Advanced Timber

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Introduction

Cameroon ranks as the fifth largest cocoa producer globally, with the sector playing a significant role in the country's rural economy. Production is predominantly carried out by smallholder farmers, whose livelihoods are closely tied to cocoa cultivation. Introduced during the German colonial period as a cash crop, cocoa has since become a cornerstone of agricultural export in Cameroon. Compared to cocoa from some neighboring countries, Cameroonian cocoa is often considered less affected by pesticide residues, enhancing its appeal in increasingly quality-conscious global markets. In recent years, producers have also benefited from favorable world market prices.

Despite its economic significance, cocoa production in Cameroon faces numerous structural and environmental challenges. The international cocoa price remains highly volatile, exposing producers to significant income uncertainty. Input costs can be prohibitively high in remote rural areas, limiting farmers' ability to invest in yield improvements. Agronomically, cocoa is highly sensitive to temperature fluctuations and drought, and remains vulnerable to a range of pests and diseases, all of which are exacerbated by climate change. Additionally, the sector is hampered by supply chain inefficiencies, including poor infrastructure and limited access to markets, while unsustainable expansion has contributed to deforestation. These issues are further compounded by sociodemographic pressures, such as aging farming populations, limited access to education and extension services, and other inherent constraints to smallholder farming systems.

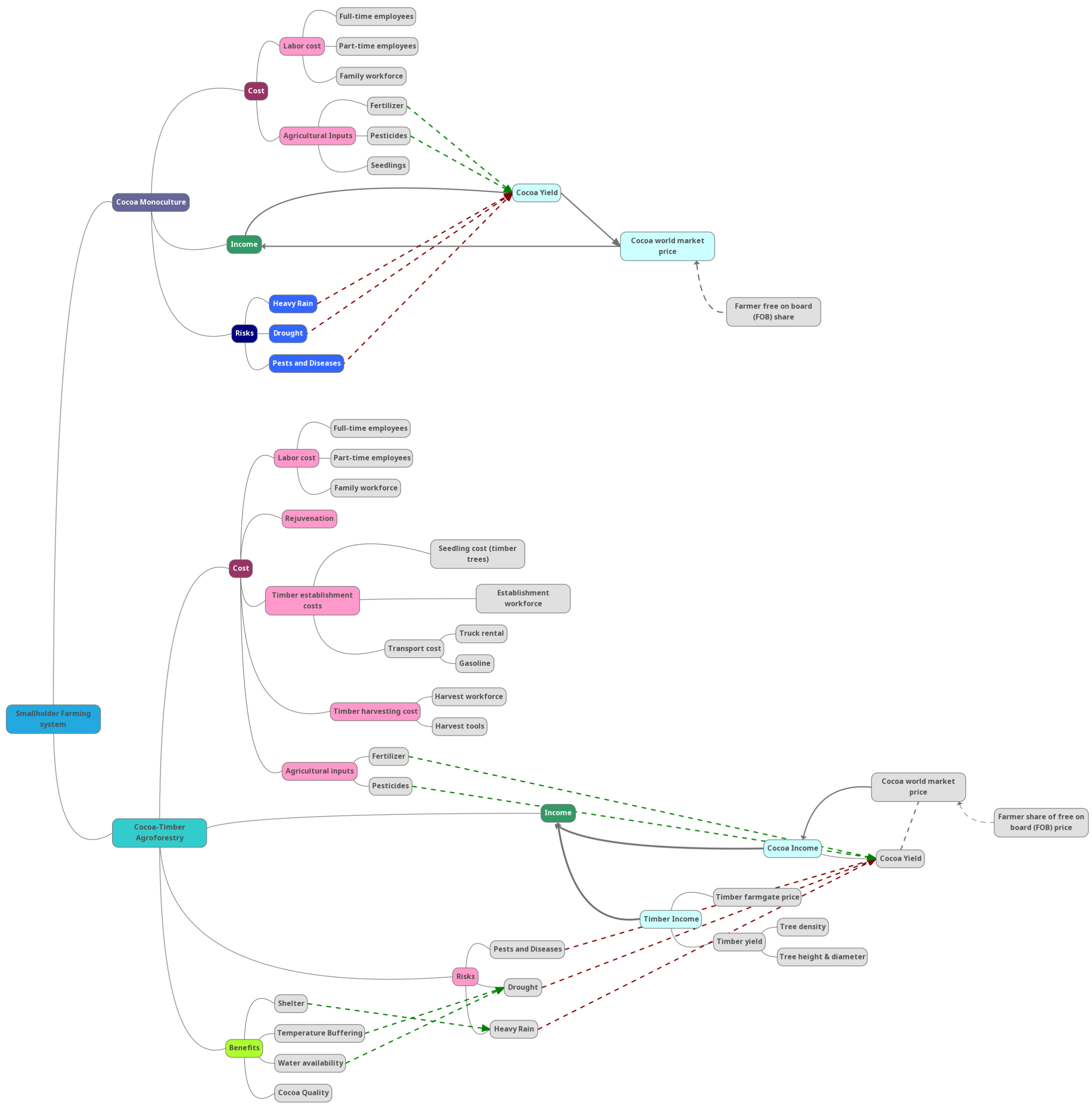
Recent market trends, however, suggest that cocoa prices may increasingly reflect the growing production risks associated with climate variability, pest pressure, and land-use constraints. Nonetheless, long-term global demand for cocoa is projected to rise steadily, driven by sustained consumption in both emerging and established markets. This continued demand underscores cocoa's strategic importance not only as a global commodity but also as a source of monetary income for otherwise predominantly subsistence-oriented smallholder farmers. Cocoa is well-suited to agroforestry systems due to its preference for shaded environments, offering opportunities for more sustainable, biodiversity-friendly cultivation practices. Furthermore, the presence of relatively well-established supply chains provides a foundation for interventions aimed at improving value addition, traceability, and farmer livelihoods.

One such improvement could be the introduction of timber trees, such as Erythrophleum ivorense into cocoa plantations. Timber constitutes another popular export product from Cameroon, which is predominantly directed to the European and Chinese market. In Europe, however, exporters of timber have to deal with regulations that aim to reduce illegal logging activities. Trees from agroforestry plantations can thus offer an opportunity for farmers to partake in the timber market in a sustainable way.

Methodology

As a baseline, cocoa farming in a standard monoculture system on 2-6 hectares are considered. The integration would occur in a randomized design with approximately 100-120 trees per hectare. The first harvest of timber is anticipated after approximately 30 years, with the total observed timeframe extending to 50 years. This long-term design allows for the evaluation of both the establishment and maturation phases of timber integration within an agroforestry context and can evaluate the economic development of farms after the onset of economic returns from farming activity. The model observes economical benefits of individual smallholder farmers and does not consider ecological benefits or benefits on a communal or regional scale.

In the cocoa monoculture system, farmer income is solely derived from cocoa yield, which is influenced by labor inputs, agricultural inputs (fertilizer, pesticides, and seedlings), and exposure to environmental risks. Labor costs are disaggregated into full-time and part-time employees, as well as family workforce contributions. Cocoa yield is negatively affected by climatic and biotic stressors, particularly heavy rainfall, drought, and pest and disease outbreaks. These risks represent significant sources of yield variability and income instability. Market prices, including the cocoa world market price and the farmer's Free on Board (FOB) share, further mediate final cocoa income. In contrast, the cocoa-timber agroforestry system integrates 120-200 timber trees per hectare into existing cocoa plots. This diversified system introduces additional cost categories, including timber establishment and harvesting costs. Timber establishment costs encompass seedling procurement, workforce for planting, and transport-related expenses such as truck rental and gasoline. Timber harvesting involves further labor and equipment costs. As in monoculture, labor and agricultural input costs remain relevant. The agroforestry system generates dual income streams from cocoa and timber. Timber income depends on timber yield and farmgate prices, which are in turn influenced by factors such as tree density and the physical characteristics of timber trees (height and diameter). Cocoa income remains tied to cocoa yield and prices, as in the monoculture system.



Where applicable, the above-mentioned factors were then estimated and set as variables. Alternatively, variables that allowed the quantification of those factors were identified and estimated. The estimations were mostly based on literature, but some, namely farm size and yield, as well as employment data were extracted from a survey carried out among 9 farmers in the region of Cameroon Sud.This survey can be accessed here (Access from the authors may be required). It is important to mention that any calculations considered the farm as a whole, and the model is not fit to calculate either cost or profit per hectare. Table 1 summarizes the variables created for the decision model in this report.

```
## Warning in styling_latex_scale(out, table_info, "down"): Longtable cannot be
## resized.
```

Table 1: Table 1: Variables used for the M
The Cocoa Price was defined 50 times to mo
ity. Price ranges 2-50 are not displayed here
cal.

Variable	lower	median	upper	distribution	description
farm__size	2.0000	NA	6.000	norm	Farm Size (ha)
dry__year__incidence	0.0010	NA	0.050	tnorm__0__1	Dry Year Incidence (probabilit
dry__year__damage	0.3000	NA	0.600	tnorm__0__1	Dry Year Damage (yield loss f
dry__year__damage__establishment	1.0500	NA	1.200	posnorm	additional damage during dry
dry__year__damage__established	0.4000	NA	0.900	tnorm__0__1	reduced damage during dry ye
heavy__rainfall__incidence	0.1000	NA	0.400	tnorm__0__1	Heavy Rainfall Incidence (prol
heavy__rainfall__damage	0.0500	NA	0.400	tnorm__0__1	Heavy Rainfall Damage (yield
heavy__rainfall__damage__established	0.7000	NA	0.900	tnorm__0__1	reduced damage during heavy
cocoa__pest__and__disease__incidence	0.8000	NA	0.900	tnorm__0__1	Cocoa Pest and Disease Incide
cocoa__pest__and__disease__damage	0.0500	NA	0.800	tnorm__0__1	Cocoa Pest and Disease Dama
labor__price	30000.0000	NA	60000.000	norm	Labor Price (CFA/month/pers
labor__persons__full__time	0.0000	NA	2.000	norm	Full-time Labor (persons)
labor__persons__seasonal	1.0000	NA	5.000	norm	Seasonal Labor (persons)
fertilizer__cost	500.0000	NA	1000.000	norm	Fertilizer Cost (CFA/kg)
fertilizer__amount	1.0000	NA	1.010	norm	Fertilizer Amount (kg)
pesticide__cost	23000.0000	NA	35000.000	norm	Pesticide Cost (CFA)
pesticide__frequency	5.0000	NA	15.000	norm	Pesticide Frequency (treatmen
family__labor	1.0000	NA	3.000	norm	Family Labor Cost (CFA/year
cocoa__harvest	150.0000	NA	4000.000	norm	Cocoa Harvest (kg)
cocoa__price__percent__farmgate	0.4500	NA	1.100	norm	Farmgate Price Share (fraction
pesticide__effect	1.0100	NA	1.028	norm	pesticide efficiency
fertilizer__effect	1.1000	NA	1.500	norm	fertilizer effect on yield
tree__density	120.0000	NA	200.000	norm	density of trees on farm
tree__growth__diam	4.5000	NA	6.500	norm	diameter growth per tree per y
tree__growth__height	20.0000	NA	50.000	norm	height increase per tree per ye
tree__initial__height	150.0000	NA	200.000	norm	tree height at time of planting
tree__initial__diameter	5.0000	NA	10.000	norm	tree diameter at planting in cr
tree__survival__rate	0.7000	NA	0.900	tnorm__0__1	tree survival rate upon establi
tree__price	167700.0000	NA	279500.000	norm	price that farmers could receiv
tree__seedlings	2000.0000	NA	3000.000	norm	price for seedlings
seedling__and__equipment__transport	80000.0000	NA	120000.000	norm	price for transport and gas
labor__persons__establishment	5.0000	NA	10.000	norm	personnel for establishment lal
impact__trees__cocoa	0.7000	NA	0.800	tnorm__0__1	yield reduction by timber trees
impact__trees__cocoa__establishment	0.6000	NA	0.700	tnorm__0__1	yield reduction by timber trees
harvest__material	150000.0000	NA	250000.000	norm	material for harvest
labor__persons__harvest	5.0000	NA	10.000	norm	personnel for harvest of timber
inflation__rate__cameroon	2.0000	NA	7.500	posnorm	cameroonian inflation rate esti
inflation__rate__world	2.6000	NA	9.000	posnorm	global inflation rate estimated
cocoa__price__world__market__1-50	278.1793	NA	3461.433	norm	World Market Cocoa Price (C

Intervention modeling

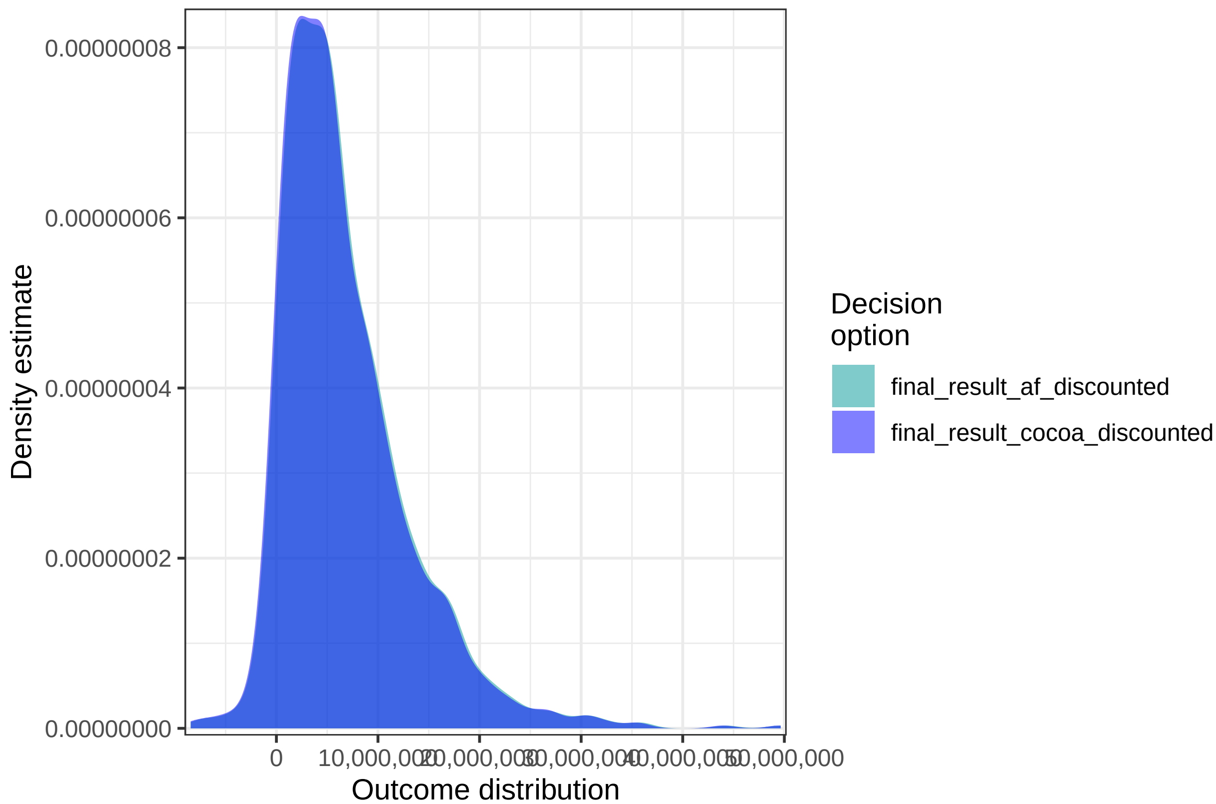
To compare the economic outcomes of cocoa monoculture with an agroforestry system integrating timber, the R package decisionSupport (Luedeling et al., 2019) was applied to perform a Monte Carlo simulation. A model function was developed to incorporate yearly cashflows over a 50-year period under two scenarios: (1) cocoa monoculture and (2) cocoa-timber agroforestry. Both models incorporate production risks (e.g., drought, heavy rainfall, pests), management costs (e.g., labor, fertilizers, pesticides), and market uncertainties (e.g., fluctuating cocoa and timber prices, inflation). For each model, parameter uncertainty was captured using probabilistic input estimates as explained above. The simulations included 1,000 iterations (mcSimulation) per scenario. Agroforestry included a delayed income stream from timber harvests starting at year 30, along with adjusted risk impacts due to tree presence. Discounted and undiscounted net cashflows were computed for both systems. Key outputs, such as net present values (NPV) and yearly cashflows, were summarized and compared using the Monte Carlo results. Distribution plots were generated with plot_distributions() to visualize the variability and outcomes across simulations.
The simulation analysis was further extended by visualizing annual discounted cashflows for both systems using the plot_cashflow() function, which displays the median values along with the 25–75% and 5–95% percentile ranges.
To assess the influence of uncertain parameters on model outcomes, a multi-variable Expected Value of Perfect Information (EVPI) analysis was conducted using the multi_EVPI() function. Finally, correlations among key input variables were examined using Pearson correlation coefficients calculated from the Monte Carlo sample (mcSimulation) and visualized with the ggcorrplot package.For that purpose, a correlation matrix was provided as seperate .csv file.

Introduction of Correlations

To explore the possibility to introduce relationships among key agroforestry variables related to timber and cocoa production, a correlation matrix was constructed. The matrix included nine variables: fertilizer cost, fertilizer amount, pesticide cost, pesticide frequency, cocoa harvest, tree density, seedling and equipment transport, harvest material, and labor persons involved in harvest. Correlation coefficients ranged from -0.5 to 1, reflecting both positive and negative associations among the variables. The correlations were based on own estimations of the author and relied on technical knowledge gained during the project. Nevertheless, they are here used as showcase example only. The correlation matrix was incorporated into a Monte Carlo simulation framework using the mcSimulation function. The resulting simulated data were visualized with ggcorrplot,

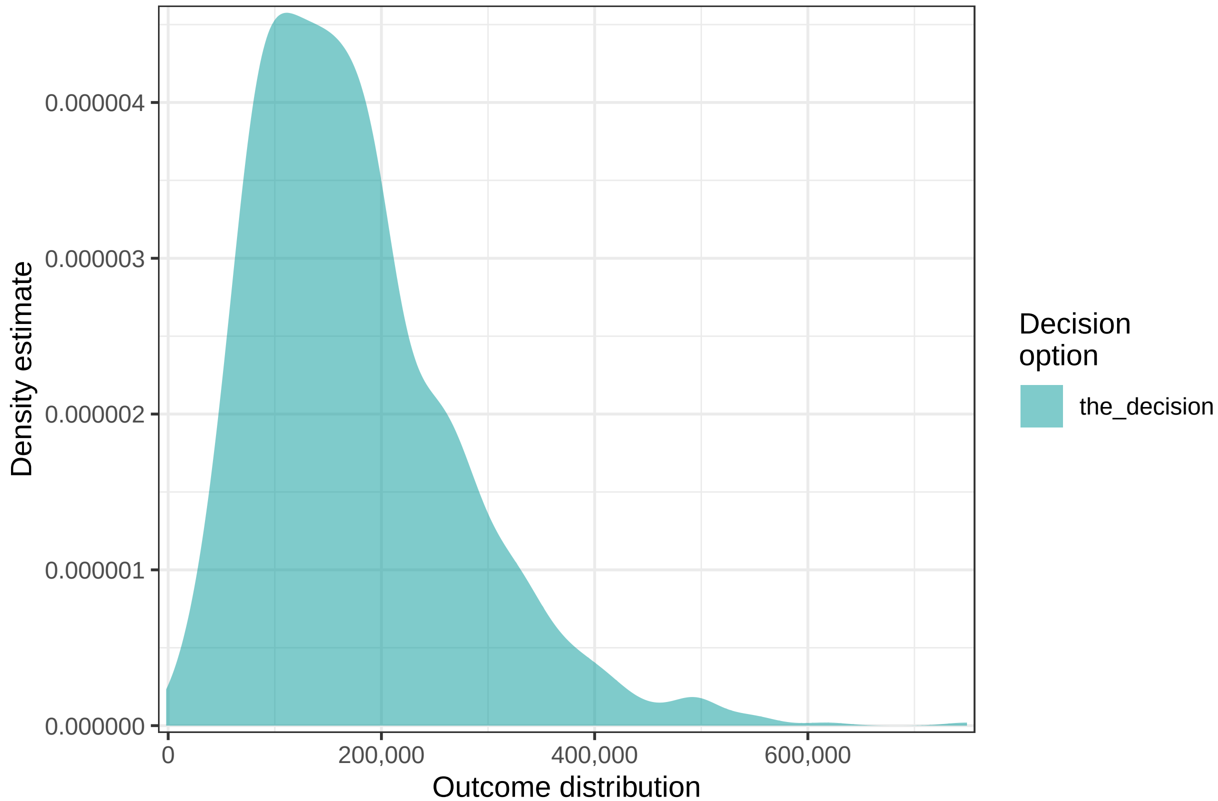
Results

Net present value after 50 years



of discounted net results for agroforestry and cocoa monoculture systems.

The generated plot shows the accumulated profit of both cocoa monoculture and timber agroforestry. On first glance, the density distributions of both systems are of similar shape, reaching from -8.439403×10^6 to 4.9521781×10^7 in case of cocoa monoculture and peaking at approximately 428 USD profit. With the intervention, the distribution reaches from simulated scenarios of -8.28325×10^6 to $4.9641979 \times 10^7$and peaking at 428 USD profit respectively. Concerning the risk of losses occurring after 50 years, the density distribution of cocoa monoculture scenarios that return a net profit <= 0 is 0.061, while the same risk to cocoa-timber agroforestry is somewhat lower at 0.048.
Figure 2 plots the value of the decision, revealing that under all circumstances, the expected value of decision is positive.



2: Expected value of decision: 'Integrating Timber Trees into Cocoa Monoculture plantations'

```
peak_index3 <- which.max(mc_simulation3[["y"]][["the_decision"]])
max3<-max(mc_simulation3[["y"]][["the_decision"]])
min3<-min(mc_simulation3[["y"]][["the_decision"]])
```

The outcome density for the expected value of integrating timber agroforestry into the cocoa plantation reaches from simulated returns of -1907 to 7.49275×10^5. It peaks at 397.

Cashflow

Important note: To display the variation of income flows, the cashflow was plotted without discount over 50 years.

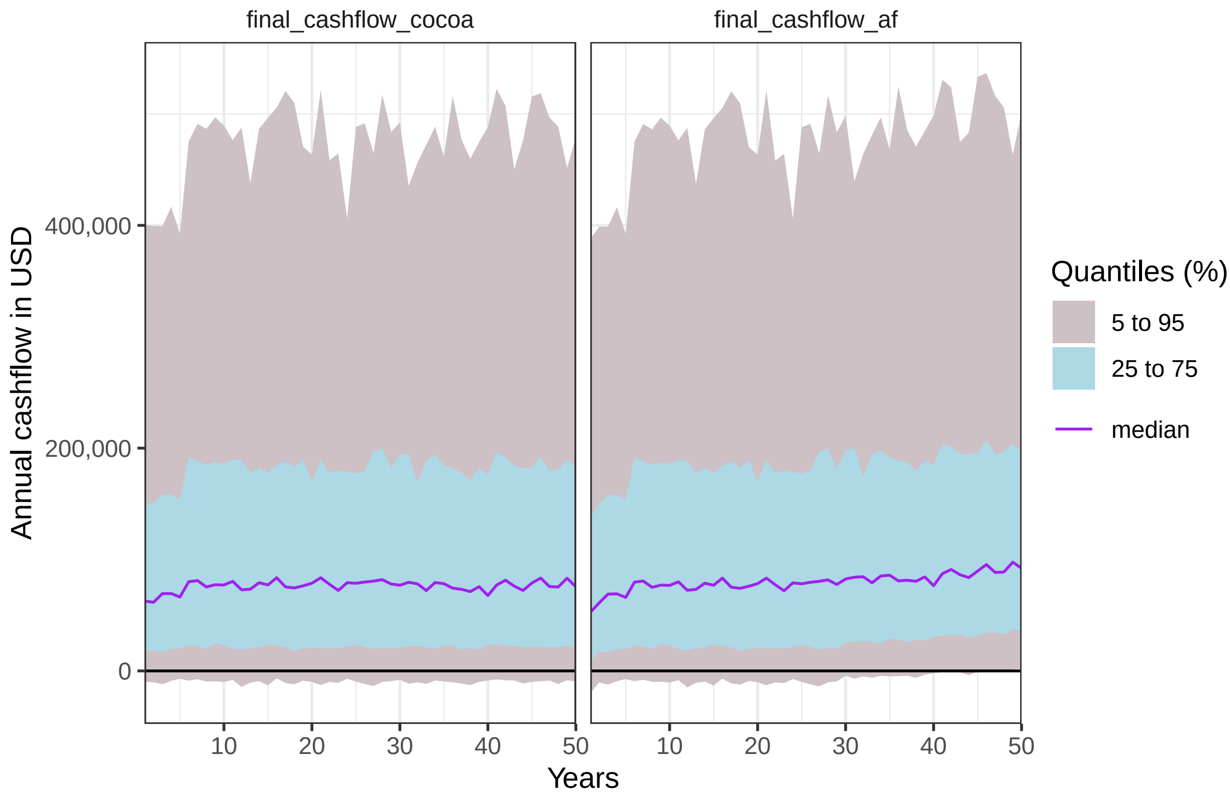


Figure 3: Cashflow simulation of cocoa monoculture (left) and cocoa−timber agroforestry (right)

Figure 3 compares the simulated annual cashflows for cocoa monoculture (final_cashflow_cocoa) and cocoa-timber agroforestry (final_cashflow_af). Both systems exhibit similar overall distributions, with wide uncertainty ranges spanning the 5th to 95th percentiles, reflecting inherent variability in market and production conditions. The median cashflow trajectory (purple line) for the agroforestry system starts at a lower point, but raises quickly and appears slightly higher than that of the monoculture from approximately year 10 onward, suggesting marginal long-term financial benefits associated with the diversified system. Notably, the interquartile range (25th to 75th percentile, lavender-blue area) is consistently wider in both systems, indicating substantial variation in expected outcomes across the simulation runs. However, the agroforestry system maintains slightly higher medians with no marked increase in downside risk. This combination results in 5th to 95th percentiles that seldomly reach below 0 from year 30, while this range reaches below 0 frequently in the cocoa monoculture plot.

##Value of information report

```
## [1] "Processing 1 output variables. This can take some time."
## [1] "Output variable 1 (mc_simulation3...y......final_result_cocoa_discounted...) completed."

## Warning: There are no variables with a positive EVPI. You probably do not need
## a plot for that.

## [1] "Processing 1 output variables. This can take some time."
## [1] "Output variable 1 (final_result_af) completed."

## Warning: There are no variables with a positive EVPI. You probably do not need
## a plot for that.
```

```
## [1] "Processing 1 output variables. This can take some time."
## [1] "Output variable 1 (mc_simulation3...y......the_decision...) completed."
```

```
## Warning: There are no variables with a positive EVPI. You probably do not need
## a plot for that.
```

The expected value of perfect information for all scenarios (cocoa monoculture, cocoa-timber agroforestry and the decision) is zero, which implies that in these simulations there is no variable that has enough influence on the final result to be worth investigating more.

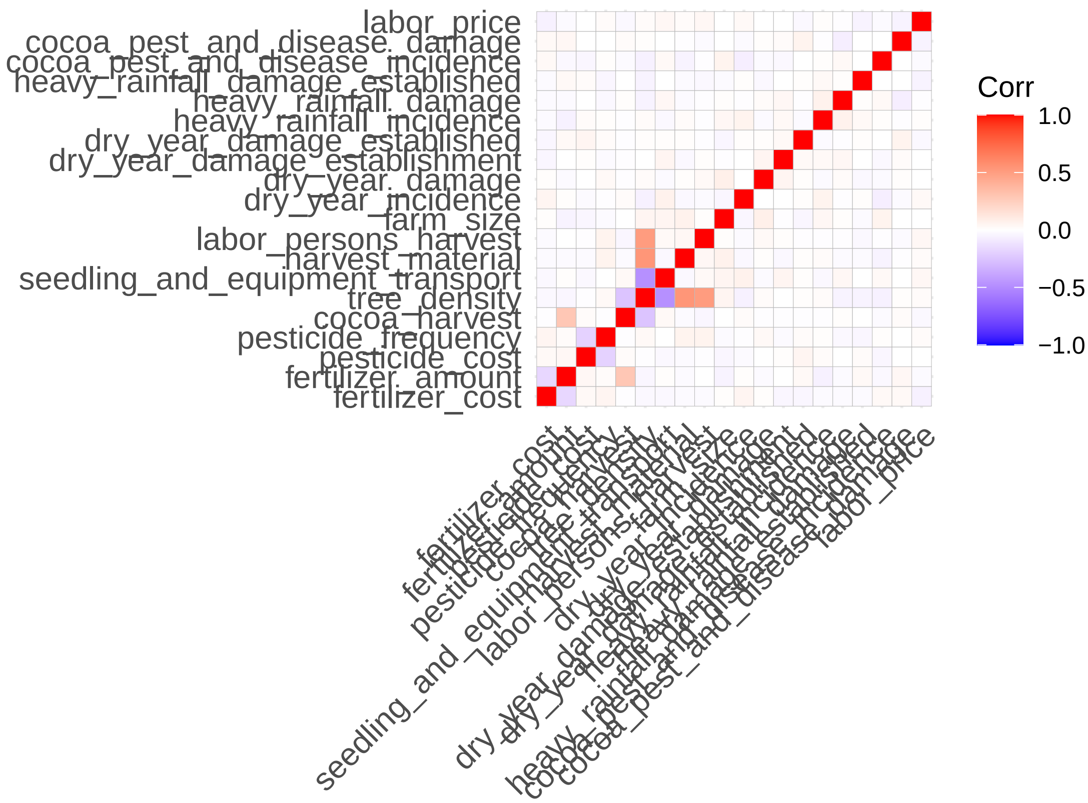


Figure 4: Correlations between variables introduced into the model

The correlation plot shows that correlations could successfully be forced into the simulation. Furthermore, it depicts some very small correlations between variables that are not present in the decision matrix, most likely due to random occurrances in model runs.

```
distribution_plot_corr<-plot_distributions(
  mcSimulation_object = correlation,
  vars =c("final_result_af_discounted", "final_result_cocoa_discounted"),
  method = "smooth_simple_overlay")
decision_plot_corr<-plot_distributions(
  mcSimulation_object = correlation,
  vars =c("the_decision"),
  method = "smooth_simple_overlay")
cashflow_correlation<-plot_cashflow(mcSimulation_object = correlation, cashflow_var_name = c("final_cas
              y_axis_name = "Annual cashflow in USD",
              color_25_75 = "lightblue", color_5_95 = "lavenderblush3",
              color_median = "purple")
```

```r
plots<-distribution_plot_corr/ decision_plot_corr /cashflow_correlation
correlation_plot+labs(caption = "Figure 5: Density distributions in correlation plot")
```

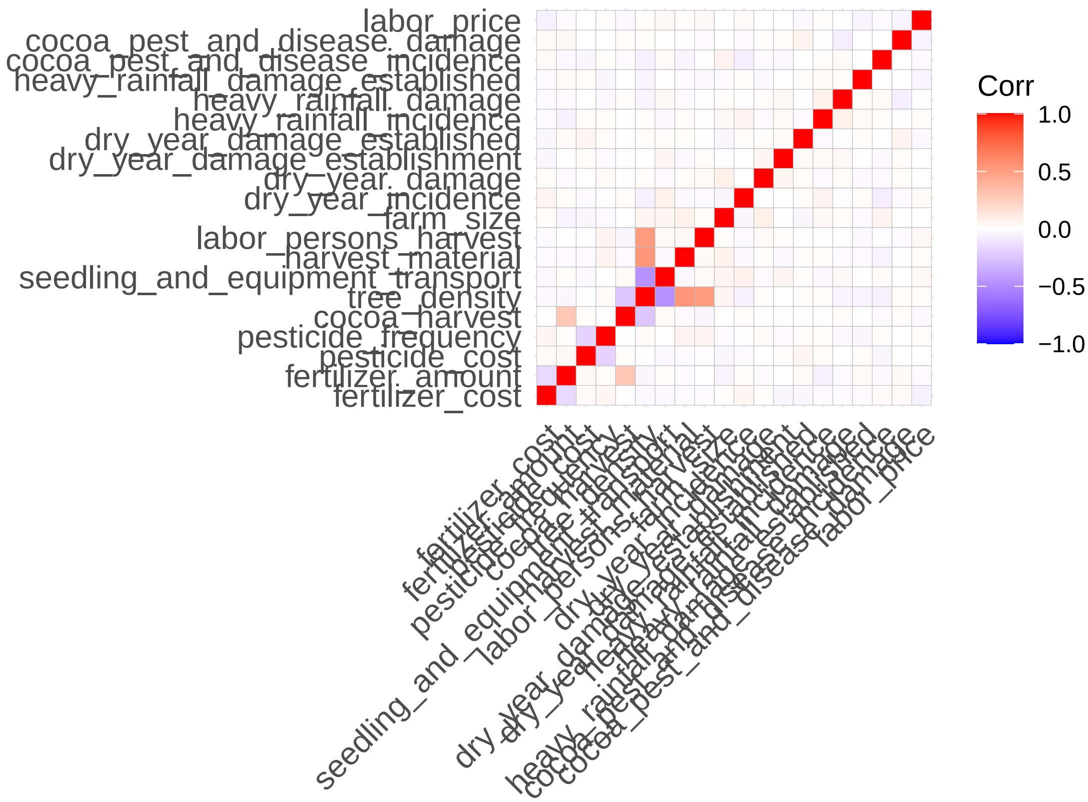


Figure 5: Density distributions in correlation plot

Figure 5 displays the analytical plots from the model with integrated correlations. There are only small differences between those and the original plots. Due to the fragile nature of the correlation estimations, they will not be discussed further in the scope of this report.

##Discussion