continuation)

<table>
<thead>
<tr>
<th>Description</th>
<th>distribution</th>
<th>lower</th>
<th>upper</th>
<th>variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farm gate price of wholesale fruits directly from the farmer to buyer (USD/kg)</td>
<td>posnorm</td>
<td>2.00</td>
<td>10.00</td>
<td>market_price</td>
</tr>
<tr>
<td>Proportion of rain events that are catastrophic</td>
<td>tnorm_0_1</td>
<td>0.10</td>
<td>0.30</td>
<td>prob_catast_rain_event</td>
</tr>
<tr>
<td>Proportion of yield lost in a catastrophic rain event (%)</td>
<td>tnorm_0_1</td>
<td>0.60</td>
<td>0.90</td>
<td>catast_yield_loss</td>
</tr>
<tr>
<td>Variety sensitive to change their behave under cover (it represent cost)</td>
<td>tnorm_0_1</td>
<td>0.40</td>
<td>0.95</td>
<td>variety_sensitivity</td>
</tr>
<tr>
<td>Cost of production in normal situation (USD/ha/year)</td>
<td>posnorm</td>
<td>12000.00</td>
<td>24000.00</td>
<td>production_costs</td>
</tr>
<tr>
<td>Cost of foliage management (USD/ha/yr)</td>
<td>posnorm</td>
<td>680.00</td>
<td>1560.00</td>
<td>foliage_management_cost</td>
</tr>
<tr>
<td>Cost of nutrition under normal management (USD/ha/yr)</td>
<td>posnorm</td>
<td>400.00</td>
<td>1100.00</td>
<td>water_management_cost</td>
</tr>
<tr>
<td>Cost of nutrition under normal management (USD/ha/yr)</td>
<td>posnorm</td>
<td>480.00</td>
<td>1200.00</td>
<td>nutrient_management_cost</td>
</tr>
<tr>
<td>Cost of maintain foliage (USD/ha/yr)</td>
<td>posnorm</td>
<td>150.00</td>
<td>500.00</td>
<td>increased_foliage_management_cost</td>
</tr>
<tr>
<td>Cost of increased water need (USD/ha/yr)</td>
<td>posnorm</td>
<td>0.01</td>
<td>0.15</td>
<td>increased_water_management_cost</td>
</tr>
<tr>
<td>Cost of the increased nutrition needs under covers (USD/ha/yr)</td>
<td>posnorm</td>
<td>0.01</td>
<td>0.15</td>
<td>increased_nutrient_management_cost</td>
</tr>
<tr>
<td>Cost of helicopter (USD/yr). Rain dependent but usually between 1 to 10 hours per hectare per year</td>
<td>posnorm</td>
<td>500.00</td>
<td>2000.00</td>
<td>helicopter_costs_visit</td>
</tr>
<tr>
<td>Probability of a bad design</td>
<td>tnorm_0_1</td>
<td>0.01</td>
<td>0.20</td>
<td>probability_of_bad_design</td>
</tr>
<tr>
<td>Probability of implementing with poor materials</td>
<td>tnorm_0_1</td>
<td>0.01</td>
<td>0.20</td>
<td>probability_of_poor_materials</td>
</tr>
<tr>
<td>Probability of bad construction</td>
<td>tnorm_0_1</td>
<td>0.01</td>
<td>0.20</td>
<td>probability_of_bad_construction</td>
</tr>
<tr>
<td>Frequency renovation of the cover (years)</td>
<td>posnorm</td>
<td>4.00</td>
<td>7.00</td>
<td>cover_renovation_freq</td>
</tr>
<tr>
<td>Costs of the cover structure cost (USD/ha)</td>
<td>posnorm</td>
<td>3200.00</td>
<td>18000.00</td>
<td>structure_cost</td>
</tr>
<tr>
<td>Labor cost for the cover installation (USD/ha)</td>
<td>posnorm</td>
<td>1400.00</td>
<td>7200.00</td>
<td>installation_labor_cost</td>
</tr>
<tr>
<td>Costs of the cover material (USD/ha)</td>
<td>posnorm</td>
<td>8800.00</td>
<td>19200.00</td>
<td>cover_material_cost</td>
</tr>
<tr>
<td>Working days in open and close the cover (days/year)</td>
<td>posnorm</td>
<td>3.00</td>
<td>14.00</td>
<td>working_days_open_and_close</td>
</tr>
<tr>
<td>Cost of a labor day of work (USD/day)</td>
<td>posnorm</td>
<td>15.00</td>
<td>35.00</td>
<td>working_day_cost</td>
</tr>
<tr>
<td>Number of days working on maintenance (days/year)</td>
<td>posnorm</td>
<td>4.00</td>
<td>15.00</td>
<td>working_days_maintain</td>
</tr>
</tbody>
</table>
Table 4: Estimates of inputs provided to the decision model for the southern-central zone

<table>
<thead>
<tr>
<th>Description</th>
<th>distribution</th>
<th>lower</th>
<th>upper</th>
<th>variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lifetime of the intervention number of years over which the cover intervention should be assessed</td>
<td>const</td>
<td>15.00</td>
<td>15.00</td>
<td>n_years</td>
</tr>
<tr>
<td>Coefficient of variation ratio of the standard deviation to the mean (a measure of relative variability)</td>
<td>posnorm</td>
<td>5.00</td>
<td>20.00</td>
<td>var_cv</td>
</tr>
<tr>
<td>The discount rate to be used throughout the project (%)</td>
<td>posnorm</td>
<td>1.00</td>
<td>10.00</td>
<td>discount_rate</td>
</tr>
<tr>
<td>The expected annual cherry fruit yield under normal conditions (kg/ha) without a cover (%)</td>
<td>posnorm</td>
<td>5600.00</td>
<td>21600.00</td>
<td>yield</td>
</tr>
<tr>
<td>Risk of a rain event to occur during the growing season before ripening of cherry fruits (%)</td>
<td>tnorm_0_1</td>
<td>0.50</td>
<td>0.80</td>
<td>rain_risk</td>
</tr>
<tr>
<td>Risk of a frost event to occur during cherry tree flowering (%)</td>
<td>tnorm_0_1</td>
<td>0.50</td>
<td>0.80</td>
<td>frost_risk</td>
</tr>
<tr>
<td>Risk of a rain event to occur during the growing season before ripening of cherry fruits (%)</td>
<td>tnorm_0_1</td>
<td>0.10</td>
<td>0.40</td>
<td>hail_risk</td>
</tr>
<tr>
<td>Risk of a rain event to occur during the growing season before ripening of cherry fruits (%)</td>
<td>tnorm_0_1</td>
<td>0.05</td>
<td>0.25</td>
<td>wind_risk</td>
</tr>
<tr>
<td>Proportion of yield lost due to fruit splitting after a rain event without a cover (%)</td>
<td>tnorm_0_1</td>
<td>0.40</td>
<td>0.70</td>
<td>splitting_loss</td>
</tr>
<tr>
<td>Proportion of yield lost due to fungus infection after a rain event without a cover (%)</td>
<td>tnorm_0_1</td>
<td>0.10</td>
<td>0.30</td>
<td>fungus_loss</td>
</tr>
<tr>
<td>Proportion of yield lost due in the case of a severe frost event without a cover (%)</td>
<td>tnorm_0_1</td>
<td>0.50</td>
<td>0.80</td>
<td>frost_losses</td>
</tr>
<tr>
<td>Proportion of yield lost due to severe hail event without a cover (%)</td>
<td>tnorm_0_1</td>
<td>0.60</td>
<td>0.90</td>
<td>hail_losses</td>
</tr>
<tr>
<td>Proportion of yield lost due to severe wind event without a cover (%)</td>
<td>tnorm_0_1</td>
<td>0.10</td>
<td>0.30</td>
<td>wind_losses</td>
</tr>
<tr>
<td>Proportion of rain damage avoided by using the cover (%)</td>
<td>tnorm_0_1</td>
<td>0.50</td>
<td>0.80</td>
<td>cover_effectiveness_rain</td>
</tr>
<tr>
<td>Proportion of frost damage avoided by using the cover (%)</td>
<td>tnorm_0_1</td>
<td>0.40</td>
<td>0.80</td>
<td>cover_effectiveness_frost</td>
</tr>
<tr>
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<td>tnorm_0_1</td>
<td>0.40</td>
<td>0.80</td>
<td>cover_effectiveness_hail</td>
</tr>
<tr>
<td>Proportion of wind damage avoided by using the cover (%)</td>
<td>tnorm_0_1</td>
<td>0.70</td>
<td>0.90</td>
<td>cover_effectiveness_wind</td>
</tr>
<tr>
<td>Advantage in ripening time due to using covers (days)</td>
<td>posnorm</td>
<td>2.00</td>
<td>10.00</td>
<td>adv_ripe_time</td>
</tr>
<tr>
<td>Time at which advanced ripening time offers a new price for the farmer (better market price) days</td>
<td>posnorm</td>
<td>3.00</td>
<td>9.00</td>
<td>adv_ripe_time_threshold</td>
</tr>
<tr>
<td>Minimum increased price as an advantage to earlier fruit ripening time due to using covers (%) below the advanced ripening time threshold</td>
<td>tnorm_0_1</td>
<td>0.20</td>
<td>0.30</td>
<td>adv_ripe_time_min_price_increase</td>
</tr>
<tr>
<td>Maximum increased price as an advantage to earlier fruit ripening time due to using covers (%) above the advanced ripening time threshold</td>
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<td>0.30</td>
<td>0.50</td>
<td>adv_ripe_time_max_price_increase</td>
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<tr>
<td>Proportion of yield lost due to firmness problems (%) (changed to yield according to experts)</td>
<td>tnorm_0_1</td>
<td>0.10</td>
<td>0.40</td>
<td>low_firmness</td>
</tr>
<tr>
<td>Farm gate price of wholesale fruits directly from the farmer to buyer (USD/kg)</td>
<td>posnorm</td>
<td>2.00</td>
<td>10.00</td>
<td>market_price</td>
</tr>
</tbody>
</table>
Table 5: Estimates of inputs provided to the decision model for the southern-central zone (continuation)

<table>
<thead>
<tr>
<th>Description</th>
<th>distribution</th>
<th>lower</th>
<th>upper</th>
<th>variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportion of rain events that are catastrophic</td>
<td>tnorm_0_1</td>
<td>0.20</td>
<td>0.50</td>
<td>prob_catast_rain_event</td>
</tr>
<tr>
<td>Proportion of yield lost in a catastrophic rain event (%)</td>
<td>tnorm_0_1</td>
<td>0.75</td>
<td>0.95</td>
<td>catast_yield_loss</td>
</tr>
<tr>
<td>Variety sensitive to change their behaviour under cover (it represents cost)</td>
<td>tnorm_0_1</td>
<td>0.40</td>
<td>0.95</td>
<td>variety_sensitivity</td>
</tr>
<tr>
<td>Cost of production in normal situation (USD/ha/year)</td>
<td>posnorm</td>
<td>12000.00</td>
<td>24000.00</td>
<td>production_costs</td>
</tr>
<tr>
<td>Cost of foliage management (USD/ha/yr)</td>
<td>posnorm</td>
<td>680.00</td>
<td>1560.00</td>
<td>foliage_management_cost</td>
</tr>
<tr>
<td>Cost of nutrition under normal management (USD/ha/yr)</td>
<td>posnorm</td>
<td>400.00</td>
<td>1100.00</td>
<td>water_management_cost</td>
</tr>
<tr>
<td>Cost of nutrition under normal management (USD/ha/yr)</td>
<td>posnorm</td>
<td>480.00</td>
<td>1200.00</td>
<td>nutrient_management_cost</td>
</tr>
<tr>
<td>Cost of maintain foliage (USD/ha/yr)</td>
<td>posnorm</td>
<td>150.00</td>
<td>500.00</td>
<td>increased_foliage_management_cost</td>
</tr>
<tr>
<td>Cost of increased water need (USD/ha/yr)</td>
<td>posnorm</td>
<td>0.01</td>
<td>0.15</td>
<td>increased_water_management_cost</td>
</tr>
<tr>
<td>Cost of the increased nutrition needs under cover (USD/ha/yr)</td>
<td>posnorm</td>
<td>0.01</td>
<td>0.15</td>
<td>increased_nutrient_management_cost</td>
</tr>
<tr>
<td>Cost of helicopter (USD/yr). Rain dependent but usually between 1 to 10 hours per hectare per year</td>
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<td>500.00</td>
<td>2000.00</td>
<td>helicopter_costs_visit</td>
</tr>
<tr>
<td>Probability of a bad design</td>
<td>tnorm_0_1</td>
<td>0.01</td>
<td>0.20</td>
<td>probability_of_bad_design</td>
</tr>
<tr>
<td>Probability of implementing with poor materials</td>
<td>tnorm_0_1</td>
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<td>0.20</td>
<td>probability_of_poor_materials</td>
</tr>
<tr>
<td>Probability of bad construction</td>
<td>tnorm_0_1</td>
<td>0.01</td>
<td>0.20</td>
<td>probability_of_bad_construction</td>
</tr>
<tr>
<td>Frequency renovation of the cover (years)</td>
<td>posnorm</td>
<td>4.00</td>
<td>7.00</td>
<td>cover_renovation_freq</td>
</tr>
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<td>Costs of the cover structure cost (USD/ha)</td>
<td>posnorm</td>
<td>3200.00</td>
<td>18000.00</td>
<td>structure_cost</td>
</tr>
<tr>
<td>Labor cost for the cover installation (USD/ha)</td>
<td>posnorm</td>
<td>1400.00</td>
<td>7200.00</td>
<td>installation_labor_cost</td>
</tr>
<tr>
<td>Costs of the cover material (USD/ha)</td>
<td>posnorm</td>
<td>8800.00</td>
<td>19200.00</td>
<td>cover_material_cost</td>
</tr>
<tr>
<td>Working days in open and close the cover (days/year)</td>
<td>posnorm</td>
<td>3.00</td>
<td>14.00</td>
<td>working_days_open_and_close</td>
</tr>
<tr>
<td>Cost of a labor day of work (USD/day)</td>
<td>posnorm</td>
<td>15.00</td>
<td>35.00</td>
<td>working_day_cost</td>
</tr>
<tr>
<td>Number of days working on maintenance (days/year)</td>
<td>posnorm</td>
<td>4.00</td>
<td>15.00</td>
<td>working_days_maintain</td>
</tr>
</tbody>
</table>