Supplementary material for Rojas et al. 2020

Eduardo Fernandez[a,*], Gonzalo Rojas[b], Cory Whitney[a], Italo F. Cuneo[b], and Eike Luedeling[a]

[a] Department of Horticultural Sciences, Institute of Crop Science and Resource Conservation (INRES), Auf dem Hügel 6, D-53121 Bonn, Germany
[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 `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.

*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.

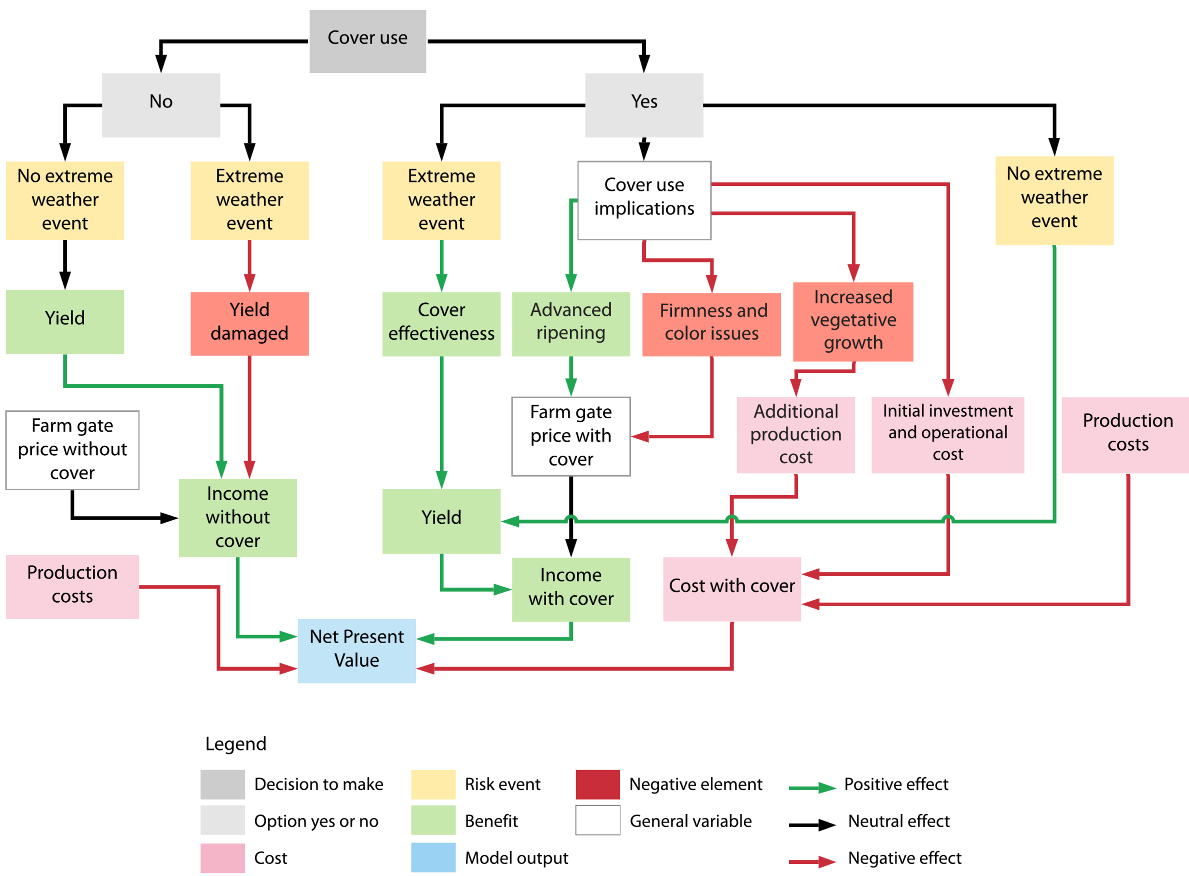

Figure 1: Impact pathway describing the relation between key variables identified by the stakeholders in our workshop

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.

Table 1: Part of the estimates of inputs provided to the decision model

Description	distribution	lower	upper	variable
Lifetime of the intervention number of years over which the cover intervention should be assessed	const	15.00	15.00	n__years
Coefficient of variation ratio of the standard deviation to the mean (a measure of relative variability)	posnorm	5.00	20.00	var__cv
The discount rate to be used throughout the project (%)	posnorm	1.00	10.00	discount__rate
The expected annual cherry fruit yield under normal conditions (kg/ha) without a cover	posnorm	5600.00	21600.00	yield
Risk of a rain event to occur during the growing season before ripening of cherry fruits (%)	tnorm__0__1	0.05	0.20	rain__risk
Risk of a frost event to occur during cherry tree flowering (%)	tnorm__0__1	0.20	0.40	frost__risk
Risk of a rain event to occur during the growing season before ripening of cherry fruits (%)	tnorm__0__1	0.01	0.05	hail__risk
Risk of a rain event to occur during the growing season before ripening of cherry fruits (%)	tnorm__0__1	0.01	0.10	wind__risk
Proportion of yield lost due to fruit splitting after a rain event without a cover (%)	tnorm__0__1	0.20	0.40	splitting__loss
Proportion of yield lost due to fungus infection after a rain event without a cover (%)	tnorm__0__1	0.05	0.20	fungus__loss

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).

```
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_ocurrence <- function (x) {
    events <- decisionSupport::chance_event(x, n = n_years)
```

```
  return(events)
}

event_severity <- function(x){
  event_severity <- vv(x, var_CV = var_cv, n = n_years)
  return(event_severity)
}

# 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_ocurrence(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
```

```r
for (i in 1 : n_years){
  if (rain_events[i] == 1 & catast_rain_event[i] == 1){
    Rain_losses[i] <- catast_yield_loss} else {
      if(rain_events[i] == 1 & catast_rain_event[i] == 0){
        Rain_losses[i] <- event_severity(rain_losses)[i]} else {
          Rain_losses[i] <- 0}}}


# Losses due to frost events

Frost_event <- event_ocurrence(frost_risk)
Frost_losses <- rep(NA, n_years)

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

# Losses due to hail events

Hail_event <- event_ocurrence(hail_risk)
Hail_losses <- rep(NA, n_years)

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


# Losses due to wind events

Wind_events <- event_ocurrence(wind_risk)
Wind_losses <- rep(NA, n_years)

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


# 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)
```

```
    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),
```

```
                        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){
```

```r
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) }
```

```
# Yield for cover systems considering firmness problem

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

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

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


## 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
```

```
  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).

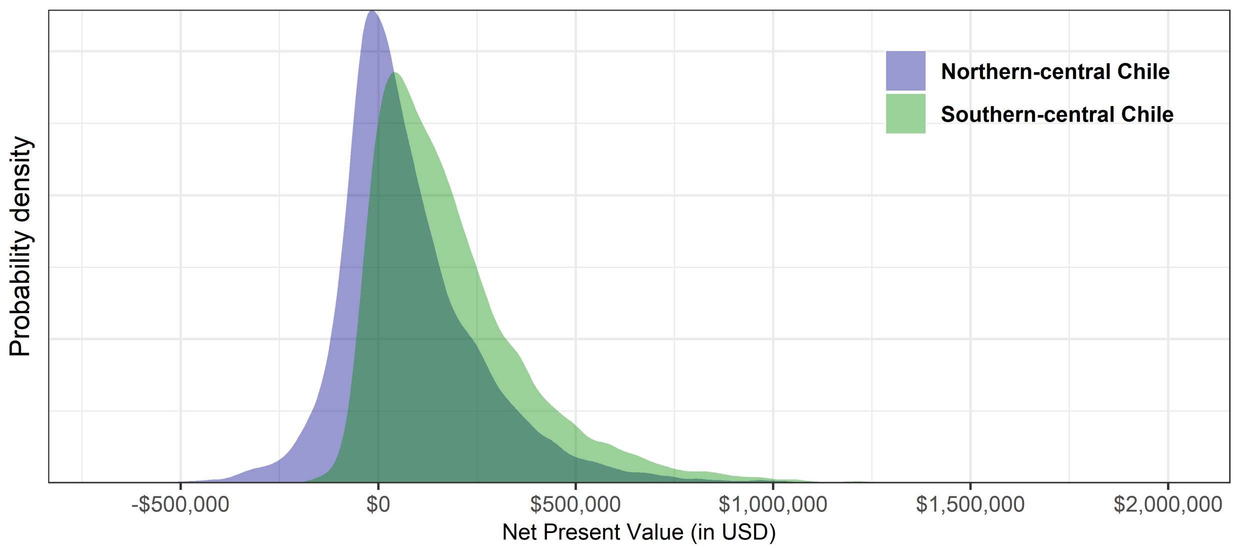

Figure 2: NPV comparison in case of adopting covers in sweet cherry orchards in northern and southern-central Chile

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.

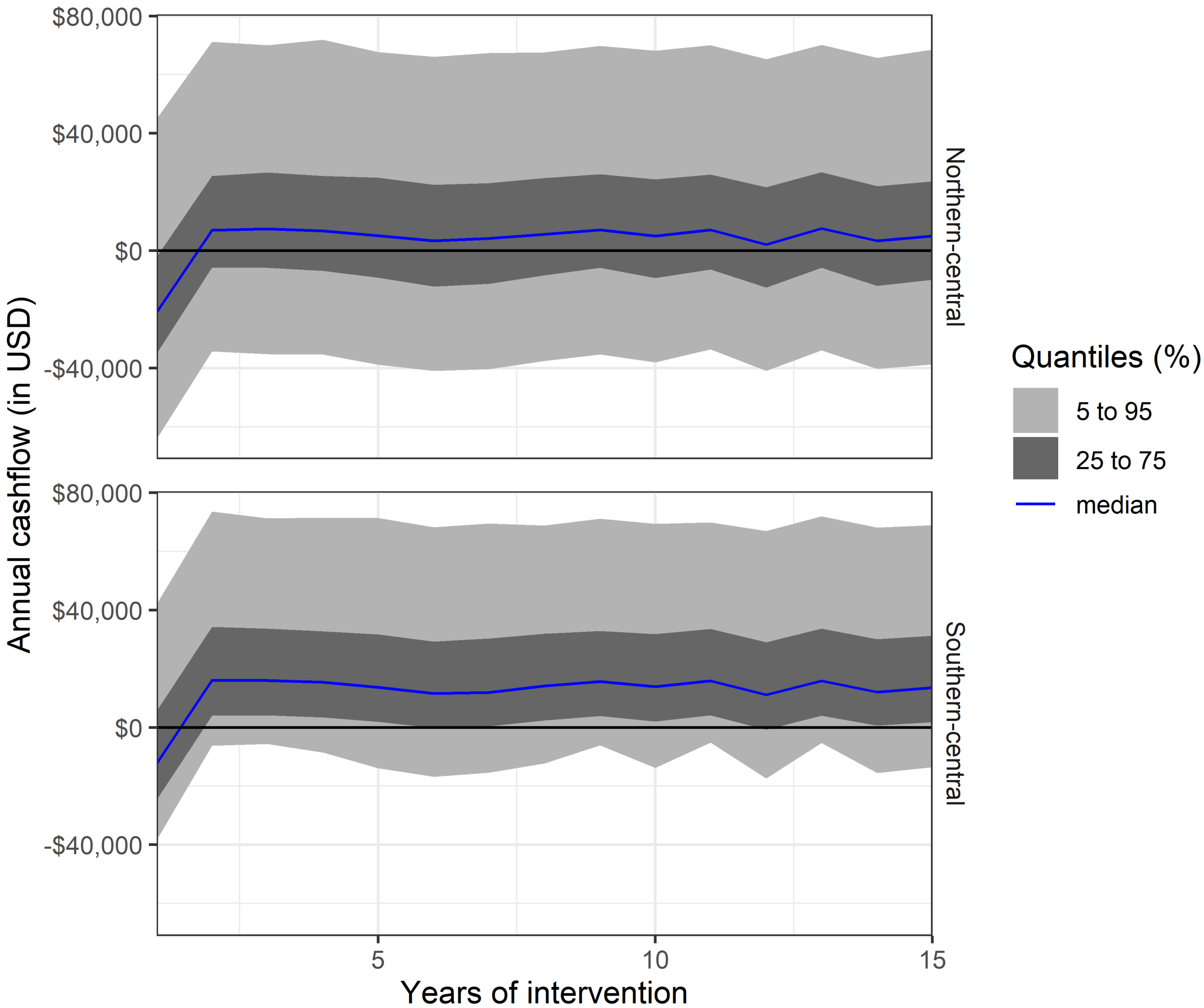

Figure 3: Cash flow comparison in case of adopting covers in sweet cherry orchards in northern and southern-central Chile

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.

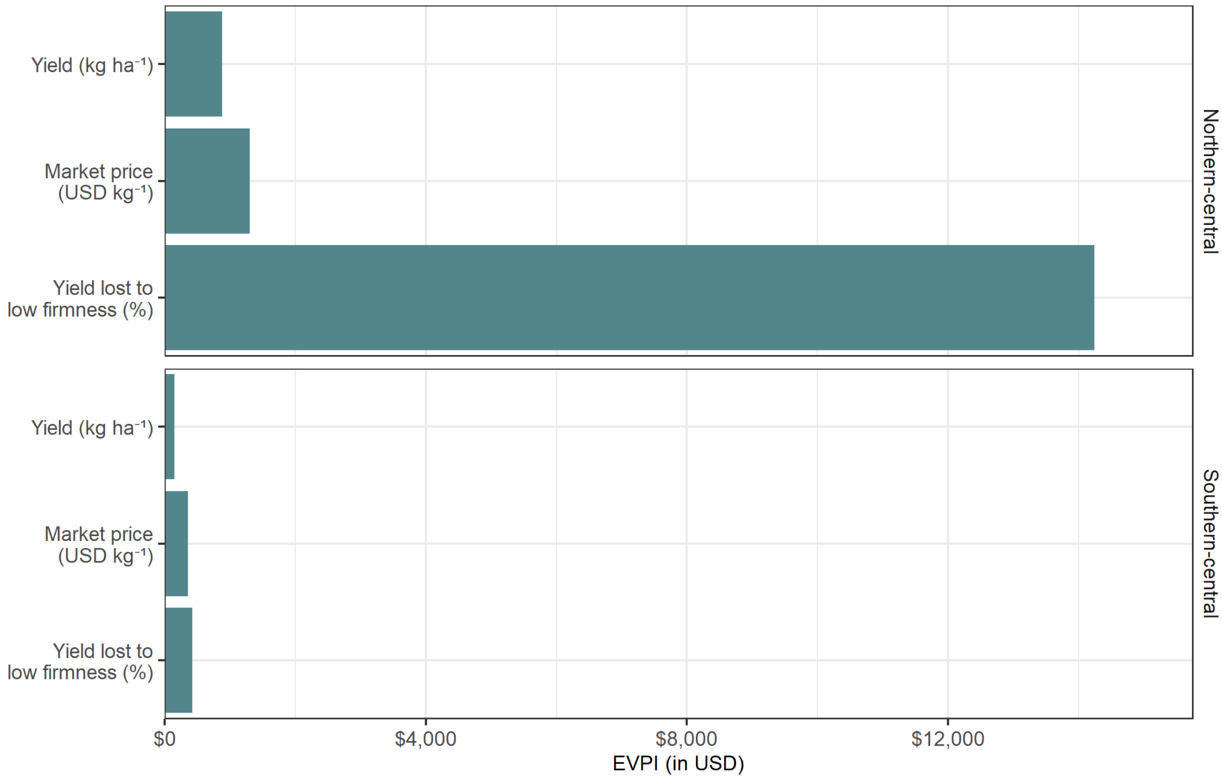

Figure 4: Expected Value of Perfect Information analysis for sweet cherry orchards applying covers in northern and southern-central Chile

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.

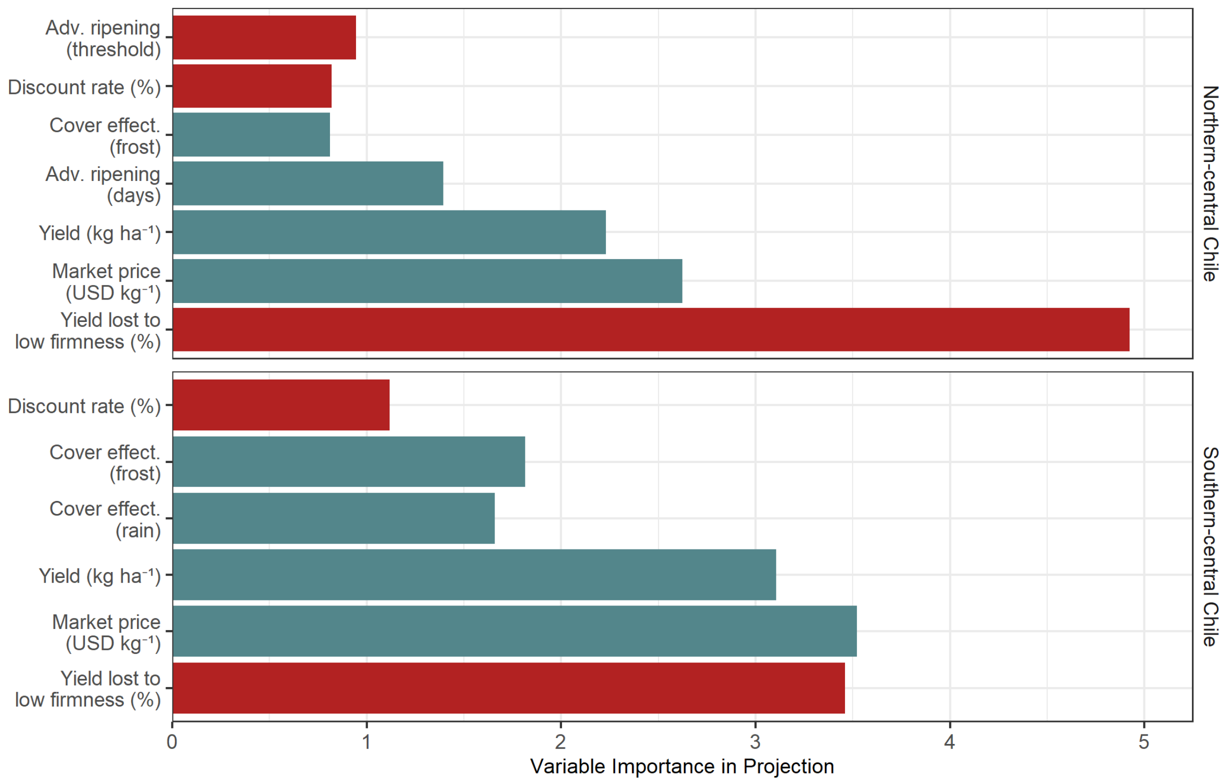

Figure 5: Results of PLS regression between the input variables and the output (NPV in this case) when covers are used in sweet cherry orchards in northern and southern-central Chile

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.

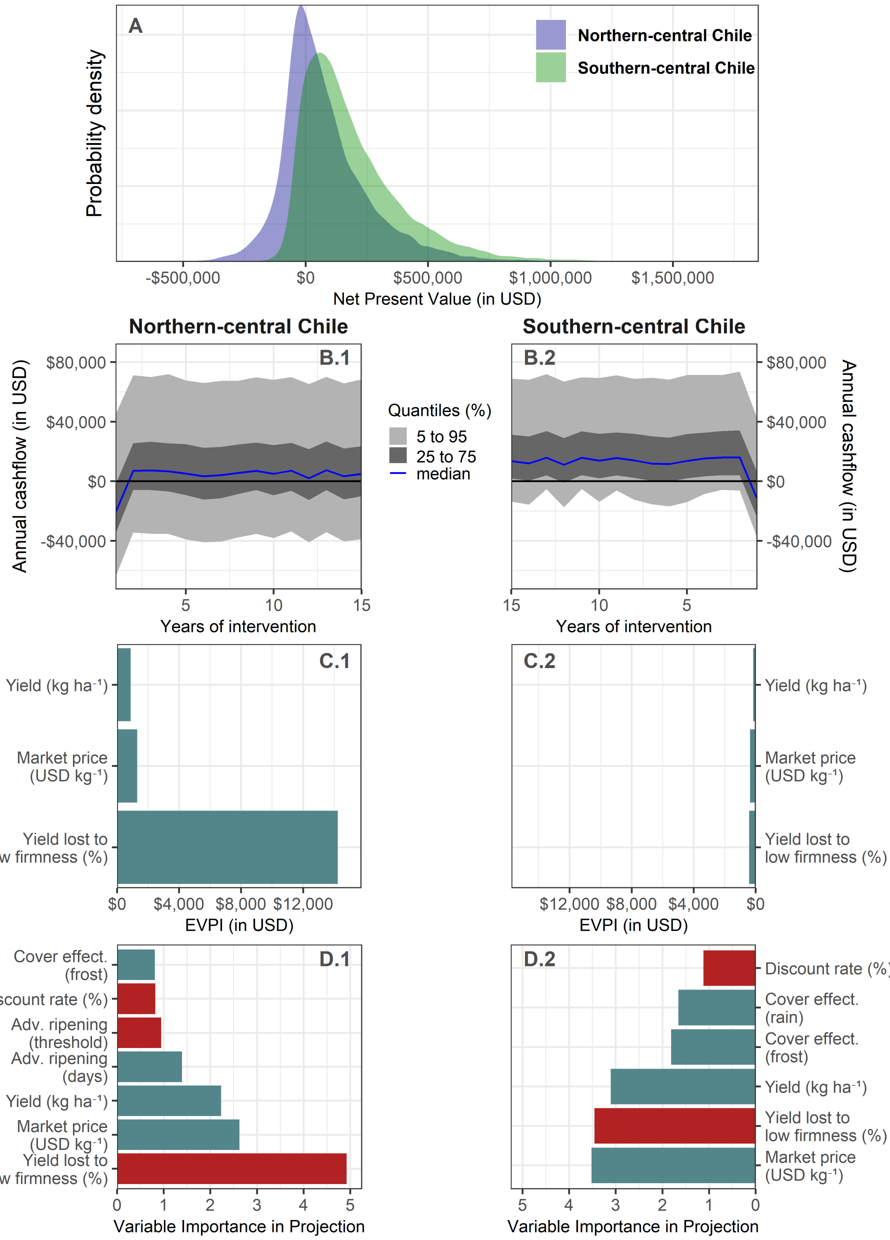

Figure 6: Compound figure showing results for NPV, cash flow, VIP and EVPI analysis in two major zones for the cultivation of sweet cherry in central Chile

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

Luedeling, E., Goehring, L., Schiffers, K., 2020. DecisionSupport: Quantitative support of decision making under uncertainty. http://www.worldagroforestry.org/

Wickham, H., Chang, W., Henry, L., Pedersen, T.L., Takahashi, K., Wilke, C., Woo, K., Yutani, H., Dunnington, D., 2020. Ggplot2: Create elegant data visualisations using the grammar of graphics. https://CRAN.R-project.org/package=ggplot2

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

Description	distribution	lower	upper	variable
Lifetime of the intervention number of years over which the cover intervention should be assessed	const	15.00	15.00	n_years
Coefficient of variation ratio of the standard deviation to the mean (a measure of relative variability)	posnorm	5.00	20.00	var_cv
The discount rate to be used throughout the project (%)	posnorm	1.00	10.00	discount_rate
The expected annual cherry fruit yield under normal conditions (kg/ha) without a cover	posnorm	5600.00	21600.00	yield
Risk of a rain event to occur during the growing season before ripening of cherry fruits (%)	tnorm_0_1	0.05	0.20	rain_risk
Risk of a frost event to occur during cherry tree flowering (%)	tnorm_0_1	0.20	0.40	frost_risk
Risk of a rain event to occur during the growing season before ripening of cherry fruits (%)	tnorm_0_1	0.01	0.05	hail_risk
Risk of a rain event to occur during the growing season before ripening of cherry fruits (%)	tnorm_0_1	0.01	0.10	wind_risk
Proportion of yield lost due to fruit splitting after a rain event without a cover (%)	tnorm_0_1	0.20	0.40	splitting_loss
Proportion of yield lost due to fungus infection after a rain event without a cover (%)	tnorm_0_1	0.05	0.20	fungus_loss
Proportion of yield lost due in the case of a severe frost event without a cover (%)	tnorm_0_1	0.30	0.60	frost_losses
Proportion of yield lost due to severe hail event without a cover (%)	tnorm_0_1	0.50	0.80	hail_losses
Proportion of yield lost due to severe wind event without a cover (%)	tnorm_0_1	0.01	0.10	wind_losses
Proportion of rain damage avoided by using the cover (%)	tnorm_0_1	0.70	0.95	cover_effectiveness_rain
Proportion of frost damage avoided by using the cover (%)	tnorm_0_1	0.60	0.95	cover_effectiveness_frost
Proportion of hail damage avoided by using the cover (%)	tnorm_0_1	0.70	0.95	cover_effectiveness_hail
Proportion of wind damage avoided by using the cover (%)	tnorm_0_1	0.90	0.95	cover_effectiveness_wind
Advantage in ripening time due to using covers (days)	posnorm	2.00	10.00	adv_ripe_time
Time at which advanced ripening time offers a new price for the farmer (better market price) days	posnorm	3.00	9.00	adv_ripe_time_threshold
Minimum increased price as an advantage to earlier fruit ripening time due to using covers (%) below the advanced ripening time threshold	tnorm_0_1	0.20	0.30	adv_ripe_time_min_price_increase
Maximum increased price as an advantage to earlier fruit ripening time due to using covers (%) above the advanced ripening time threshold	tnorm_0_1	0.30	0.50	adv_ripe_time_max_price_increase
Proportion of yield lost due to firmness problems (%) (changed to yield according to experts)	tnorm_0_1	0.10	0.40	low_firmness

Table 3: Estimates of inputs provided to the decision model for the northern-central zone (continuation)

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

Table 4: Estimates of inputs provided to the decision model for the southern-central zone

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

Table 5: Estimates of inputs provided to the decision model for the southern-central zone (continuation)

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